§16. Production of Shear Flow by Electron Beam on LHD and Confinement of Nonneutral Plasmas

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An innovative idea of generating a radial electric field in plasmas has been proposed. The method applies the physics of non-neutral plasmas in which excess electrons may successfully be trapped just inside the separatrix surface of a closed magnetic configuration. To obtain the non-neutral condition in the boundary layer with the excess electrons, one has to inject electrons across the separatrix. Several i dea can be considered. One of them is to cause electrons to move chaotically around the boundary layer. In this case, a part of electrons could be expected to travel across the separatrix. This is because even the magnetic moment of electron is not conserved, which operates electrons i n a n on-ordered way. An experimental test h as been performed on the Proto-RT (Prototype Ring Trap) device at the University of Tokyo. The machine is one of the internal ring devices and has a symmetric axis. Thus, in the experiment on Proto-RT, an inhomogeneous AC electric field is a pplied to electrons t rapped a round t he separatrix surface in order to violate the conservation of magnetic moment there. A helical magnetic configuration, on the other hand, is asymmetry. This means that no (global) adiabatic invariant is inherently existed. Thus, this property strongly suggests the possibility of the penetration of electrons across the separatrix even in an electrostatic magnetic field. And, as a result, a strong radial electric field due to the externally injected electrons may be generated in the boundary layer of the helical configuration. In order to test that, we have initiated experiments on the Compact Helical System (CHS) device.

CHS is a medium size device whose major and averaged minor radii are 1.0 and 0.2 m, respectively. A detail explanation o f t he de vice c an b e f ound i n R ef. 1 . O n t he CHS experiments, there are two parameters which are essential to form a helical configuration. One of these is the radial position of magnetic axis (R_{ax}). For the conventional experiments focusing on the study of CHS hot plasmas, R_{ax} is usually set around 92.1 cm. However, for this setting, the inside edge of separatrix surface interfaces with the vacuum chamber that works as a limiter. Thus, at the presented experiment, we have shifted R_{ax} outwardly in radial direction and fixed at 101.6 cm in order to completely isolate the separatrix surface from the chamber. The other is the magnetic field strength of helical configuration. The field strength at R_{ax} is usually more than ~ 0.9 T for hot plasma experiments in the pulsed operation. The presented experiments, on the other hand, have been performed under an electrostatic operation to both create a well-controlled helical field and avoid experimental difficulties. Typical field strength for the presented experiments at R_{ax} is ~ 0.05 T for R_{ax} = 101.6 cm where the gyroradius of electron ρ_e is calculated to be ~ 0.23 cm for the case of $v_\perp \sim 2\times10^7$ m/s ($E_\perp \sim 1.2$ kV). Electrons are launched from a typical diode-type electron gun with LaB_6 cathode which can be operated in r elatively strong field. It a lso achieves h igher current densities with lower temperature than pure tungsten because of lower work function. A schematic drawing of the gun is shown in Fig. 2. As described, the LaB_6 cathode is quadrate (1.5 cm each). And, the emitter has also a quadrille shape with tungsten wires. The beam current (j_b) of the electrons is variable. However, for the present research we have kept j_b at a constant value of ~ 10 mA for V_{acc} = 1.2 kV where V_{acc} is the potential difference between the LaB_6 cathode and the (grounded) emitter. Detailed explanation of the electron gun is described in the companion annual report[2)].

At the first series of the experiment, an electron beam is injected into the CHS vacuum helical field (no plasmas) via stochastic field region. Space potential ϕ_p due to the injected electrons (nonneutral plasmas) is measured by a high impedance emissive probe. As recognized from Fig. 1, despite launching from the 1.7 cm outside of the separatrix surface, substantial ϕ_p is established in the boundary layer of the CHS helical configuration for R_{ax} = 101.6 cm. In consequence of that, a strong radial electric field up to ~ 10 kV/m is established there.

Regarding with the penetration length of electrons, data of the measured particle flux Γ indicates that the thickness of the penetration layer δ is at least seen to be ~ 8 cm. This value is about 40 times greater than ρ_e. On the other hand, the rise-up time of Γ inside the separatrix is about ~ 300 μs which is comparable with a single collision time of electron against background neutral particles τ_{en} (~ 330 μs) at $P_0 \sim 1\times10^{-7}$ Torr. Therefore, the diffusion process due to the classical collisions is insufficient to explain the the penetration of injected electrons. Further studies is thus required to the experiments.

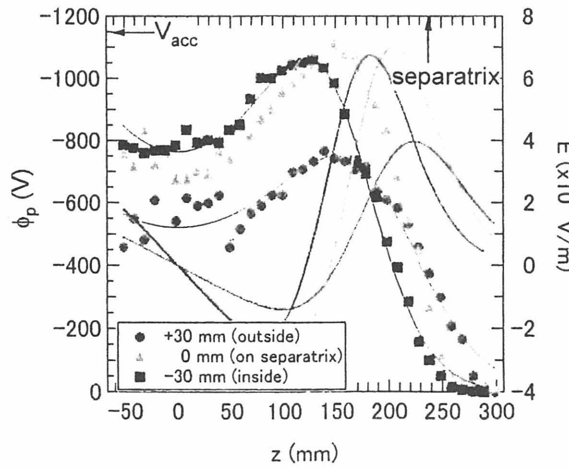

Fig. 1. Radial profiles of space potential a nd t he electric field formed by the injected electrons in a CHS vacuum magnetic field.

1) Matsuoka, K. et al., Fusion Technol. **17**, (1990) 86.
2) Yoshida, Z., Himura, H. et al., 'Shear-flow Drive and Production of Non-neutral Plasma by Electron Injection to Helical System', NIFS Report Apr. 2001 – Mar. 2002.