

## §4. Simulation Study of the Dynamics of the Radial Electric Field in Helical Plasmas

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The turbulence-driven transport and the formation mechanism of transport barriers are critical issues to realize improved confinement modes in toroidal plasmas. One possible mechanism to explain the transport barriers is the structural transition in the profile of the radial electric field  $E_r$  and the suppression of turbulence by its shear. In tokamaks, the model of L/H transition and the edge localized modes (ELMs) which is based on the bifurcation of the radial electric field was presented. A self-generated oscillation of the edge density and temperature takes place. In helical plasmas, the neoclassical helical-ripple transport plays a dominant role in the process of forming the profile of  $E_r$ . The bifurcation of  $E_r$  in helical plasmas takes place and the resultant strong shear of  $E_r$  was predicted to induce the transport barrier. At the state of the positive  $E_r$  in the core region, the electron internal transport barrier (e-ITB) is observed when the Electron Cyclotron Resonance Heating (ECRH) is applied which is localized around the plasma center. The temporal evolution equation for the radial electric field is solved in helical plasmas. The cyclic phenomena in the temporal evolution of the radial electric field, namely the electric field pulsations, have been observed in the core region of Compact Helical System (CHS) and Large Helical Device (LHD). The periodic oscillation of the electric potential which includes the intermittency characteristic is shown in LHD. In our previous work for the analysis of the temporal evolutions of the radial electric field, the stationary solutions of the radial electric field were obtained. The temporally oscillating solutions of  $E_r$  in the core region have not been shown yet.

The temporal evolution of  $E_r$ ,  $T_e$ ,  $T_i$  and  $n$  is studied. The self-generated oscillation of  $E_r$  is obtained in the core region. The time period of the limit cycle is about 10ms, which is determined by the typical transport time scale. The self-generated oscillation of the radial electric field is shown to have two time scales: a slow time scale of the transport time scale (about 10ms) and a fast time scale at the transition (about 1ms). The temporal change of the  $E_r$  profile causes the temporal change of the radial profile of the neoclassical and anomalous diffusivities. Owing to the influence of  $E_r$  on transport coefficients, the temporal evolution of the radial  $T_e$ ,  $T_i$  and  $n$  profiles takes place as the limit cycle in the core region.

We study the conditions in the parameter space, where the self-generated oscillation occurs. When the intensity of source is varied, the mean values of the temperatures and the density change, and the temporal evolution of calculations reaches either the stationary state or the self-generated oscillation. Furthermore, the profile of the stationary electric field takes different types

of roots. At first, stationary electric fields in the entire radial region become the electron root ( $E_r > 0$ ) in the region labeled e-root in Fig. 1 on the  $\bar{T}_e/\bar{T}_i - \bar{n}$  plane, where the bar shows the line-averaged value. In the regime of the low density  $\bar{n} \approx (1 - 3) \times 10^{18} m^{-3}$  and the high electron temperature  $\bar{T}_e/\bar{T}_i > 3$ , the positive and stationary solutions of  $E_r$  are found. Secondly, if the density gets larger, the electric field in the core plasma takes the electron root, and the electric field in the outer plasma takes the ion root ( $E_r < 0$ ) in the region labeled e-i root. In the region labeled e-i root, the type of the transition is classified to the hard or soft one. The multiple solutions of  $E_r$  are shown in the enclosed region inside the e-i region:  $1 < \bar{T}_e/\bar{T}_i < 2$  and  $\bar{n} \approx (0.2 - 1.4) \times 10^{19} m^{-3}$ . In this region, the so-called hard transition occurs between the multiple ambipolar  $E_r$  and the reduction of the anomalous heat diffusivity is shown due to the strong shear of the radial electric field. In the region labeled e-i region outside this enclosed region, the slow (and namely, the soft) transition takes place spatially and temporally since there are no multiple solutions of the ambipolar  $E_r$ . In the enclosed region, the shaded region is shown for the self-generated oscillation:  $1 < \bar{T}_e/\bar{T}_i < 2$  and  $\bar{n} \approx 10^{19} m^{-3}$ . In the enclosed region outside the shaded region, the stationary profile of the radial electric field is obtained even if there are multiple solutions of the ambipolar  $E_r$  at some radial locations. When the value of the density increases further:  $\bar{n} \approx 2 \times 10^{19} m^{-3}$ , all radial stationary electric fields changes to the ion root in the parameter region labeled i root. The parameter region of the two patterns for the temporal evolutions: the stationary state and the self-generated oscillation are examined on the  $\bar{T}_e/\bar{T}_i - \bar{n}$  plane. The physical mechanism to realize a self-generated oscillation is also studied, concerning the flux-gradient relation which includes the hysteresis characteristic 1).

- 1) S. Toda and K. Itoh, Plasma Phys. Contr. Fusion **53** (2011) 115011.

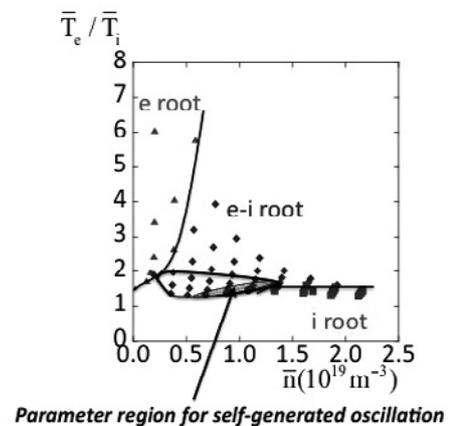


Fig. 1: Parameter space for the self-generated oscillation