§10. Theoretical Study towards the Extension of High Ion Temperature Regime in LHD

Yokoyama, M., Matsuoka, S. (Grad. Univ. Advanced Studies), Funaba, H., Ida, K., Nagaoka, K., Yoshinuma, M., Takeiri, Y., Kaneko, O., LHD Experiment Group

Experiments have been conducted in LHD to extend ion-temperature (T_i) regime, to achieve 5.6 keV[1)]. In such plasmas, typically T_i is higher than the electron temperature (T_e) in the core region. The negative radial electric field (E_r) (ion root) has been predicted there, based on the neoclassical (NC) ambipolarity, and it has been verified with the potential measurement by utilizing the heavy ion beam probe (HIBP)[2)]. The E_r can reduce NC transport in low-collisional high-T_i LHD plasmas[3)]. However, it is increasing as T_i is increased even with the presence of E_r, although the degree of the increase is much smaller than that predicted from the "pure (E_r=0)" $1/\nu$ ripple transport. Thus, it is important to consider plausible approaches to reduce (at least) the NC ion diffusion for the further extension of T_i-parameters. For this purpose, NC calculations have been performed with the GSRAKE code[4)], which is based on the bounce-average approach.

Another low-energy (60 keV) neutral beam will be installed in FY2010 to increase the ion heating power. It may be concerned that the ripple transport gets worse as T_i is increased in near-term LHD experiments. Figure 1 predicts that this concern is not the case. It shows the dependence of NC ion and electron fluxes, $\Gamma_{i,NC}$ and $\Gamma_{e,NC}$, on E_r. The open symbols represent those at ρ=0.2 in a particular example of high-T_i plasmas so far obtained ("base case"), and solid ones those in an artificial case with only T_i is doubled ("double-T_i case"). Since T_e is fixed, $\Gamma_{e,NC}$ does not change. The equilibrium is fixed as it is for the "base case". An artificial case is considered to be corresponding to the expected selective ion heating. The point of intersection of $\Gamma_{i,NC}$ and $\Gamma_{e,NC}$ corresponds to the NC ambipolar E_r for each case. The $\Gamma_{i,NC}$ at E_r=0 for "double-T_i" case is almost one-order larger than that for the "base case", which is understood from the $T^{3.5}$-dependence of "pure" ripple transport. However, as seen in Fig. 1, the ambipolar flux given at the ambipolar E_r is almost unchanged due to the enhancement of ion-root E_r. Therefore, in the near-term LHD experiment with selective ion heating, ion-root enhancement is predicted to avoid the appearance of deteriorate level of NC ripple transport. This scenario can be called as "ion-root" scenario.

On the other hand, when it is aimed to achieve high-T_i plasmas in a higher density than the current level (~1.4×10^{19} m^{-3}), T_i/T_e ratio becomes closer to 1 with the equipartition of the energy. It is then required to draw appropriate scenario to avoid the ripple transport in such a condition. Since T_i and T_e are almost the same at ρ=0.4 in a "base case", both T_i and T_e is simultaneously varied based on it. Here, the equilibrium is unchanged regardless the varied temperature. The density is also unchanged. Figure 2 shows the dependence of the NC ion heat diffusivity ($\chi_{i,NC}$) on temperature. The case with about 3 keV corresponds to the "base case", and the indicated numbers denote the multiplication factor of temperature (from 0.5 to 4). The ion-root E_r becomes smaller in the magnitude as the temperature is increased, which is due to the increase of $\Gamma_{e,NC}$ as a result of the increase of T_e. The decrease of the magnitude of ion-root E_r results in the significant increase of $\Gamma_{i,NC}$ and then $\chi_{i,NC}$ as seen in Fig. 2. It is considered from this tendency that the "ion-root" scenario is not appropriate for plasmas with T_i~T_e. However, once the temperature reaches a certain value (1.5 times, in this particular case), the electron-root E_r can appear with the significant reduction of $\chi_{i,NC}$ with the favorable nature of its decrease as the temperature is increased. It should be also pointed out that since Fig. 2 is obtained for the current level of the density, further 50 % increase of temperatures will provide the opportunity of the experimental verification of the electron-root E_r in core of high-T_i plasama. This amount of temperature increase might not be so unrealistic in the coming experiments. This approach utilizing the electron-root E_r, can be called as "electron-root" scenario.

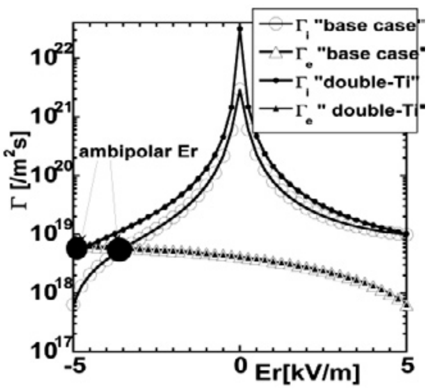

Fig.1: $\Gamma_{i,NC}$ and $\Gamma_{e,NC}$, on E_r. The open symbols represent those at ρ=0.2 in an example of high-T_i plasmas ("base case"), and solid ones those in an artificial case with only T_i is doubled ("double-T_i case") .

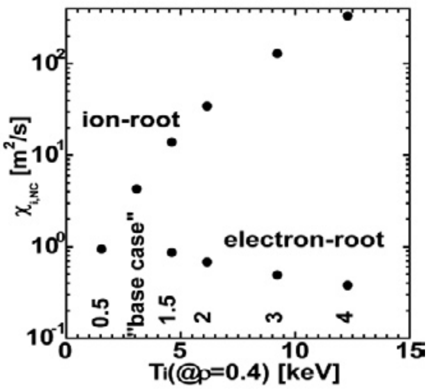

Fig.2: Dependence of $\chi_{i,NC}$ on temperature. The case with about 3 keV corresponds to the "base case", and the indicated numbers denote the multiplication factor of temperature (from 0.5 to 4).

1) Kaneko, O., Yokoyama, M., et al., Plasma and Fusion Res. **4** (2009) 027.
2) Ido. T. et al., to be presented at the 37th EPS Conf. on Plasma Phys., Dublin Ireland, (Jun. 2010).
3) Yokoyama, M., et al., Phys. Plasmas **15** (2008) 056111.
4) Beidler C.D., and Haeseleer, W.D., Plasma Phys. Control. Fusion **37** (1995) 463.
5) Yokoyama, M., et al., Nucl. Fusion **42** (2002) 143.