§8. Data Analysis of Hot Nonneutral Plasmas Confined on Magnetic Surfaces of CHS

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Research on nonneutral plasmas confined on toroidal magnetic surfaces has been intensively conducted in recent years[1, 2]. Despite the closed magnetic surfaces, no break-up of those is required when the plasmas are produced. In experiments on devices of the Compact Helical System (CHS) and the Heliotron J, an electron-gun (hereafter, e-gun) has been installed in the stochastic (or ergodic) magnetic region (SMR) surrounding the last closed flux surface (LCFS) and just ejected thermal electrons in the SMR. Then, within the order of 10 μs after the injection, those have penetrated deeply in the helical magnetic surfaces (HMS), spread rapidly in the whole of the closed surfaces, and finally formed a helical nonneutral plasma there. This property actually offers several advantages especially in developing an instrument for trapping high-energy particles.

Since the observed penetration has happened in much shorter than any classical binary collision time, some cross-field transport associated with free-streaming of electrons along the stochastically wandering field lines had been considered as a possible mechanism. However, no electron orbit that extended to the innermost region of HMS was found in three dimensional numerical calculations of a single electron motion in CHS vacuum magnetic fields. However, there exist two experimental findings that have remained to be excluded in the past calculations. One is the effect of space potential ϕ_s in the SMR, which has been discovered in not only the CHS experiments but also the neutral experiments. Actually, ϕ_s attributes to the bunch of electrons confined in the SMR so that ϕ_s can be sorted as self electric potential. The other is the fact that ϕ_s varies on the HMS, in other words, values of ϕ_s are non-constant along magnetic field lines of helical nonneutral plasmas, which has been established recently. Obviously, these proofs would affect on the electron orbit, which calls for a renewed calculation including them.

Under this collaboration program, we numerically find the inward propagation of a single electron injected into the SMR where negative ϕ_s is extended. The physical mechanism can be explained as follows; in the SMR, the pitch angle of the injected electron is changed considerably during it circulates in the SMR. Due to the pitch angle scattering, the particle sometimes turns to be a helically trapped particle in the upper side region of the HMS and starts a downward movement along one of the $|B_{min}|$ contours, that is, an inward drift motion across the HMS. Actually, considerable propagation across the HMS has been observed for several cases. Readers can see the highlights of the event in Ref. (3). The paper shows a typical set of time evolutions of all plasma parameters. Those have been calculated numerically for the case where the electron is injected toroidally. The electron orbit projected onto a $\psi^{1/2} - \phi$ plane is shown in Fig. 1.

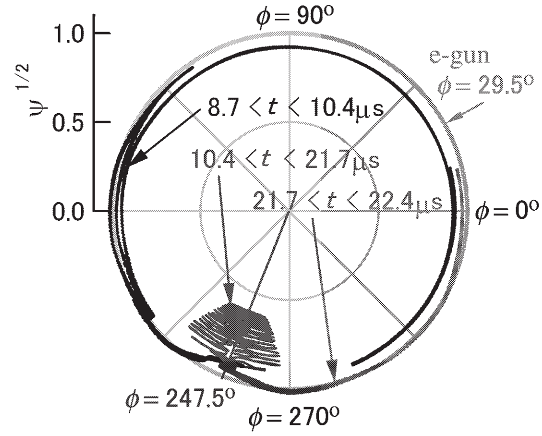

Fig. 1: The electron orbit for $8.7 < t < 22.4$ μs projected onto the $\psi^{1/2} - \phi$ plane, where ϕ is the toroidal angle of the injected electron. The passing electron turns to be a helically trapped electron, and then starts a movement across helical magnetic surfaces inwardly.

At $t = 0$ μs, the electron is injected from the e-gun into the SMR. Since the position is represented using $\psi^{1/2}$, the period of $\psi^{1/2} > 1$ means that the injected electron is circulating in the SMR, in other words, outside the LCFS. On the other hand, when $\psi^{1/2} < 1$, the electron is inside the LCFS, which thus indicates that the inward penetration of the electron has happened. In fact, in Fig. 1, such penetration can be clearly recognized for the period of $t > 10.4$ μs.

When the inward penetration occurs, considerable changes have also appeared in time histories of both ϕ and the pitch angle. As clearly seen from the data in Fig. 1, the electron is completely trapped in the vicinity of $\phi \sim 247.5^o$. During this phase, the value of pitch angle has changed periodically between 70^o and 110^o (not presented here). These results indicate that the electron turns to be a *'helically trapped electron'*, when it starts the movement across the HMS. The detail of this work will be reported soon.

1) H. Himura *et al.*, Phys. Plasmas (2007) vol.14, pp.022507.

2) M. Hahm *et al.*, Phys. Plasmas (2008) vol.15, pp.020701.

3) K. Nakamura, H. Himura *et al.*, *accepted for publication in J. Plasma Fusion Res. Series* (2009).