§7. Outward Electron Orbit Extending to Inward Part of Closed Helical Magnetic Surfaces Surrounded by Shifted Negative Space Potential

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In helical nonneutral experiments on the Compact Helical System device, an electron-gun (e-gun) has been installed in the stochastic (or ergodic) magnetic region (SMR) surrounding the last closed flux surface (LCFS). From the e-gun, thermal electrons have been injected in the SMR. Then, within the order of 10 μs after the injection, those have penetrated deeply in the closed magnetic region, spread rapidly in the whole of the closed surfaces, and finally formed helical nonneutral plasmas there. Investigating this mechanism, we calculate single electron orbits with assumptions of two experimental findings recently; one is the effect of space potential ϕ_s in the SMR and the other is the fact that the value of ϕ_s is nonconstant along magnetic field lines of helical nonneutral plasmas. Results obtained from the renewed calculation are as follows.

Numerical calculations including finite ϕ_s in the SMR have shown that some of injected electrons start a movement to cut in the closed magnetic surfaces when they are completely trapped in a helical ripple by the pitch angle scattering due to the presence of $\mathbf{E}_s$ (= - grad ϕ_s) in the SMR. Since the strength of B where the helically trapped particle exists is relatively weak, the contour plot of minimum strength of B that is so called the mod $|B|$ contours represents the trajectory along which the guiding center of the helically trapped particle drifts across closed magnetic field. Blue bean-shaped curves in Fig. 1 show the mod $|B|$ contours calculated for the case of R_{ax} = 101.6 cm, while red ellipses represent the helical magnetic surfaces. As clearly understood, the mod $|B|$ contours never coincide with the magnetic surfaces. Consequently, any charged particle must drift across magnetic surfaces, if it should become a helically trapped particle exactly on one of the mod $|B|$ contours.

In Fig. 1, the Poincare plots of the orbit of the helically trapped electron that was injected in the SMR are also drawn. In addition, for convenience of reference, the region where the assumed ϕ_s exists is color-highlighted. Comparing the Poincare plots with the mod $|B|$ contours, it is clearly understood that the electron turns to be a helically trapped particle on one of the mod $|B|$ contours (at $\Psi^{1/2} \sim 0.9$) and then initiates a drift motion along one of the contour curves. Therefore, it is concluded that the observed inward penetration is caused by the particle motion of a helically trapped particle.

Another fact which supports this conclusion is that the injected electron has always drifted from the upper ($z > 0$) to the downside ($z < 0$) in the closed magnetic region, when it starts the inward drift motion. This direction is actually consistent with that of the conventional toroidal drift expected for particles having negative charge.

Since helically trapped electrons can drift not only inwardly but also outwardly, the question may be asked on how they are stored up inside the closed magnetic region. For the case presented here, finite '*negative*' ϕ_s due to space charge of electrons has been extended to the EMR and its vicinity, as highlighted in Fig. 1. As also recognized from the trajectory of the penetrating electron in Fig. 1, the helically trapped electron can certainly propagate from the outward negative ϕ_s region to the inward vacuum region (non-colored), but not from within outward, because of the electrostatic force. In other words, the negative ϕ_s region acts as a *'potential barrier'* to the electrons that move outwardly. Needless to say, if no negative ϕ_s exists in the EMR and its vicinity, any trapped electron necessarily escape out from the LCFS as moving along the mod $|B|$ contours and finally hits the chamber wall. Thus, such a reflection is never the case for conventional confinement experiments on neutral helical plasmas.

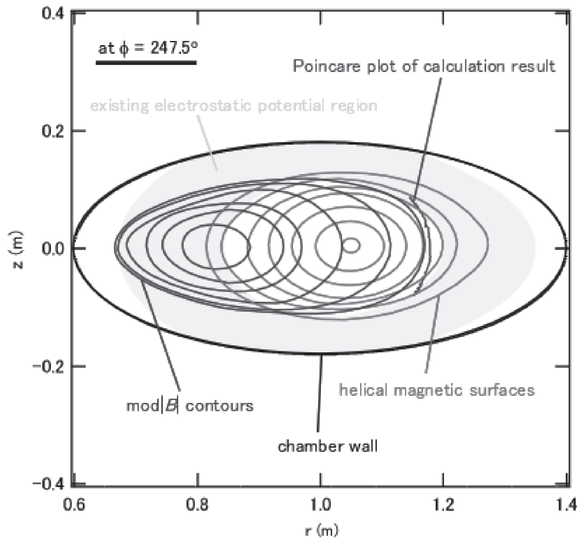

Fig. 1 Comparison of the trajectory of the penetrated electron with the mod $|B|$ contours. It is almost coincided with the one of the mod $|B|$ contours, showing that the penetration is caused by a helically trapped particle.

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