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Momentum and energy lost to the wall in a magnetic nozzle plasma thruster and performance improvement

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Plasma acceleration and momentum conversion in a magnetic nozzle are related to various particle acceleration in naturally occurring and artificial plasmas. One of the fascinating applications of the plasma momentum would be electric propulsion, where the thrust is equivalent to the momentum exhausted from the system per unit time. By employing an electrodeless plasma source upstream of the magnetic nozzle, no electrode contacts to the plasma, yielding the long lifetime propulsion device even for high power operation of the thruster. The direct measurement of the thrust can provide the information on the momentum exhausted from the system [1], while the local information of the momentum flux cannot be obtained via the thrust assessment.

The reaction force can be exerted on the physical boundaries and the magnetic nozzle, where the electron pressure, the dynamic momentum of the ions lost to the boundaries, and the Lorentz force due to the internal plasma current are the key element of the force transfer mechanisms. Previous experiments have shown the axial momentum lost to the wall is negligible when the propellant gas is highly ionized, where the axially accelerated by the ions and lost to the radial wall transfer their dynamic axial momentum to the wall [2], leading the degradation of the thruster performance. The physical process of the momentum lost to the wall has been qualitatively analyzed in a particle-in-cell simulation before [3], while the calculation area is still narrow due to the calculation cost, compared with the experiment.

Here the momentum vector measurement instrument (MVMI) is developed to identify the momentum and energy lost to the thruster wall and study the momentum conversion process in the magnetic nozzle [4]. Non-negligible axial momentum is found to be lost to the wall when injecting the propellant gas from the upstream of the source [5]. The estimated energy lost to the wall implies that the loss can be decreased by increasing the magnetic field strength [6]. Based on these insights, the thruster is redesigned to have a peak magnetic field strength of about 700 Gauss and the gas injection port near the thruster exit. The whole structure of the thruster is attached to the pendulum thrust balance immersed in vacuum and the thrust is directly measured. The results show the thruster efficiency approaching 20 %, being highest to date [7].

Finally, a bi-directional plasma ejection from the source is observed when having the two open-source exits. Interestingly, the ejection of the plasma to the upstream and downstream side can be controlled by the magnetic field configuration or the propellant injection. The new application of the thruster to an active space debris removal will be discussed [8].

References

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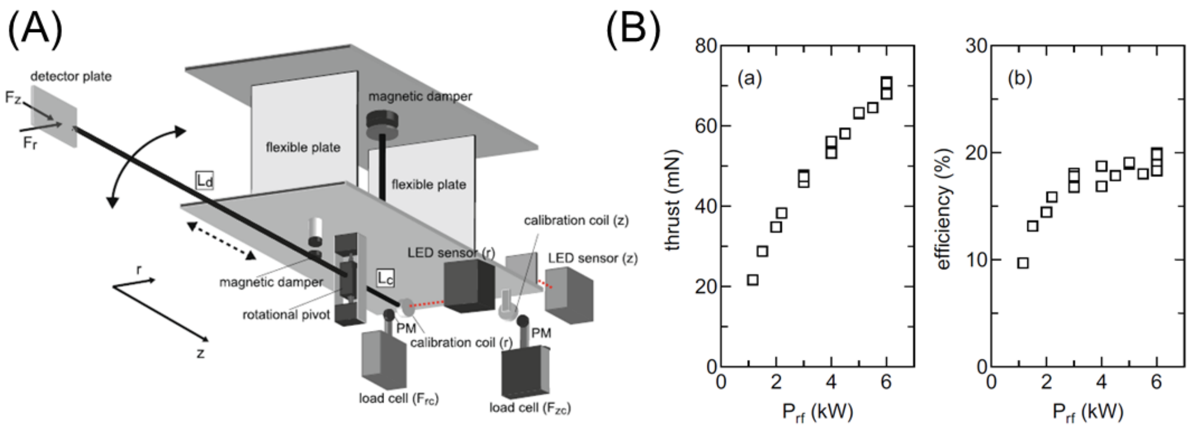

Fig.1: (A) Schematic diagram of the MVMI. (B) The recently updated performance of the magnetic nozzle rf plasma thruster.