§ 5. Production of Shear Flow by Electron Beam on LHD and Confinement of Non-neutral Plasmas

Himura, H., Wakabayashi, H., Kurihara, T., Fukao, M., Yoshida, Z. (Univ. Tokyo)
Isobe, M., Okamura, S., Nishimura, S., Suzuki, C., Matsuoka, K., Yamada, H.

In these days, many studies on plasma flow have intensively been performed both theoretically and experimentally. In particular, works on generation of a strong electric field in the boundary layer of a closed magnetic surface in toroidal plasmas are hot topics in relation with the research to improve confinement properties by a fast shear flow. As a method for producing the flow, a self-electric field E formed by injecting excess electrons has been proposed. It actually expects that the electrons, being injected from a chaotic magnetic region, drift across the magnetic field. In order to test the idea experimentally, experiments have been conducted on the Compact Helical System (CHS) at National Institute for Fusion Science (NIFS), Japan. The purpose of this study is to investigate (1) the motion of charged particle magnetized strongly in the region where the field itself is chaotic, (2) how a strong self-electric field is generated in the boundary layer of helical magnetic surface and (3) what properties are realized in the electrons confined in such a helical symmetric surface. In the last academic year, much progress were made in the experiments. In this report, we divide the results in three parts and briefly explain them in the following.

I. Penetration of electrons inside the helical magnetic field via stochastic magnetic layer

Before describing the details of experimental results, we explain the setup of this research. As for the source of electrons, they are injected from a simple electron gun which equips with a LaB_6 as the cathode in this research. The gun is placed in the stochastic magnetic layer surrounding the helical magnetic surfaces. The directed energy of electrons is variable in the range from 0.2 to 1.2 keV. The field strength, on the other hand, is also variable in the range between 0.2 and 0.9 kG. With regard to diagnostics, we have employed two electrostatic and emissive probes in the same way as the Proto-RT experiments to detect both electron flux and space potential in helical fields. One of the probes is installed along the z axis, the other being along the r axis. Both are movable to measure spatial distribution of the two plasma parameters, which thus provides a part of full 3-D information of those parameters around the toroidal direction of helical plasmas.

Remarkably, despite being launched from the outside of magnetic surfaces, electrons travel across the magnetic field **B** and penetrate deeply inside the closed surfaces. The electrostatic probe outputs sufficient electron flux even around the magnetic axis. Since the average radius $\bar{r}$ is about 20 cm, the electrons travel more than 20 cm that is about 100 times larger than electron Larmour radius. This is never caused a simple orbital injection of electrons. No numerical calculation of motion of a single electron describes such an orbit. In the calculation, no loss cone orbit is also appeared. As for the time scale of the observed penetration, it happens in 100 μs, while the electron-neutral collision time is about 500 μs. Thus, it indicates that the penetration of electrons is caused by a collisionless mechanism that has never been observed in past toroidal nonneutral plasmas confined in axisymmetric geometries. Actually, a fluctuation can be recognized significantly in the data of electron particle flux during the penetration, which indicates the existence of some collective phenomenon that may bring about the inward transport of electrons.

II. Profiles of potential and particle flux in equilibrium

About 150 μs after the injection of electrons, values of space potential and also electron flux seem to be saturated at each measurement point, suggesting that the electrons reach an equilibrium state in the helical magnetic surface. As for the value of space potential, the emissive probe shows the value of ~ 1.2 kV at the core, which is comparable to the initial potential energy of the injected electrons. From this value, the formed electric field by electrons can be calculated to be about 3 kV/m. This value is sufficient to cause 10^4 ~ 10^5 m/s toroidal flow if the electrons are still successfully confined even under the condition where a helical (neutral) plasma exists in background.

Only near the boundary layer of helical magnetic surface, the self electric field is clearly formed. No gradient of space potential can be observed around the magnetic axis, indicating no electric field there. This result indicates the existence of little electrons there, contrary to the distribution assumed in past numerical studies on equilibrium of helical nonneutral plasmas. Regarding with the electron density of the helical nonneutral plasmas, it is about 10^{11} m^{-3} much smaller than the Brillouin density limit. Also, in the data of electron flux, a shear profile is clearly observed because of inhomogeneous **E** and **B** in the helical configuration. From the observed profile, it is inferred that the electron density may have also sheared profile. This is unstable profile against the diocotron mode (that is the Kelvin-Helmholtz mode in neutral plasmas) as widely-known in nonneutral plasma physics. However, no distinguishable instability can be observed in this phase. This might be due to the shear profile of velocity field inside the magnetic surface.

III. Disruption of the helical nonneutral plasmas

The stable phase described above section lasts for 1 - 4ms and then, starts to disrupt. The frequency is about 50 kHz which seems to be independent the strength of magnetic field. On the other hand, the growth time is about 50 μs which is hardly slow to be attained with pure electrons. Actually in experiments, the disruption repeats in every several milliseconds. The time interval depends on the value of cross-section of injected electrons against background neutrals. It strongly suggests that the electrons hit the background neutrals and produce ions inside the magnetic surface. And, some ion-related instability is driven inside there, which kicks out the ions and also electrons outside the closed magnetic surface.