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数値解析によるレーザー核融合ロケットの磁気スラストチャンバにおけるプラズマデタッチメントの検証

Numerical Analysis of Plasma Detachment in Magnetic Thrust Chamber of Laser Fusion Rocket

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For a future manned Mars exploration, it is needed to investigate a spaceship which has both advantages of large thrust and high specific impulse. Because it takes more than 500 days with the current chemical and electric propulsion rockets for a long-distance flight from the earth to Mars and back, and this flight causes astronauts to suffer from cosmic ray exposure, psychological burden due to the long stay in a closed space, and loss of bone density due to the weightlessness of the space. One of candidates for the spaceship is a laser fusion rocket (LFR) [1]. A LFR is a rocket which uses a laser to induce a nuclear fusion reaction, and transforms propellant into high-temperature and high-density plasma with the enormous energy obtained by the reaction. Then, the LFR ejects the high-speed plasma guided to a magnetic field generated by a superconducting coil to obtain acceleration. The propulsion mechanism of the LFR is called a magnetic thrust chamber [2], which utilizes the interaction between the plasma and the magnetic field.

In the process, one of the issues is a plasma detachment from magnetic lines of force. Since the magnetic lines of force in the magnetic thrust chamber circle around the body, if the ejected plasma is trapped by the magnetic lines of force and goes around the body in a circle, no thrust is generated. Numerical analysis has confirmed that the magnetic thrust chamber can change the direction of motion of ions in the plasma, however the detachment has not yet been confirmed. Furthermore, electron detachment is not considered, and if only ions are detached, the difference in spatial distribution may cause an electrostatic field, which may pull back the ions as shown in Fig. 1.

In this study, we assume that the propellant plasma in the magnetic thrust chamber is a collisionless high-temperature plasma, and perform a Full-Particle-In-Cell simulation In order to reduce the computational cost, we adopt a two-dimensional position space and three-dimensional velocity space for plasma calculation based on the first principle, and the Finite Difference Time Domain (FDTD) method for electromagnetic field calculation. The simulation is performed on a parallel computing system using the ITO computer at Kyushu University.

We confirmed a time variation of the spatial distribution of the electron density is almost the same as that of the ion density, and the electron flux, which changes from moment to moment, is oriented in the same direction as the ion flux, not in the direction of the magnetic lines of force, indicating that the electrons follow the motion of the ions. It was also revealed that most ions and electrons do not conserve their initial magnetic moment, and that the plasma detaches from the magnetic field lines in the magnetic thrust chamber. It was shown that detachment occurs when the electron Larmor radius becomes larger than the scale length of the magnetic field change in a region with a large magnetic field gradient near the diamagnetic cavity, which results from the interaction between the magnetic field and the plasma. It is also shown that the electrons are accelerated by the fluctuating electric field based on plasma oscillations, and that the conservation of magnetic moment is violated.

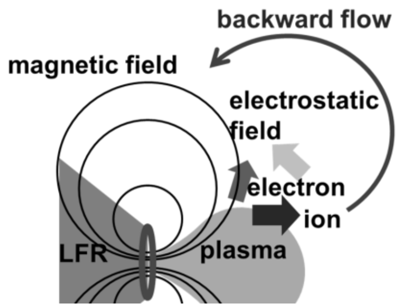

Fig. 1 Possibility of backward flow due to electrostatic field created by difference in inertia between ions and electrons

Reference

[1] R. Hyde, et al., AIAA Paper, 72, 1063, 1972

[2] Y. Nagamine and H. Nakashima, Fusion Science and Technology, 35, 62-70, 1999