§5. Transport Analysis of the Electric Pulsation in Helical Plasmas

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The formation mechanism of transport barriers is important issue to realize improved confinement modes in toroidal plasmas. One possible mechanism to explain the transport barriers is the spatial transition in the profile of the radial electric field E_r and the suppression of turbulence by its shear. In helical plasmas, the limit cycle phenomena in the temporal evolution of the electrostatic potential, namely the electric pulsation, have been observed in the core region. Related with the electric pulsation, the electron internal transport barrier is observed in the electron temperature profile. In our recent work, temporally oscillating solutions of the radial electric field are obtained. A neoclassical transport database DCOM/NNW for LHD (DGN/LHD) has been constructed. In order to estimate the neoclassical transport and the ambipolar radial electric field for LHD in details, the DGN/LHD for the nonaxisymmetric part of the radial flux is adopted in the diffusive equations. The DGN/LHD is used for the simulation to reproduce the electric pulsation in the core region and to predict the parameter region for the electric pulsation in the LHD experimental results. The variation of the solution type from the stationary state to the oscillatory state is also examined.

The one-dimensional transport analysis for the LHD-like plasma has been performed and the profiles of n, T_e, T_i and E_r are solved as the initial value problem. The self-generated oscillation in a limited region of the parameter space is examined near the radial transition layer due to the multiple ambipolar E_r in the core plasma region. The absorbed power of electrons is set to be 1MW and the coefficient S_0 is taken as $6.5\times10^{21}\mathrm{m}^{-3}\mathrm{s}^{-1}$ to set the line-averaged values as $\bar{T}_e = 1.5\mathrm{keV}$ and $\bar{n} = 1.3\times10^{19}m^{-3}$, where the quantity with the bar represents the line-averaged value. The absorbed power of ions is taken as 100kW to set $\bar{T}_i = 0.56\mathrm{keV}$. The temporal evolution in the time interval $0.90\mathrm{s} \le \mathrm{t} \le 1.00\mathrm{s}$ of the radial electric field, E_r is plotted in Fig. 1. The lines labeled by $\rho = 0.1$, $\rho = 0.2$, $\rho = 0.3$, $\rho = 0.5$ and $\rho = 1.0$ show the temporal evolutions of E_r. The temporal evolutions in the core region (at $\rho = 0.1$, $\rho = 0.2$ and $\rho = 0.3$) are confirmed to clearly show the characteristic of the limit cycle, when the DGN/LHD database is used for the neoclassical transport. The time period of the limit cycle is about 12ms, which is determined by the typical transport time scale. 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. When the positive E_r is shown in the core region, the radial transition takes place at the radial point ρ_T, where the parameter ρ_T is the radial location of the transition point from the positive E_r to the negative E_r. Because of the shear of the radial electric field at ρ_T, the reduction of the anomalous heat diffusivity is found around $\rho = \rho_T$.

We study the conditions in the parameter space, where the self-generated oscillation occurs. At first, stationary electric fields in all radial region become positive in the region labeled 'e root' on $\bar{T}_e/\bar{T}_i - \bar{n}$ plane. Secondly, if the density gets larger, the electric field in the core region takes the positive value and the electric field in the outer region takes the negative value labeled 'e-i root'. At all points in the e-i root region, the multiple solutions of the ambipolar E_r at a radial point are examined. The region for the self-generated oscillation is shown: $2 < \bar{T}_e/\bar{T}_i < 3$ and $\bar{n} \approx 1\times10^{19}\mathrm{m}^{-3}$, using the DGN/LHD database for the neoclassical diffusion coefficient. The region for the self-generated oscillation is inside the region for the multiple E_r of the ambipolar condition. The multiple solutions for E_r at a radial point for the ambipolar condition are essential for the internal transport barrier. The results using DGN/LHD database show the higher value of T_e/T_i for the multiple solutions for E_r for the ambipolar condition than the results in the analysis using the analytic formula was adapted. When the value of the density increases further : $\bar{n} \approx 2\times10^{19}\mathrm{m}^{-3}$, all radial stationary electric fields change to negative in the parameter region labeled 'i - root'. The physical mechanism to realize a self-generated oscillation was studied, which relates the flux-gradient relation with the hysteresis characteristic. The larger value of $\bar{T}_e/\bar{T}_i$ is predicted for the self-generated oscillation when the DGN/LHD is used compared with the analysis when the analytic formula is adopted.[1)]

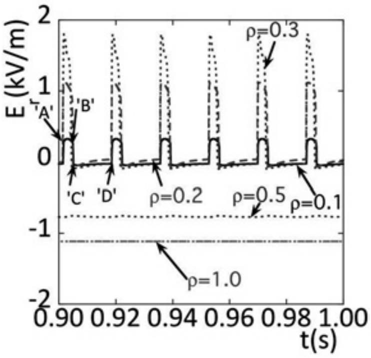

Fig. 1: The self-generated oscillation of the radial electric field

1) Toda S. and Itoh K., 24th IAEA Fusion Energy Conference, 8-13 October 2012 San Diego, United States of America, TH/P2-22