§23. Transport Model including the Particle Pinch Effect Arising from a Two-dimensional Structure of the Electric Field in Tokamak H-modes

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One of the problems on tokamak H-mode physics is the rapid formation mechanism of a density pedestal on an L/H transition. The poloidal shock structure in toroidal plasmas is a steady density or potential jump in the poloidal direction, resulting from plasma compressibility and toroidicity. Formation of the poloidal shock structure is predicted in H-mode transport barriers [1], which induces a convective particle flux in the radial direction [2]. Therefore, the 2-D steep structure must be taken into account for transport analyses. We have studied 2-D electric field structures by extending the 1-D model in tokamak H-modes, and constructed a transport model including the 2-D effect to reveal the self-consistent mechanism of the density pedestal formation on the L/H transition.

The analyses were carried out with edge plasmas in tokamak H modes, which are induced either spontaneously or by electrode biasing. 2-D structures of the electrostatic potential, density and flow velocity are calculated with the momentum conservation equation including the nonlinearity in bulk-ion viscosity and turbulence-driven shear viscosity [2]. The model equation, which describes the poloidal variation as deviation from the flux-surface-averaged quantities, is solved with the equation describing the radial structure by using the shock ordering. Our evaluation clarifies the validity of the previous 1-D L/H transition theory and this iterative process to obtain the 2-D structure.

The analyses show that the poloidal electric field generates convective particle fluxes in the H-mode transport barriers. The poloidal electric field generates an E × B convective flow in the radial direction, so the flux-surface-averaged radial flux is calculated to estimate its effect on particle transport. The E × B drifts of ions and electrons direct to the same direction, depending on the sign of the radial electric field, the toroidal magnetic field and the plasma current [3]. Adding the diamagnetic flow with electrons which satisfied the Boltzmann relation on the same flux surface, the electron radial flux is canceled to be zero. On the other hand, the ion radial flux is generated, and its particle velocity is more than 1 [m/s] in the transport barrier region. This radial ion flux affects the radial electric field by contributing to the radial current, and the additional current $J_\mathrm{p} = e(1 + T_\mathrm{i}/T_\mathrm{e})\langle nE_\mathrm{p}/B\rangle$ arises from the 2-D effect. If there is a mechanism to violate the Boltzmann relation of electrons, such as electron-ion collisions, the 2-D structure contributes to the radial electron flux. Here, we introduce this effect deductively by using the phase delay δ between the potential and the density to be $\Gamma_\mathrm{e} = \langle nE_p/B\rangle[1 - \exp(-i\delta)]$. The phase delay δ is taken as a prescribed parameter here.

Taking into consideration of the ion and electron radial fluxes, the transport model including the 2-D effect was constructed. The structure of the transport model is described in Fig. 1. There are two kinds of driving force; one is the external drive V_ext, which is the imposed biasing voltage taken as a control parameter in the case of the electrode-biasing H mode, and the other is the internal drive α, which is the temperature gradient taken as a control parameter in the case of the spontaneous H mode. A control of these driving parameters changes the radial electric field, and an L/H transition is taken place. The large radial electric field forms a 2-D electric field. Then, particle fluxes Γ_i and Γ_e are induced. The ion flux Γ_i contributes to the radial current and the electron flux Γ_e contributes to the convective component in the continuity equation written as

$$\frac{\partial n}{\partial t} = -\nabla\left(nV - D_a \nabla n\right) + S, \qquad (1)$$

where V, D_a and S are the flow velocity, diffusion coefficient and particle source, respectively. The density profile is reflected into the ambipolar electric field X_a. In this way, a self-consistent loop is closed in our transport model.

Using this model, a self-consistent evolution of the density profile was calculated in the L/H transition. The generation of a particle pinch associated with the poloidal shock structure can give a rapid density increase if the phase difference δ is substantial. The time constant of the E_r evolution is less than 1 [ms], which is characterized by the poloidal transit time t_p, which is of the order of the duration for which the particle with the thermal velocity completes one poloidal rotation. The time constant of the density evolution is ~ 10 ms, which is characterized by the diffusion term in Eq. (1), but the convection, which evolves with the time scale of the electric field, is large enough to affect particle transport in the ramping up phase. The difference in the time evolution of E_r is small, but ramping up speed of the density is 1.1 times larger in the case with $\delta = 0.5$ than that with $\delta = 0$. Existence of the 2-D structure can accelerate the density evolution. Thus, this convective particle flux is a new candidate for the cause of the rapid establishment of the density pedestal after the onset of the L/H transition.

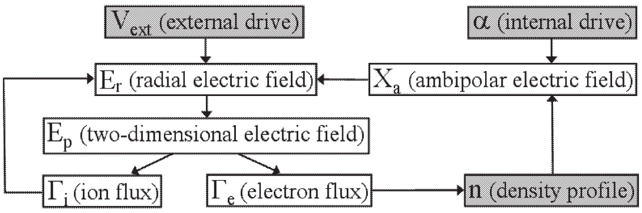

Fig.1: Structure of the transport code including the 2-D electric field effect.

References
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