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Dependence of electromagnetic acceleration on strength of rotating magnetic field in additional plasma acceleration under a magnetic nozzle

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Electrodeless plasma thrusters are being researched and developed for space propulsion, and their thrust performance is steadily improving. A maximum thrust efficiency of 30% was achieved in 2022 [1], and further improvement is expected. The additional plasma acceleration method is one of the approaches to improve performance and enables control of thrust value and fuel efficiency depending on space missions. The Rotating Magnetic Field (RMF) plasma acceleration method [2] is proposed as an additional plasma acceleration method. This RMF current drive method has conventionally been proposed in the nuclear fusion community to form a field-reversed configuration [3]. An azimuthal electron current is driven, an axial Lorentz force acts on electrons, and total plasma acceleration is performed after ion acceleration via an ambipolar electric field. Our group has recently focused on the physical behavior of plasma flow under the RMF acceleration method concerning the RMF operational conditions. Among the conditions, the strength of the RMF is a critical parameter for the RMF acceleration effect, and this study investigates the influence of the plasma flow changing the strength. The schematic of the RMF acceleration method is shown in Fig. 1. Permanent magnet arrays, mounted above a radio-frequency (RF) antenna, form a magnetic nozzle in the RMF antenna region. The RMF antenna consists of four rectangle-shaped, five-turn coils.

Figure 2 shows the dependence of the x-axis profiles of electron pressure p_e and ion Mach number in the z-direction M_{iz} on the RMF current applied to the RMF antenna, I_{RMF} at $z = -250$ and -130 mm. Note that the RMF field strength is in proportion to the I_{RMF}. The increment of p_e is up to 1.1 Pa at $(z, x) = (-250, 0$ mm), and the radial gradient of p_e becomes evident with increasing I_{RMF}. That is a critical factor in enhancing plasma acceleration. A peaked density profile appeared in the RMF antenna region, indicating that the RMF application affects plasma dynamics and the additional plasma acceleration effect. In the radial outer region, a noticeable increase in M_{iz} is found at both $z = -250$ and -130 mm. The axial Lorentz force derived from the diamagnetic current becomes apparent in the outer region with increasing I_{RMF}. Afterward, ions in the radially outer area can be accelerated because of the enhanced ambipolar electric field caused by axially accelerated electron transport. Even on the z-axis, M_{iz} increases with I_{RMF} increment. This acceleration can be yielded by developing an axial electric field derived from the gradient of plasma potential concerning the high-pressure increment in the RMF antenna region.

In this presentation, we evaluate the electromagnetic acceleration effect and report that the force increases with the increase in RMF strength and the influence on spatial profiles of the plasma parameters.

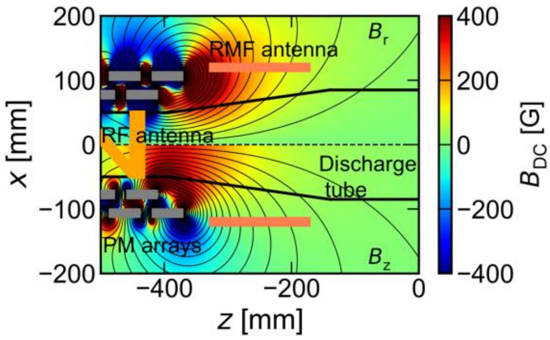

Figure 1. The RMF thruster setup with contour maps of the DC B-fields B_r (upper) and B_z (lower) components.

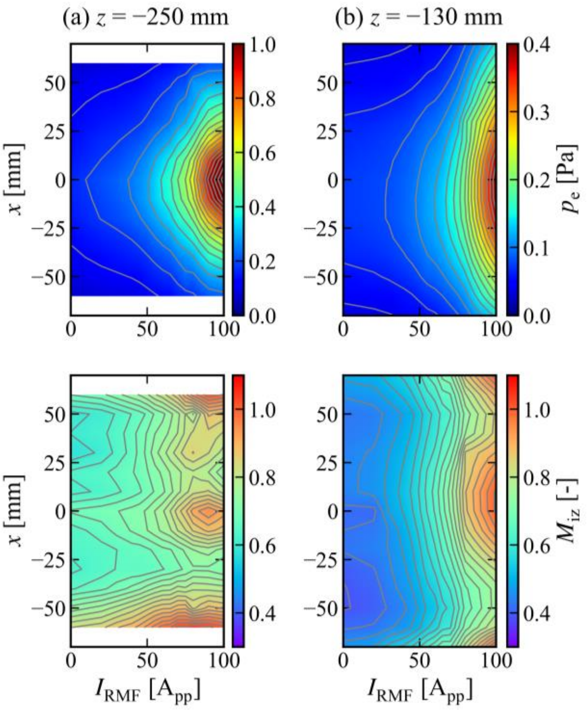

Figure. 2 Dependence of x-axis profiles of p_e and M_i on I_{RMF} at $z = -250$ and -130 mm.

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