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Bi-directional plasma thruster for small space debris removal

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Active debris removal (ADR) in space are emergent technologies to sustain space activity around the Earth. The previous investigation of the size distribution of the debris have shown the number of the debris smaller than 10 cm is much larger than that of the large size debris. Collisional impact by the debris causes serious damage to the spacecraft even for the smaller debris as the velocity of the debris reaches several km/s, while it is hard to track the small debris due to a spatial resolution of the tracking system and too large number of the debris. If remedial action for the small debris is not taken in near future, it becomes obviously difficult to sustain the proper use of the Low-Earth Orbit (LEO). It would be extremely difficult to remove the small debris by the previously investigated contact-type ADR method, as it will require a significantly precise accuracy for sensing the debris motions. Even for the contactless laser ablation and the collimated ion beam, the precise identification of the debris orbit has to be performed. Therefore, a concept of the ADR technologies for the small debris is an emergent topic for sustainable space activities.

Here utilizing a bi-directional plasma thruster whose plume significantly expands along a magnetic nozzle [1] is proposed to remediate or remove small debris from Earth orbit, where the debris are decelerated by continuously exerting a force to debris by the plasma beam and zero net force exerted to the thruster is maintained by ejecting the plasma to the opposite side [2]. A laboratory experiment demonstrates the bi-directional plasma ejection from a radiofrequency plasma thruster having upstream and downstream open source exits as drawn in Fig.1, which can be operated with abundant argon propellant and with no electrode exposed to the plasmas, providing the long-life time even for a high electric power operation [3]. The plasma ejection from the thruster is obviously controlled by the magnetic field configuration, by which the acceleration, deceleration, and debris removal modes can be switched by changing the magnetic field configuration. Furthermore, the symmetric configuration having a cusp field near the rf antenna can improve the force transfer to the debris as well as the simple thruster configuration ejecting the plume only to the downstream side [4]. Based on the results in the laboratory experiments, the deorbit time of the small debris is very briefly discussed by using a simple model considering a gravitation force and a deceleration force exerted to the debris.

When applying the axially symmetric cusp field configuration, about 25 mN force is exerted to a 45-cm-diameter target plate located at 30 cm downstream of the thruster for about 5 kW rf power operation, providing the force density of about 150 mN/m^2. Let us consider the small debris of a cube with 10 cm long sides and of 1 kg; then the plasma irradiation area can be estimated as 0.1x0.1=0.01 m^2. Therefore, the force exerted to the small debris can be estimated as 1.5 mN, providing the debris removal within about 5 days. Since the system can exerted the force to multiple debris existing within the plasma plume are, the proposed method might lead an efficient debris removal technology.

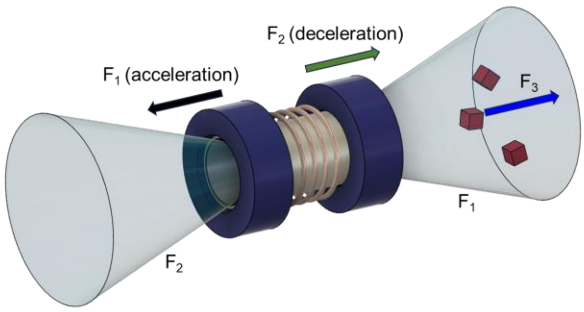

Figure 1 Concept of the active debris removal by the bi-directional helicon thruster.

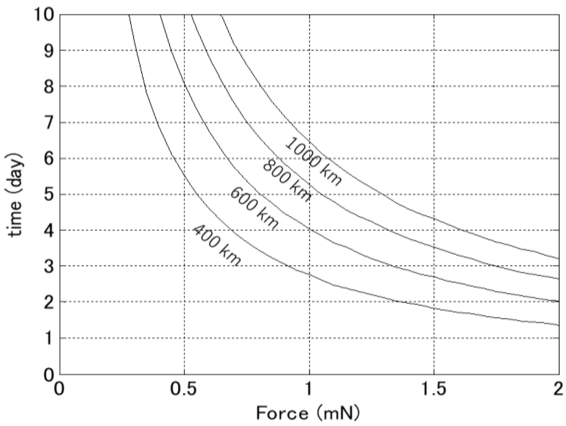

Figure 2 Time required for transferring the 1kg mass debris from the altitudes shown in Fig.2, as a function of the deceleration force exerted to the debris.

References

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