§1. Dynamic Transport Study of Heat and Momentum Transport in the Plasma with Improved Ion Confinement in LHD

Ida, K., Lee, H. (NFRI), Osakabe, M., Yokoyama, M., Suzuki, C., Nagaoka, K., Seki, R., Yoshinuma, M., Tamura, N., LHD Experiment Group

Dynamic transport study taking account of the slowing down effect on the neutral beam injection (NBI) heating is applied to the high ion temperature plasma with an ion internal transport barrier (ITB) obtained by carbon pellet injection in LHD. The transient increase of ion heating is clarified during the density decay phase just after the carbon pellet injection by considering the slowing down effect. The dynamic transport analysis also includes the change in heat flux due to the change of kinetic energy inside the plasma with the time scale of the global energy confinement time, which is required to investigate the heat and momentum transport during the transient phase more exactly$^{1)}$.

In the transport analysis of the NBI heated plasma in LHD, the NBI heating profiles are obtained by the FIT-3D code $^{2)}$, where the steady-state solution of the Fokker-Planck equation is solved based on the birth profile of fast ions calculated by the Monte-Carlo method with the radial redistribution of fast ions due to prompt orbit effects. Since the FIT-3D code gives only a steady-state solution, a correction due to the slowing down process is necessary to evaluate the heat flux in the transient phase just after the onset of the NBI especially in the low density discharge, where the slowing down time is comparable to the confinement time. Figure 1 shows the comparison between the corrected absorbed power to electrons and ions, P_e^{SD} and P_i^{SD}, and that of the steady-state solution from the FIT-3D code, P_e^{ST} and P_i^{ST}. The corrected absorbed power clearly shows that there is a gradual increase of absorption power especially to the ions just after the onset of the NBI.

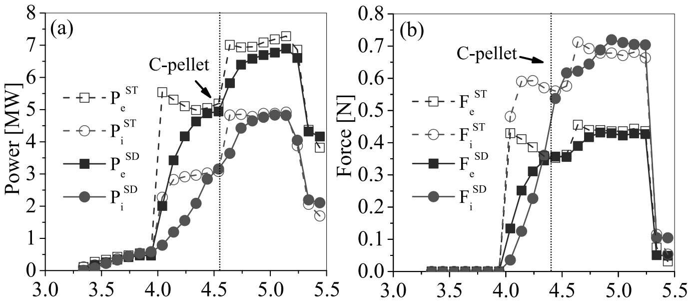

Fig. 1: Time evolution of (a) absorbed powers to electrons and ions in the steady-state and corrected with slowing down effect, $P_{i,e}^{ST}$ and $P_{i,e}^{SD}$, and the steady-state and the corrected input torque, $F_{i,e}^{ST}$, $F_{i,e}^{SD}$.

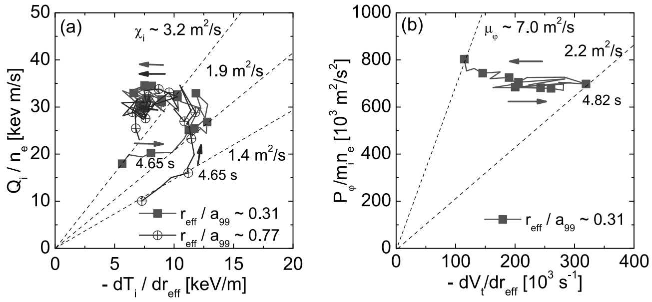

Fig. 2: (a) The ion heat flux normalized by the electron density as a function of the ion temperature gradient inside the ion ITB region ($r_{eff}/a_{99} \sim 0.31$) and outside the ion ITB region ($r_{eff}/a_{99} \sim 0.77$), respectively. (b) The momentum flux normalized by the electron density and bulk ion mass as a function of the toroidal velocity gradient is also plotted at $r_{eff}/a_{99} \sim 0.31$.

The result of the dynamic transport analysis on the heat and momentum transport is shown in Fig. 2. It is found that there is a significant improvement of the ion heat transport in the core region at $r_{eff}/a_{99} \sim 0.31$ (inside the ion ITB) during the transient phase (χ_i decreases from 3.2 m^2/s to 1.9 m^2/s), whereas no clear improvement (along the line with constant thermal diffusivity of 1.4 m^2/s in Fig. 2(a)) is observed near the plasma edge at $r_{eff}/a_{99} \sim 0.77$ (outside the ion ITB) as shown in Fig. 2(a). On the other hand, there is no increase of the electron temperature gradient even when the electron heat flux is increased. The ion heat transport is improved (the thermal diffusivity is reduced) even the heat flux is increasing in the core, although there is no improvement of the ion heat transport near the edge. After the formation of the ion ITB, the degradation of ion heat transport starts from the edge region (t=4.65 sec) and propagates to the core. The mechanism of the edge transport degradation and its propagation to the core is not clear yet in this experiment. Further study on the turbulence and its propagation is necessary. The momentum flux (P_ϕ) is normalized by the electron density and bulk ion mass and plotted versus the radial gradient of toroidal velocity (V_t) as shown in Fig. 2(b). The velocity gradient in the core increases due to the reduction of viscosity (μ_ϕ), while the edge velocity gradient is always small due to the parallel viscosity. It is also shown that the momentum confinement is also improved during the transient phase (μ_ϕ decreases from 7.0 m^2/s to 2.2 m^2/s) as well as the ion heat confinement.

1) Lee, H., et. al., submitted to Plasma Phys. Control. Fusion

2) S. Murakami et. al., Fusion Technol. 27 (Suppl. S) (1995) 256