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High-Dense, Helicon Plasma Acceleration Using Rotating Magnetic Field Method

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Electric plasma propulsion systems have been developed due to recent needs in the field of space propulsion, considering a higher fuel efficiency than that of chemical one: application to a small satellite, such a "CubeSat" [1], and an ejected ion beam from an accelerator for dealing with space debris [2], etc. As examples of practical electric thrusters, ion gridded and Hall thrusters were demonstrated, achieving some space missions. However, there is a problem of degrading a thrust performance due to an interaction between plasma and electrodes for plasma generation / acceleration, which leads to limitation of operation time and contamination.

To solve the problem, "electrodeless" plasma propulsion systems have been proposed under the Helicon Electrodeless Advanced Thruster (HEAT) project [3]. Helicon Plasma Thruster (HPT) is a part of electrodeless plasma acceleration methods and are being actively investigated [4]. In this scheme, helicon wave [5], which is a boundary whistler wave, can be excited by the use of an external radio frequency (rf) antenna wound around a quartz tube, and high-dense plasma generation is conducted by helicon wave propagation in a plasma column. In a typical HPT scheme, generated plasma is expected to be accelerated by a pressure gradient in the downstream direction and by a diamagnetic current effect, leading to an axial thrust in the presence of the divergent magnetic field as well as a magnetic nozzle. However, the ratio of thrust to power of typical HPT is at most ~ 15 mN/kW [6] so far, that is not satisfied judging from a present practical level. Based on that, Rotating Magnetic Field (RMF) method is being studied [7] to enhance the thrust performance as an additional plasma acceleration scheme.

In this acceleration scheme, a steady azimuthal current is expected to be induced in the plasma by non-linear effects, i.e., the Hall term. Hereby, the axial Lorentz force can be generated in the presence of an external divergent magnetic field caused by permanent magnet arrays. Previously, plasma density increase was found by 2D spatial electron density measurement in the original RMF acceleration [8], triggering other plasma acceleration mechanism, e.g., an axial plasma pressure gradient and diamagnetic effect caused by a radial density gradient. Here, two-phase, opposing coils are wound in the downstream region of a plasma generation as the RMF antennas. Current phase difference ϕ between the two phases decides the rotation direction of the magnetic field and the azimuthal current (normally, ϕ = 90 deg. was used to induce a forward thrust). Dependences of plasma parameters (an electron density and an ion velocity) on ϕ were obtained in the downstream of the RMF antenna, that indicated the RMF acceleration effect [7].

Two topics will be presented in this conference. First one is 2D spatial measurement of three-axis, alternating current (ac) component of RMF with the RMF current frequency f_{RMF} by the use of a three-directional magnetic probe. Here, the field penetration into plasma was investigated by comparing the profiles between w/o and w/ plasma by means of Milroy's expression [9]. Furthermore, RMF components with twice as f_{RMF} were also deduced by using Fast Fourier Transform (FFT) through low- and high- pass filters to estimate dc component of the azimuthal current derived from Maxwell-Ampére law. Obviously, this ac component of $2f_{\mathrm{RMF}}$ cannot cause the forward thrust in time average due to the sign change, but this amplitude is comparable to dc one, enabling to deduce the net thrust of RMF scheme except for the diamagnetic and pressure gradient terms. Spatial dependence of the azimuthal current direction on ϕ will be also shown.

The second one is an effect of the RMF input power more than a few kW applied to RMF antennas on the axial thrust. An increment of the RMF strength is expected to enhance the field penetration condition as well as the RMF acceleration effect, that was suggested in Ref. [10]. Dependences of some operation parameters, e.g., rf power for plasma generation, propellant gas (Argon) pressure (thus, gas flow rate), and external magnetic field strength and shape, etc, will be presented. In addition, we are going to investigate the thrust performance by the use of a new smaller, target type thrust stand, which is being designed at the present stage, and the RMF application for future space propulsion will be also discussed.

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