Characteristics of nonlocally-coupled transition of the heat transport in LHD*

N. Tamura, K. Ida, S. Inagaki[a], K. Tanaka, T. Tokuzawa, K. Itoh,
T. Shimozuma, S. Kubo, H. Tsuchiya, Y. Nagayama, K. Kawahata, S. Sudo, H. Yamada
and LHD experiment group

National Institute for Fusion Science,322-6 Oroshi-cho, Toki 509-5292, Japan
[a]Research Institute for Applied Mechanics, Kyushu Universtiy, 6-1 Kasuga-kouen Kasuga, Fukuoka 816-8580, Japan

ntamura@LHD.nifs.ac.jp

A full understanding of electron and ion heat transport in magnetically-confined toroidal plasmas is crucially necessary to have power over burning fusion plasmas, since the burning plasma is highly autonomous and consequently there are very limited control knobs. Nowadays it is common knowledge that the electron and ion heat transport of the magnetically-confined toroidal plasmas is governed by micro-turbulences, which is referred to as "anomalous transport". Unfortunately, characteristics of the turbulence-driven heat transport are still less well understood due to the existence of incomprehensible phenomena beyond the standard diffusive paradigm. One of the well-known examples of such phenomena is a core electron temperature T_e rise in response to an edge cooling ("nonlocal transport phenomenon") [1, 2], as shown in Fig.1. On the "nonlocal transport phenomenon", the nonlocal T_e rise in response to the edge perturbation takes place almost simultaneously at the wider region (e.g. from $\rho = 0$ to $\rho \sim 0.4$) in contrast with the transition to Core Electron Root Confinement (CERC) [3], which usually appears from the center of the plasma and spreads to the adjoining outer region [4]. Recent studies have suggested that a long-ranged fluctuation could have a key role in the nonlocal T_e rise in response to the edge cooling [5].

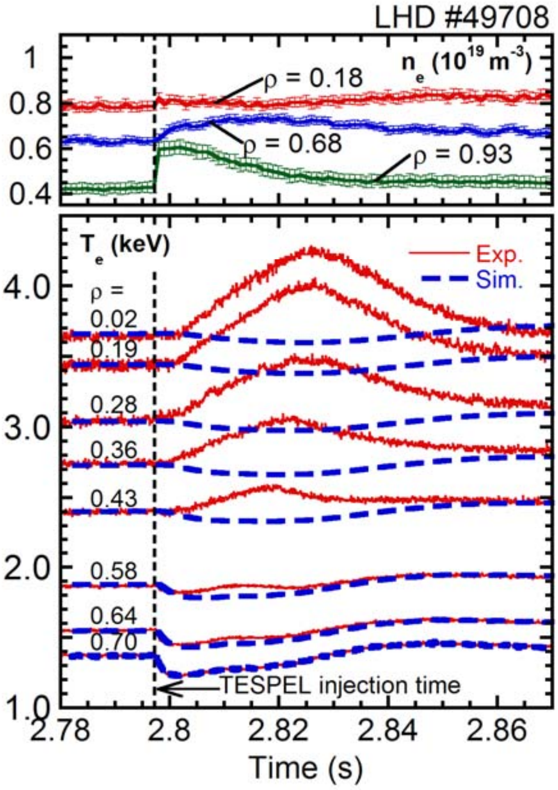

Fig. 1. Typical example of nonlocal transport phenomenon in LHD

In turbulent heat transport of the magnetically-confined toroidal plasmas, there are two types of transition: one is categorized as a first-order transition, which exhibits a discontinuity in the space derivative of the electron temperature ∇T_e and another as a second-order transition, which exhibits a discontinuity in the time derivative of the ∇T_e [6]. At the initial phase of the nonlocal transport phenomenon, the first-order transition is found to take place in the edge region (ρ = 0.6 ~ 0.7 at least) and consequently the second-order transition appears in the core region. Moreover, in the edge region, the second-order transition subsequently takes place. This second-order transition in the edge region seems to propagate from the edge to the core with a diffusive time-scale. However, the resultant second-order transition in the core region (ρ = 0.2 ~ 0.4 at least) seems to start simultaneously. Nevertheless, it all seems to start from the edge after all.

In order to gain insight into the transition property of the electron heat transport in the nonlocal transport phenomenon, it is important to know a robustness of the electron heat transport before and after the transitions. For this purpose, a transport potential analysis [7] is applied to the nonlocal transport phenomenon. In this analysis, a probability density function P as a function of displacement of ∇T_e from the transport curve is introduced. In general, the probability density function P can be expressed as $P(-\nabla\delta T_e) = \exp(-S)$. Here S is a transport potential and evaluated from the experimentally-obtained probability density function. In the wide core region (ρ = 0.2 ~ 0.4 at least), a wide and shallow potential wells are found to exist. Thus the change in the electron heat transport in the core region during the nonlocal transport phenomenon could be probabilistic. And it also suggests that the nonlocal transport phenomenon does not necessarily require the well-known turbulent transport reduction process, the breaking of turbulent eddies (i.e. the disappearance of the nonlocality) [8]. This feature is favorable for the simultaneous second-order transition of the electron heat transport in the wide core region. On the other hand, in the edge region, another transport branch is clearly identified. This branch does not have a stronger attraction, compared with the original branch, and thus the plasma in the edge region can go back easily to the original branch.

In conclusion, a new analysis on the nonlocal transport phenomenon in LHD provides us the following new findings. The nonlocal transport phenomenon takes place as a result from a combination of the first-order transition of the electron heat transport in the edge region and the unstable transport state in the wide core region, which is characterized by the wide and shallow transport potential well. The existence of the unstable transport state in the wide core region clearly suggests that the increase in core T_e does not necessarily require the strong suppression of turbulence. The second-order transition of the electron heat transport degraded the increased core T_e, which is started from the edge.

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