§14. Two-dimensional Structure and Particle Pinch in Tokamak H Mode

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In tokamak H modes, a large poloidal flow exists in an edge transport barrier, and the electrostatic potential and density profiles can be steep both in the radial and poloidal direction. Two-dimensional structures of the potential, density and flow velocity near the edge of a tokamak plasma are investigated. The poloidal asymmetry of the structure generates inward particle pinch, and gives explanation for the rapid establishment of the edge density pedestal on the onset of L/H transition, the small time constant of which has not been clarified yet.

The analysis is carried out with the momentum conservation law with the shock ordering \(^n\), which is \(\ln(n/n_0) = \mathcal{O}(\varepsilon^2)\), where \(n\) and \(\varepsilon\) are the density and the inverse aspect ratio, respectively. The model includes the nonlinearity in bulk-ion viscosity and turbulence-driven shear viscosity \(^2\). The radial and poloidal structures are coupled with each other by the shear viscosity term, and the magnitude of the shear viscosity determines steepness and position of the shock structure. In shock ordering, a structure of the flux-surface-averaged part is solved first, and using this poloidal flow profile, a two-dimensional structure can be obtained iteratively.

For the case with a strong radial electric field (H mode), a two-dimensional structure in an edge transport barrier is obtained, giving a poloidal shock with a solitary radial electric field profile. Figure 1 shows a profile of the poloidal electric field in the electrode-basing H-mode \(^3\). The region where the poloidal Mach number has large value is localized in the middle of the electrode-biasing region, so a localized large poloidal electric field exists at the points of the shock in those with large poloidal Mach number. In addition, the magnitude of the poloidal Mach number varies in the radial direction, and the poloidal position of the shock varies in the radial direction accordingly.

The poloidal electric field induces convective transport in the radial direction, and poloidal asymmetry makes the flux-surface-averaged particle flux directly inward with a pinch velocity on the order of 1 [m/s]. Figure 2 represents the radial profiles of the flux-surface-averaged radial flux \(\nabla n\) in the strong and weak \(E_r\) cases. In the strong \(E_r\) case, which is relevant to the H-mode or electrode-biasing experiments, a large convective particle flux is induced in the radial direction. The radial flux has negative value, so it points inward to the plasma center. A large poloidal flow with radial shear enhances the inward pinch velocity. Figure 2 shows that the radial flux has maximum in the radial position where the poloidal flow shear is large. That is coming from the form of the shear viscosity.

The increase of the inward convective particle flux has a large impact on the density pedestal formation on the onset of L/H transition. The H-mode pedestal can be formed in shorter time \(\tau \ll 10\) [ms]. Suppression of turbulence and reduction of diffusive transport occurs in transport barriers. The reduction of diffusion coefficient explains steepening of the H-mode pedestal, but the time constant of the pedestal formation is difficult to explain. That is, it takes longer time to form the pedestal with reduced transport coefficient in the H mode. In L/H transition, the magnitude of a poloidal flow changes abruptly, so that the convective transport changes abruptly in the supply region of the plasma.

Fig.1: Two-dimensional structure of the poloidal electric field with strong and inhomogeneous \(E_r\) (electrode biasing H-mode case).

Fig.2: Radial profiles of flux-surface-averaged particle flux in the case of weak homogeneous and strong inhomogeneous \(E_r\) (L-mode and electrode biasing H-mode case, respectively).

References