§15. Transport Characteristics in Stochastic Magnetic Boundary of LHD

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The behavior of divertor plasma parameters against the upstream density reflects the transport characteristics in the SOL. Here we investigate the impact of flux tube geometry in the stochastic SOL on the divertor plasma.

Figure 1(a) shows the parallel plasma flow ($nV_{//}$) distribution in a poloidal plane obtained by the 3D modelling. In the stichastic region of LHD, there exist many remnant islands as shown in Poincare plot superposed om Fig.1(a). It is seen that the plasma flow is well regulated by the island structure. This is due to the helical field line structure in the islands as shown in Fig.1(b), where the flow directions become opposite around the O-point. The Mach probe measurements clearly detected such a flow alternation in the edge region of LHD [1]. When the flux tubes go through the high field region (HFR, i.e. near helical coils), the increasing magnetic field strength compresses the flux tubes in radial direction. This gives rise to a strong parallel flow shear between the islands of different mode numbers because of the phase shift in $nV_{//}$ between the odd and even mode number islands. This flow shear results in a perpendicular loss of the parallel plasma pressure.

By taking into account the parallel momentum loss via perpendicular friction, the two point model is extended to more general case as [2],

$$T_d \approx C_1 P_{SOL}^{10/7} n_u^{-2} (1 + f_{m0} / T_d^{0.5})^2, \quad (1a)$$

$$n_d \approx C_2 P_{SOL}^{-8/7} n_u^{3} (1 + f_{m0} / T_d^{0.5})^{-3}, \quad (1b)$$

with,

$$f_{m0} = \frac{D}{2c_{s0}} \frac{\bar{n}}{n_d} \frac{M \bar{T}^{0.5}}{T_d^{0.5}} \frac{L_C}{\lambda_m^2}. \quad (1c)$$

The subscripts u and d indicate the values at upstream and downstream (divertor), respectively. λ_m is the characteristic scale length of perpendicular flux, and $\bar{n}, \bar{T}, M$ represent density, temperature averaged along field lines, Mach number and $c_{sd} = c_{s0} T_d^{0.5}$. C_1 and C_2 are numerical constants. f_{m0} represents momentum loss factor due to the perpendicular interaction. It is noted that λ_m and L_C are determined sorely by megnatic field structure and that the deformation of flux tubes through streaching, bending and compression as discussed above, increases the ratio L_C / λ_m^2, resulting in larger f_{m0}. With no perpendicular momentum loss, $f_{m0} \to 0$, the solution becomes those of conduction limited regime in tokamak devices. At the opposite limit, i.e. $f_{m0} / T_d^{0.5} >> 1$, for the typical edge plasma parameters of LHD with λ_m~0.01 m and L_C~10 m, Eqs.(1a,b) then become,

$$T_d \propto P_{SOL}^{5/7} n_u^{-1}, \quad n_d \propto P_{SOL}^{-1/14} n_u^{1.5}, \quad (2)$$

where we see significantly moderate dependences of downstream parameters on upstream density, in contrast to those of tokamaks. Figure 2 shows divertor plasma density measured with divertor probes as a function of upstream density (values at LCFS as representative ones), together with the 3D modelling results. It is found that the dependences of n_{ed} are much weaker than $n_{ed} \propto n_u^3$ observed in the conduction limited (high recycling) regime of tokamaks [3]. Taking into account the variation of P_{SOL} due to NBI power deposition for different densities, eq.(2) yields a weaker dependence of n_{ed} on n_u, plotted as bold dashed lines, which agree better with the experiments and the 3D modelling resultsDespite the significant simplifications made in the analytical model, the analysis clearly shows the importance of perpendicular interaction between flux tubes in the stochastic boundary, which affects the divertor plasma behavior significantly, leading to the rather weak sensitivities of n_{ed} on the upstream density.

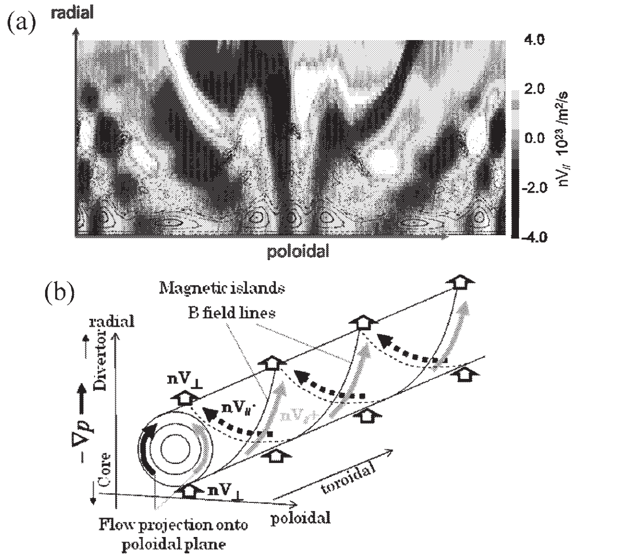

Fig.1 (a) Parallel plasma flow ($nV_{//}$) distribution obtained by EMC3-EIRENE on poloidal cross section. Yellow and blue colors mean positive and negative flow direction in toroidal angle. (b) Schematics of parallel flow formation at the island.

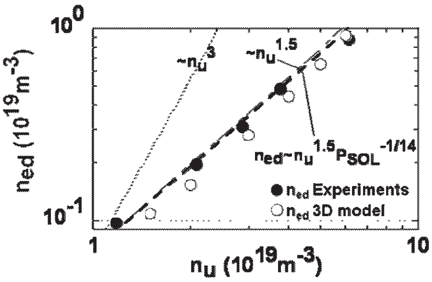

Fig.2 Dependence of divertor density on the upstream density, obtained from divertor probe measurements (closed circles) and the 3D modellings (open circles). The dependence of eq.(2) is also shown.

1) Ezumi, N. et al. to appear in PFR.
2) Kobayashi, M. et al., to appear in JPFR.
3) Shimomura, Y. et al.: Nucl. Fusion **23** (1983) 869.