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Study on Electromagnetic Plasma Acceleration Using Rotating Magnetic Field Scheme

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Abstract : In the field of a space propulsion, an electric propulsion system has been developed because its fuel efficiency is much higher than a conventional chemical one. However, the practical electric propulsion systems, e.g., an ion engine, have a problem of short lifetime due to a damage of generation and acceleration electrodes of the plasma. A helicon plasma thruster is proposed as a long-lifetime electric thruster which has non-direct contact electrodes. In this system, both generation and acceleration methods of a dense plasma are executed by antennas from the outside of a discharge tube. Development of the helicon plasma thruster has been conducting under the Helicon Electrodeless Advanced Thruster (HEAT) project. Our helicon plasma thruster has two important processes. First, we generate a dense source plasma using a helicon wave with an excitation frequency between an ion and an electron cyclotron frequencies, fci and fce, respectively, applied from the outside of a discharge using a radio frequency (RF) antenna. The helicon plasma source can provide a high-density (~1019 m-3), a high-ionization ratio (up to several tens of percent), and a high particle generation efficiency. Second, in order to achieve high thrust and specific impulse, we accelerate the dense plasma by the axial Lorentz force fz using the product of the induced azimuthal current jθ and the static radial magnetic field Br, shown as fz = jθ × Br. The HEAT project has proposed several kinds of electrodeless acceleration schemes, and in our particular case, a Rotating Magnetic Field (RMF) method has been extensively studied. The RMF scheme was originally developed as a concept to maintain the Field Reversed Configuration (FRC) in a magnetically confined fusion research. Here, RMF coils are expected to generate jθ due to a nonlinear effect shown below. First, the rotating magnetic field Bω is generated by two pairs of RMF coils with AC currents, which have a phase difference of 90 degrees between the pairs. Due to the Faraday's law, an axial electric field is induced. Second, an axial current is generated by the effects of an electron-ion and an electron-neutral collisions through the Ohm's law. Third, the azimuthal electric field is generated by the nonlinear term, and the retarding torque generated by the collision effects again. Then, azimuthal current jθ is generated as $j\theta = - n_e$ er • 2π fRMF. Finally, the axial Lorentz force fz for plasma acceleration is generated. Here, jθ is proportional to n_e and frequency of RMF coil current fRMF, when Bω is fully penetrated into the plasma. Our previous study has achieved 19 % increase of ion velocity using the 5 MHz and 50 A of the RMF coil power supply. In this presentation, we will show the improvement of the ion velocity using the lower frequency and higher current supplied by RMF power supply. In conclusion, helicon high-density plasma production and electromagnetic acceleration by the RMF scheme with a concept of electrodeless condition have been successfully executed.

Keywords : electric propulsion, electrodeless thruster, helicon plasma, rotating magnetic field
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