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Deflected thrust vector of a magnetically steered radiofrequency plasma thruster

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A magnetic nozzle (MN) electrodeless radiofrequency (rf) plasma thruster has been investigated as one of future electric propulsion devices. Because of the absence of electrodes exposed to plasmas, it is expected that the lifetime of the thruster would be longer than that of other types of electric propulsion devices, e.g., a gridded ion thruster and a Hall effect thruster. When utilizing the electric propulsion devices to artificial satellites, a thrust vector control technique is also important for an accurate orbit control, which has been often accomplished by a mechanical gimbal structure or multi-channel thrusters, resulting in the complicated structure design of the satellite.

The thrust generation mechanisms of the MN rf plasma thrusters have been vigorously investigated.[1,2] During the plasma expansion along the MN, a current-free double layer or ambipolar electric fields are often formed near the thruster exit and accelerate the ions electrostatically, which provides the momentum ejection from the system, i.e., thrust.[1] In addition, the plasma-induced azimuthal current and the radial magnetic field generate a Lorentz force, which provides an increase in the thrust; hence the force is normal to the magnetic field lines, where the net radial thrust induced by the Lorentz force integrated over the volume is zero for the axisymmetric system.[3] In other words, the thrust components except for the axial one would be generated when applying non-axisymmetric MN, being proposed as a magnetic steering. The deflection of the supersonic ion beam induced by a current-free double layer has actually been observed when deflecting the magnetic field lines.[4] Numerical model has also proposed the deflections of the plasma jet and the thrust vector with a 3D-MN, where the Lorentz force has also been accumulated in the thrust calculation,[5] while no experiments have verified the magnetic steering of the thrust vector.

In the present study, additional horizontal solenoids are installed in the MN rf plasma thruster to deflect the MN. The axial and horizontal thrust components, the plasma density, and the ion energy distribution are measured, demonstrating the concept of the magnetic steering of the MN rf plasma thruster.

Fig. 1(a) shows the schematic diagram of the experimental setup. The thruster structure is attached to a pendulum thrust balance similar to the previous axial thrust measurement.[6,7] The thrust force is a reaction force of the momentum ejection from the system; the force is exerted to the thruster structure, e.g., the mechanical boundary and the magnetic fields, and induces the spatial displacement of the pendulum. Therefore, the thrust can be obtained from the plasma-induced displacement, which is measured by a laser sensor. The thruster structure is shown in Fig. 1(b). The axial magnetic field is applied by Solenoid 1 and the horizontal magnetic field is applied by Solenoids 2 and 3. By changing the magnitude of the current supplied to Solenoids 2 and 3, the degree of the MN deflection can be controlled. The axial and horizontal thrusts are independently measured by the horizontally and axially movable pendulum thrust balance as shown in Figs. 1(c) and 1(d); the thrust vector can be identified.

The measured axial and horizontal thrust components show that the thrust vector can be deflected by several degrees, demonstrating the thrust vector control by the magnetic steering.[8] The detailed experimental results and discussion will be shown in the presentation.

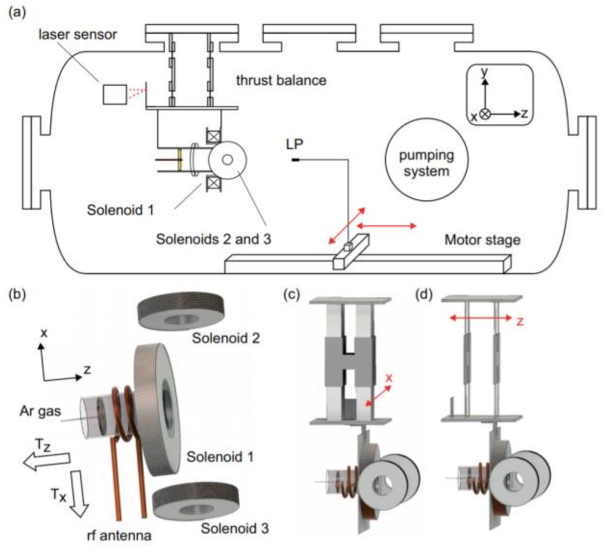

Fig. 1. Schematic diagrams of (a) the experimental setup and (b) the MN rf plasma thruster. The thrust balance configurations for the measurements of (c) horizontal and (d) axial thrust components.

References

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