§11. Observation of Nonlocal Electron Temperature Rise in the LHD Plasma Right after a Tracer-Encapsulated Solid Pellet Injection


The clarification of electron heat transport in magnetically confined plasmas is still one of the important issues, since the performance of a probable fusion reactor should be determined by an electron heating as a result of the interaction between electrons and alpha particles as a fusion reaction product. One of the significant issues found in electron heat transport studies is nonlocal transport phenomena observed in transient transport experiments on many tokamaks and few helical systems. In particular, a perverse change (especially rise) of core electron temperature $T_e$ invoked by the rapid cooling of edge plasma is the most typical and mysterious feature in the nonlocal transport phenomena, which observed in various tokamaks. There seems to be no changes of the thermodynamic forces, such as those due to the temperature gradient and/or the density gradient, in the core plasma at the onset of the core $T_e$ increase. Consequently, the phenomenon observed implies the aberration of local transport paradigm and is considered as a result of the nonlocality in the electron heat transport. On the contrary, the core $T_e$ rise responding to the edge cooling has not been observed so far in helical systems.

In the last LHD experimental campaign, as shown in Fig. 1, we observed an instantaneous rise of the core $T_e$ when a tracer-encapsulated solid pellet (TESPEL) is injected to induce a rapid cooling of the edge plasma in the LHD. A presumable reduction of electron heat transport does not depend on local variables and those gradients, since no appreciable change of the electron density, electron temperature and those gradients in the plasma right before the core $T_e$ increase. Therefore this experimental result shows evidence of the nonlocal transport phenomenon in helical plasma. Figure 1(b) shows the dependence of a normalized electron temperature gradient $R/L_{Te}$, where $R$ and $L_{Te}$ is a major radius and the scale length of the $T_e$ gradient respectively, on the ECH power normalized by a line averaged electron density $n_{eav}$ for the plasmas as shown in Fig. 1(a). A clear transition of the $R/L_{Te}$ can be seen when an electron internal transport barrier (ITB) is formed in the core region. When the nonlocal $T_e$ rise resulting from the edge cooling appeared, the $R/L_{Te}$ inside the ITB region increased accompanied by the lower ECH power normalized by the $n_{eav}$. From the comparison based on the same ECH power normalized by the $n_{eav}$, the $R/L_{Te}$ increased approximately by 31%.

Therefore the ITB in the LHD plasma is enhanced by the nonlocal $T_e$ rise. The onset mechanism of the nonlocal $T_e$ rise in response to the edge cooling is not correlated with the neoclassical bifurcation property of a radial electric field for the electron ITB formation in the LHD plasma, since the ECH power normalized by the $n_{eav}$ is decreased (that is, the collisionality is increased) by the TESPEL introduced electron density.

Nevertheless the experimental result shown here produces evidence that the nonlocal $T_e$ rise can take place in toroidally confined plasmas, not only in tokamak plasmas. The physical mechanism invoking a presumable reduction of electron heat transport still remains an open question.

Fig. 1. (a) An example of the nonlocal $T_e$ rise observed in the LHD plasma. A TESPEL is injected at the time of $\sim 1.4$ s. (b) Comparison of normalized electron temperature gradient $R/L_{Te}$ of the plasma at $\rho = 0.15$ between with (closed circles) and without (closed square) the TESPEL injection as a function of ECH power normalized by the line averaged electron density $P_{ECH}/n_{eav}$. 15