§ 24. Dependence of Helical Non-Neutral Plasmas on Injection Angle of Electron Beam on CHS

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There has been a great interest in plasma flow in recent years. Several studies have been conducted in production of a strong electric field $\boldsymbol{E}$ in a boundary layer of plasmas in order to improve particle confinement by a sheared plasma flow. As a method of producing $\boldsymbol{E}$, we have proposed a non-neutral condition of plasmas. In linear non-neutral plasmas such as Malmberg traps, non-neutral plasmas have been well confined and stabilization of the plasmas have successfully been demonstrated. On the other hand, in a toroidal helical configuration, no studies have been performed yet. In fact, it is unclear whether we can inject electrons from the outside of the magnetic surface with three-dimensional structure to produce the non-neutral helical plasmas, and whether electrons are confined in the boundary region of helical field. In order to investigate the problems above, we have performed experiments on the CHS device. Electrons are injected from an electron gun (e-gun) settled on the stochastic region, outside the last closed flux surface (LCFS). In this paper, dependence of helical non-neutral plasmas produced in CHS on beam condition is described.

In experiments, it is observed that the potential structure of helical non-neutral plasmas strongly depends on the injection angle α, density, and the energy of the electron beam. Above all, we explain the dependence upon injection angle in the following. Figure 1 shows a change in plasma potential ϕ measured at r = 118 cm when α is varied every 15 deg. from 0 to 360 deg. The definition of α is described in Fig. 3. Two profiles in Fig. 1 are obtained with the same set of the experimental parameters except the direction of coil current, which means $\boldsymbol{B}$ is flipped each other: (1) the normal case (black circle) and (2) the reverse case (white circle). The gun is settled at r = 117.5 cm which is 1.5 cm outside the LCFS. As seen in Fig. 1, ϕ does not strongly depend on α except a narrow 'window' of α ~ 120 and 300 deg. for the solid and dashed data, respectively. And, the difference in those two values of α is 180 deg. Since the coil current is flipped for the two cases, these results reflect symmetry of the measured data against $\boldsymbol{B}$.

The question may be asked on the profiles of ϕ in Fig. 1 with such a weak dependence on α except the 'window' region. The thermal electrons emitted from the cathode of e-gun are accelerated by the electric field $\boldsymbol{E}_g$ between a pair of electrodes. Then, it is generally considered that the electrons are injected along $\boldsymbol{E}_g$ from the anode. However, in experiments, a transverse component of the helical magnetic field $\boldsymbol{B}$ exists between the electrodes as well. Thus, the emitted electrons never move straightly towards the anode but drift across $\boldsymbol{E}_\perp$ (a normal component of $\boldsymbol{E}_g$ to $\boldsymbol{B}$) and $\boldsymbol{B}$ by $\boldsymbol{E}_\perp \times \boldsymbol{B}$ drift. This means that a parallel component of $\boldsymbol{E}_g$ along $\boldsymbol{B}$ also exists and the component $\boldsymbol{E}_{/\!/}$ plays a roll to accelerate the electrons along $\boldsymbol{B}$ inside the e-gun. This effect brings a finite parallel velocity of electrons $\boldsymbol{v}_{/\!/}$, which is comparable to the $\boldsymbol{E}_\perp \times \boldsymbol{B}$ perpendicular velocity $\boldsymbol{v}_\perp$. In fact, the pitch angle of electron, which is determined by the ratio $\boldsymbol{v}_\perp / \boldsymbol{v}_{/\!/}$, launched from the e-gun is calculated to be at most 20 deg. in experiments. As a result, with such a small pitch angle, the injected electron move still as passing particle rather than helically trapped particle, which actually can also be recognized by orbit calculations of the electron including the effect of $\boldsymbol{v}_{/\!/}$. Thus, in this case, electrons are still ejected almost parallel to B even for the cases of α = 300 (the normal case) and = 120 (the reverse case) where the e-gun is set quasi-perpendicular to $\boldsymbol{B}$. Therefore, such a weak dependence on α should be observed in the measured ϕ profiles shown in Fig. 1.

Let us now return to the 'window' where ϕ significantly drops for α ~ 120 (the normal case) and 300 (the reverse case) deg. The reason is still unclear but it might be due to an interaction of the injected beam electrons with the electron plasmas confined. In Fig. 2, a typical profile of radial potential and the corresponding electric field are shown. Because of the strong radial electric field (up to 9 kV/m) and the magnetic field strength at 0.45 kG near the LCFS on the measurement port, an expected poloidal flow can be calculated to be 2.0×10^5 m/s. And in Fig. 3, one finds that ϕ drops when α is anti-parallel to the expected poloidal flow. In this case, some instability may occur and it might degrade the confinement properties of helical electron plasmas. In order to examine the mechanism experimentally, measurements of the instability and electron flow will be performed.

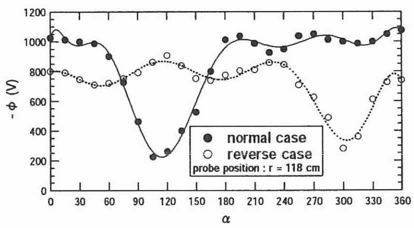

Fig.1 Dependence of plasma potential on injection direction

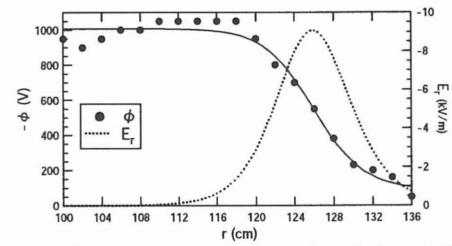

Fig.2 Radial profile of potential and electric field

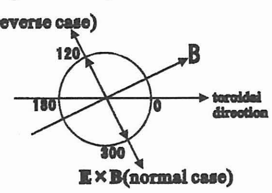

Fig.3 End-on view of e-gun port seen from the experimenter