§1. Theoretical Analysis of Structure of Radial Electric Field in Helical Systems

Toda, S., Itoh, K., Itoh, S.-I., Yagi, M. (RIAM, Kyushu Univ.), Fukuyama, A. (Kyoto Univ.)

Recently, the internal transport barrier has been found in electron resonance heating (ECRH) plasma in the compact helical system (CHS), and the steep gradient of the radial electric field is observed in the core plasma. To study the existence of the transport barrier in the experimental conditions of helical plasmas, there are two important issues. The first is the formation of the electric field domain interface which is associated with the steep gradient of $E_r$. This could be investigated quantitatively because the neoclassical transport is found to play the dominant role in generating the structure of the electric field in helical plasmas. The second is the study of turbulent transport and neoclassical energy transport so as to understand the formation of the internal transport barrier. In order to analyze the structure of the electric field quantitatively, the self-consistent transport study is done in which both the electric field bifurcation and suppression of the anomalous transport are included. The magnitude and the spatial distribution of the transport reduction are studied. The hard transition of $E_r$ which induces the steep gradient is examined. The reduction of the anomalous transport is obtained due to the strong electric field shear at the electric domain. The neoclassical diffusivities are found to have a peak near the domain interface where the electric field vanishes.

The stationary solutions of the radial electric field are shown in Figure 1. The profiles of the density and the temperature are obtained. At the point $r=r_T$ (0.12m), the transition of the radial electric field is found. The circles in figure show the values of the electric field which satisfy the local ambipolar condition for the calculated profiles of the density and the temperatures. Multiple solutions are allowed for the local ambipolar condition in the parameter region examined here. In the case of Figure 1, the electron root ($r<r_T$) for $E_r$ is sharply connected to the ion root ($r>r_T$) with a thin layer between them. The transition points should be determined by the Maxwell construction. The peak at the transition point $r=r_T$ is found in the profile of the radial electric field gradient. The magnitude of the peak of the electric field shear in this study is twice as that of the case for the constant $D_{Te}$ which gives the same half width at the half maximum. The condition for the suppression due to the electric field shear is satisfied where the width in the profile of the electric field shear is smaller than 0.007(m).

The transport barrier is obtained for the both channels of the neoclassical transport and the anomalous transport, although it is not very clear in both $T_e$ and $T_i$ profiles. The profile of the anomalous diffusivity is obtained. At the transition point, the suppression is obtained due to the strong electric field shear. The neoclassical diffusivities of electrons $\chi_{Te}^{\text{NEO}}$ and ions $\chi_{Ti}^{\text{NEO}}$ are also obtained. When the spatial transition occurs, the electric field goes across zero. Therefore, the neoclassical diffusivities have a peak near the surface where the relation $E_r=0$ holds, because they depend on the value of $E_r$ itself. The sum of the anomalous and neoclassical diffusivities is obtained. The total suppression can be seen but is small compared with that of the anomalous diffusivity. This is because the neoclassical diffusivity has a peak near the radius $r=r_T$.

The structure of the radial electric field in helical plasmas is theoretically studied. The analysis is done by use of one-dimensional transport model equations. Theoretical model is adopted for the anomalous heat diffusivity and the anomalous diffusion coefficient of the electric field. The hard transition with the multiple ambipolar $E_r$ is obtained in the structure of the radial electric field in this study of $T_e/T_i$=2. The connection from the positive electric field (electron root) to the negative electric field (ion root) is seen with the steep gradient. The reduction of the anomalous diffusivities is obtained at the electric domain due to the strong electric field shear. When the value of $T_e$ is much higher than the value of $T_i$ ($T_e/T_i$>10) and the transition type becomes soft (without multiple ambipolar solution for $E_r$), the gradient of the electric field gets weaker at the electric domain interface. In that case, no suppression of the anomalous transport diffusivities is obtained and the transport barrier is not seen. The condition for the suppression of the anomalous diffusivities is found as high $T_i$ ($T_i/T_e$>1/3) in addition to the low density and high $T_e$.

![Figure 1 Radial profile of the electric field.](image-url)

Reference