§26. Extended Investigations on Dynamics of Improved Confinement in Heliotron-J Plasmas

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In order to untangle the complexity related to the dynamics of improved confinement in a comprehensive manner amongst various toroidal confinement systems, comparative studies of transport barrier formation phenomena have been intensively performed with emphasis on the spontaneous formation and viscous damping of sheared flow in the edge, influence of rational surfaces and magnetic topology. The ultimate goal of the research herein described is to establish the control scheme of confinement state in reactor relevant plasmas, though profound understandings in transport dynamics in topological space, such has the wave number of turbulence.

In particular, as a part of the 3D turbulence correlation diagnostics, exploratory experiment for the development of advanced AM microwave reflectometer has been undertaken.

H-mode has been found pervasively not only in tokamaks but also in various helical devices, and it has been confirmed in Heliotron-J that the heating power threshold follows the scaling of $P_{th} \propto n_e^{0.75} B_t$, which is identical to tokamaks. Although the value of magnetic filed is not adequately scanned, considering that the edge transport barrier dynamics has to do with the neoclassical ion root in helical plasmas, similarity in the scaling expression is indeed confusing. In addition, the existence of the low density limit for transitions at $1.5 \times 10^{19} m^{-3}$ was also identified, which is thought to be related to the role of impurities or neutral particles. However, the influence of rational surfaces or magnetic topology seems more predominant and geometry dependent in helical plasmas, as the iota value of 0.54-0.56 is prerequisite in Heliotron-J, presumably due to the damping augmentation of sheared flow in the edge. The effect of edge q-value in tokamaks, on the other hand, is present only in few devices, such as DIII-D. The proposed hypothesis thereby is the enhanced fluctuations. Although planned experiment to scan the ratio of TA and TB systematically, aimed at elucidating the magnetic topology effect, further investigations with the direct flow and fluctuations measurement would make a substantial step forward.

Other distinctive features in Heliotron-J H-mode are quite rapid increase in n_e and moderate changes in T_e i.e., an improvement in particle transport is predominant over the reduction in thermal diffusivity. Similar observations are mainly in small tokamaks, though appropriate interpretations have not yet reported. As the neoclassical theory indicates, heavier impurities have stronger inward convection velocity, and the radiation power increases rapidly to result in the loss of power balance in Heliotron-J plasmas. Therefore, deliberate vessel conditioning, such as Ti gettering or replacement of the first wall is above all important to extend the period of improved confinement.

Quantitative comparison of H-mode transition condition between JT-60U and Heliotron-J has been performed in terms of the edge collisionality $\nu^* \propto n_e T_e^{-2}$, defined as the ratio of collision and bounce frequencies. It has been found in JT-60U that the value of ν^* at the transition is mostly around unity, the theoretical prediction of which is 1.7 except in the range below the low density limit or over half the Greenwald limit. As the spatially resolved kinetic measurement is not yet affordable in Heliotron-J, ECE intensity at the normalized radius of approximately 1/3 and line averaged density have been adopted to monitor the temporal evolution of during the H-mode discharges. In spite of the difference in the transition mechanism, as previously mentioned, it was heuristically found that the value of stays around a fixed value. In addition, transition takes place a certain period of time (typically around 50ms) after the value of ν^* reaches the target number. Occasionally, it seems that the plasma is waiting for n_e to build up to $1.5 \times 10^{19} m^{-3}$ for transitions or it may be related to the preceding phase observed in Wandelstein-VIIAS. After the transition, ν^* continuously increases in accordance with density, whereas it decreases in JT-60U.

In regard to the internal barrier formation in Heliotron-J, the predicted threshold heating power is around 1MW for strong transition, based on the public ITB database. As the heating power routinely applied is 0.7 MW, an increase of the heating power of combined heating experiment is anticipated. Based on the fact that the ITB formation condition had better be considered not in terms of the global parameter but the local quantity, the criteria of $R/L_T$of 8-12 (typically 11) has been derived, using the comprehensive database accumulated in JT-60U and LHD in the 2002 campaign. Here, represents the characteristic scale length of temperature gradient, and R is the major radius. It should be noted here again that ITBs in the electron system is produced by the neoclassical electron root formation in LHD.

In order to investigate the influence of magnetic shear and other contributions, such as the difference in the particle orbit and deposition characteristics, the beam switching experiment has been performed in Heliotron-J. The temperature gradient was evaluated based on the ECE signal at 1/3 plasma minor radius. It was documented in LHD that counter injection case is advantageous, as it reduces the central magnetic shear. A slight decrease in L_T was observed in the case of balanced injection, however, the result was obscure, and it may be related to an increase of total heating power.

As to the turbulence diagnostics, mentioned at the beginning, a rudimentary Q-band (33-50GHz)equipment has been initiated which could be extended to fast AM reflectometer. An active multiplier and the X-mode launching layout have been employed for broader spatial measurement, i.e., ITB and H-mode.