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Effects of high-energy electrons on the low- and high-temperature plasma expansion in the divergent magnetic fields

Kazuma Emoto,[1] Satoshi Togo,[1] Yoshinori Takao,[2] Kazunori Takahashi,[3,4] and Mizuki Sakamoto[1]
[1] Plasma Research Center, University of Tsukuba, [2] Division of Systems Research, Yokohama National University, [3] Department of Electric Engineering, Tohoku University, [4] National Institute for Fusion Science
e-mail (speaker): emoto@prc.tsukuba.ac.jp

Convergent and divergent magnetic fields are employed to extract directional plasma flow from the source. Recently, the application of electric thrusters has actively been studied and developed, which are expected to be mounted on space satellites and probes and impart the thrust as a reaction force [1]. In the thrusters, the convergent and divergent magnetic fields have a similar role to the de-Laval nozzle. The plasma expands in the divergent magnetic fields, where the diamagnetic current is induced and the Lorentz force is exerted on the plasma [2,3]. In considering the plasma expansion, the density and temperature were discussed with the polytropic index in recent papers [4,5]. It was implied that the potential structure in the divergent magnetic field significantly affected to the plasma expansion [5].

Because the potential structure modifies the electron trap or loss, the plasma expansion is also expected to depend on the electron energy, where many laboratory experiments have shown non-Maxwellian electron energy distribution [6]. To analyze the plasma expansion depending on electron energy, fully kinetic simulations were conducted using particle-in-cell and Monte Carlo collision techniques. As a result, the high-energy free electrons showed adiabatic expansion, whereas the low-energy trapped electrons indicated isothermal expansion [7]. It was numerically shown that the high-energy free electrons expanded more efficiently in the divergent magnetic field without heat dissipation.

More recently, the effect of the high-energy free electrons on the formation of density profiles was numerically discussed [8]. In this paper, it was reported that the high-energy electrons were generated in the peripheral region by the RF heating, and the magnetized high-energy electrons generated the hollow density region at the center of the convergent and divergent magnetic field. These results are consistent with previous experimental work [9]. Therefore, the high-energy free electrons have an important role in the convergent and divergent magnetic field.

To further investigate the role of high-energy electrons, we have started to build a fully kinetic simulation of high-temperature plasma expansion. GAMMA 10/PDX is modeled to kinetically simulate the high-temperature plasma expansion, which is the largest tandem mirror device and has a divergent magnetic field at the ends of the device [10]. It can be investigated how the role of high-energy electrons changes between low- and high-temperature plasmas. In GAMMA 10/PDX, additionally, the plasma temperature can be actively controlled by ion cyclotron radio frequency and electron cyclotron resonance heating [11,12]. Therefore, the energy dependency on plasma expansion can be validated using experimental data.

In the conference, the numerical studies on the electric thrusters using the divergent magnetic field will be discussed, and the recent progress of fully kinetic analysis for the high-temperature plasma expansion will be reported.

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