§21. Comparisons of Edge Pedestal Structure in Tokamak and Helical Systems

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It is important for integrated understanding of toroidal system to compare the edge pedestal structure in fusion plasmas between tokamak and helical devices and investigate the process of the formation of the edge pedestal structure. It has been well known in H-mode plasmas observed in tokamaks that the edge pedestal structure is formed by the improvement of the reduced heat and particle transport. However, a plasma parameter determining the spatial width of the edge transport barrier (ETB) has been unknown, and thus this is one of the most crucial issues in the international tokamak physics activity (ITPA). Main difficulties of identifying a decisive factor which determines the edge pedestal structure are as follows: (1) Since the edge magnetic shear, radial electric field, rotation profile, edge current, pressure profile, and particle orbit loss are strongly correlated in physics and/or in experimentally accessible region, it is hard to separate the process of the ETB formation; (2) While temperature profile is determined by the heat transport, density profile is strongly influenced by the particle source profile (neutral penetration). Therefore, the ETB formation is related to both plasma process and atomic process; (3) The ETB formation is affected by the transport and MHD instability (ELM).

On the other hand, a priority of Japan which owns both large tokamak and helical devices is a large capability of understanding of the toroidal system using these plasmas in reactor size devices by dimensionless parameters, such as, collisionality, Lamor radius and beta value. Comparison of spatial structure of temperature, density, rotation and ELM perturbation in a similar edge pedestal condition between LHD and JT-60 enables us to separate several processes correlated to each other and to examine the physics process predicted by theory based model. In addition, understanding of the edge pedestal structure in H-mode accompanied by the ergodic layer in peripheral flux surfaces could largely contribute to the mitigation and stabilization of type-I ELM observed in tokamaks.

In LHD, the low to high confinement transition (L-H transition) was observed in a unique helical divertor configuration surrounded by ergodic layer, exhibiting rapid increase in edge electron density with sudden depression of Hα emission. Just after the transition, edge transport barrier (ETB) is formed at edge region in magnetic hill region, developing a steep density gradient. ETB region extends in ergodic layer beyond the last closed flux surface defined by the vacuum field. Moreover, ETB region is deformed by the presence of m/n=2/3 island related to edge MHD mode and has a plateau region. The development of the ETB may be modified be the presence of a static magnetic island inside the ETB region.

The width of ETB is defined by the distance between the plasma boundary and the radial position where the density rise reaches the maximum, and is evaluated as the value averaged over toroidal magnetic surface. The dependence of the ETB width on the toroidal field strength was investigated by scanning the strength of B_{to} from 0.5T to 1.5T with the condition that the rotational transform at ETB is fixed, that is, the poloidal field strength at ETB is simply proportional to B_{to}. The ETB width has no clear dependence on B_{to}. Neutral penetration does not play an essential role in determining the ETB width on LHD. The other candidate factor which could explain the expanded width of ETB may be ELM activities and/or edge MHD modes. In order to investigate this effect, the width was compared with the electron beta value β_e^{ETB} evaluated at the ETB shoulder. The width increases with β_e^{ETB} and is approximately scaled with $(\beta_e^{ETB})^{0.5}$. In LHD, the width may be easily controlled by resistive interchange modes excited at ETB region in magnetic hill. Similarly to LHD, it has been found in JT-60U that the spatial width of the ETB in H-mode plasmas depends strongly on the beta value. In addition, the spatial width of the ETB does not depend on the influx of neutral particles.

In addition, ELMs are excited by low n=1 or 2 resistive interchange modes (RICs) in LHD. On the other hand, ETB plasmas always exhibit ELM-free in the configuration of R_{ax}=3.9m and R_{ax}=4.0m, having clear reduction of magnetic and electron density fluctuations. ETB in the H-mode develops just inside the $\iota/2\pi=1$ surface. Ultra soft X-ray fluctuation data suggest that the ELMs are excited by medium n (≥4) RICs. The differences in ETB formation and ELM activities are thought to link to the location of low order rational surfaces and the degrees of magnetic hill/well in the edge region. In particular, ELM-free phase in the configuration of R_{ax}=3.9m and R_{ax}=4.0m accompanies a rapid increase in electron density with a clear ETB formation and then giant ELMs appears. ELM energy losses reach 4-5% of total energy while ELM frequency increases with the heating power. This tendency is similar to type-I ELM characteristics in tokamaks. A detailed analysis on the edge pedestal structure and MHD stability will be compared between LHD and JT-60.

1) F. Watanabe et al., "Characteristics of edge MHD modes and ELM activities observed in Large Helical Device plasmas", to be published in Contributions of Plasma Physics.
2) K. Toi, F. Watanabe, S. Ohdachi et al, "L-H Transition and Edge Transport Barrier Formation on LHD", to be published in Fusion Science & Technology.
3) K. Toi, F. Watanabe, K. Tanaka, et al, "Effects of Edge Magnetic Field Structure on Formation and stability of Edge Transport Barrier in the Large Helical Device", to be presented in 15th International Congress on Plasma Physics (ICPP2010), 8-13 Aug., 2010, Santiago.