§20. Study of Nonlocal Electron Heat Transport on the High Temperature Plasmas of LHD

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In order to achieve a reliable predictive capability for well-controlled fusion plasmas, a definitive understanding of turbulent transport is highly required. The recent study of turbulent transport suggests the importance of an edge-core interaction and coupling in the nonlocal response observed in many tokamaks and helical systems. The recent edge cooling experiment in the LHD shows the nonlocal electron temperature T_e rise invoked by the rapid cooling of the edge plasma. Nonlocal transport phenomenon in helical device would be very useful to obtain a comprehensive understanding of the turbulent transport in magnetically confined toroidal devices, since the helical devices are free of net-current and have different magnetic shear from that of tokamaks. Figure 1 shows a typical result of the peripheral cooling experiment by a TESPEL injection. Within the time displayed in Fig. 1, the plasma is heated continuously by co-NBI (injected power ~ 2 MW) and ECH (injected power ~ 1.7 MW). Since the power of the neutral beam mainly goes into the electrons due to its high acceleration energy (~ 140 keV), the electron heat transport is the dominant thermal loss channel. The TESPEL penetration depth is around ρ ~ 0.8. A significant rise of the core T_e in response to the edge cooling can be immediately recognized in Fig. 1. During the rising phase of the core T_e, neither density peaking nor significant change in low-*m* MHD modes are observed. As shown in Fig. 1, the discrepancy between the T_e measured and that simulated, which is obtained by solving the perturbed heat transport equation with a simple diffusion model, is quite noticeable in the core (ρ < 0.6) region. Even with the model based on the assumption that heat flux has a strong non-linear dependence on T_e and/or T_e gradient cannot reproduce the cold pulse propagation with inversion of polarity. A transient analysis of electron heat transport indicates an abrupt reduction of electron heat diffusivity takes place with no change in local parameters in the region of interest. Therefore the sudden rise in the core T_e invoked by the edge cooling in the LHD can be caused by a nonlocal effect. In the LHD, the nonlocal T_e rise is observed in various plasmas. For example, the observation of nonlocal T_e rise in a plasma heated only with ECH (i.e. net-current free plasma) can completely rule out the contribution of the toroidal plasma current as a reason for the non-local T_e rise.

The interaction of turbulence over long distance (nonlocality of the turbulence) has been studied as a possible candidate for the nonlocal behavior in the electron heat transport. Microturbulence theory predicts two candidates for the electron transport, ETG and TEM modes. Based on a simple mixing length estimate, an ETG driven electron heat diffusivity is generally much lower than an ITG/TEM driven one. Thus the ETG turbulence might be ruled out of the candidates of the nonlocal T_e rise. The nonlocal transport observed in the ECH plasma, which has the weakly driven ion heat channel, may suggest that ITG turbulence also could be ruled out. The TEM modes are generally coupled to ITG modes and are stabilized in high collisionality regimes. Thus it is important to study a dependence of the nonlocal transport on the collisionality. In the low density (low collisionality) plasma, the core T_e rise takes place almost as soon as the TESPEL penetrates. However, when the n_e increases, the delay of the core T_e rise appears. (e.g. at ρ = 0.12, ~ 5 ms delayed at a line averaged density of 0.94 x 10^{19} m^{-3}) It should be noted here that even with a delayed onset time of nonlocal T_e rise, the time of the T_e rise in the core region still has kind of a spatial uniformity. The amplitude of the core T_e rise decreases with increasing n_e as well as in tokamaks. Figure 2 shows the delay until the T_e (ρ = 0.12) rise over the level just before the TESPEL injection as a function of collisionality ν_b^*, which is electron collisionality obtained at ρ = 0.12 normalized by bounce frequency of banana orbit. The low collisionality (ν_b^* < 1) is favorable for a strong nonlocal effect producing. In the high collisionality regime, the nonlocal T_e rise is never observed. Therefore the TEM turbulence may play an important role in the nonlocal transport phenomenon.

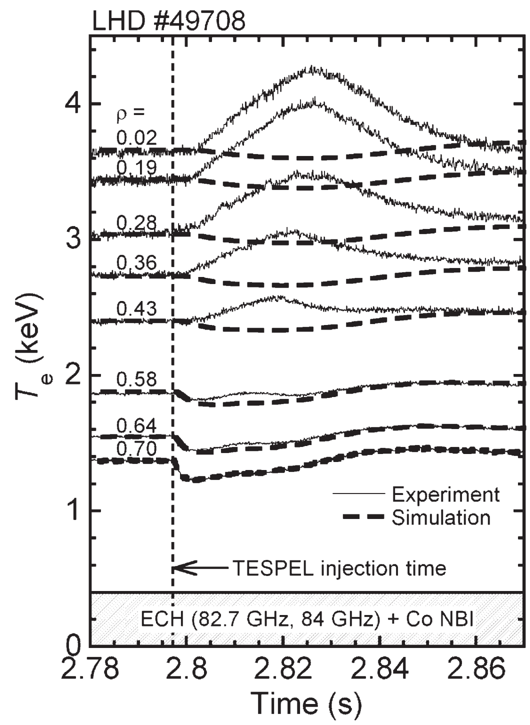

Fig. 1. Time evolution of the measured electron temperature (solid line) at different normalized minor radii. The simulated temperature (broken line) is also plotted. The TESPEL injection time is indicated as the vertical dashed line.

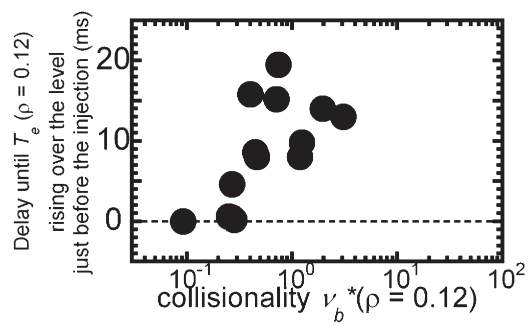

Fig. 2. The delay until the T_e rise over the level just before the TESPEL injection as a function of the collisionality ν_b^*.