§11. Heat Pulse Propagation across the Rational Surface in Large Helical Device Plasma with Counter Neutral Beam Injection

Yakovlev, M., (Graduate University for Advanced Studies)
Inagaki, S., Shimozuma, T., Kubo, S., Morisaki, T.,
Nagayama, Y., Kawahata, K., Komori, A.

The core electron temperature flattening ($\rho < 0.3-0.4$) is observed in the LHD inward shifted plasma with counter neutral beam injection (Ctr-NBI) as shown in Fig.1(a). To study this phenomenon the heat pulse experiments are performed by modulated on-axis ECH. Typical parameters in these experiments are following: a major radius of 3.5m, an averaged minor radius of 0.6m and magnetic field at axis of 2.83T, line averaged density of $2.0 \times 10^{19} \text{ m}^{-3}$, injected neutral beam power of 1-6MW. The phase delay and amplitude profiles of heat pulse indicate the monotonic heat pulse propagation from core to edge in Co-NBI plasmas, where T_e flattening has not been observed, as it shown in Fig.1. A unique feature of heat pulse propagation is observed near the $m/n = 2/1$ rational surface in Ctr-NBI plasmas. The simultaneous response of temperature perturbation on the radially separated flux surfaces is observed. The non-monotonous heat pulse propagation can not be explained by any one-dimensional heat transport models. The change in topology due to the presence of a magnetic island structure is used to explain this non-monotonous heat pulse propagation. In fact, the $m/n = 2/1$ natural island has been observed in the electron beam mapping experiments on LHD. The ECE system views the region near the O-point of the $m/n = 2/1$ natural island. Thus, the growth of $m/n = 2/1$ natural island can explain the non-monotonous heat pulse propagation in the Ctr-NBI plasmas.

A heat transport model based on the magnetic island structure is shown in Fig.2. The one-dimensional heat transport inside the island, i.e. presence of nested closed flux surfaces and $\chi_{\perp} \ll \chi_{\parallel}$ are assumed inside the magnetic island, where $\chi_{\perp}$ and $\chi_{\parallel}$ are heat diffusivity perpendicular and parallel to magnetic field, respectively. The simultaneous response of T_e perturbations on radially separated flux surfaces (i.e. $\rho \sim 0.2$ and $\rho \sim 0.5$) can be explained by parallel heat transport on the separatrix of the island due to the large parallel heat diffusivity. The phase delay behaviour from $\rho = 0.2$ to $\rho = 0.33$ and from $\rho = 0.5$ to $\rho = 0.33$ indicates heat pulse propagation from island edge to O-point. The estimated O-point location from the position of the local peak in phase delay profile is in agreement with the $m/n=2/1$ rational surface location. The large difference in phase delay between O-point and edge of the island discloses that there are nested closed flux surfaces inside the island. The clear structure of the $m/n = 2/1$ island showed by phase delay means that the $m/n = 2/1$ island does not rotate, otherwise the phase delay inside of island must to have same values due to averaging of sampled data from ECE.

The magnetic island enlargement is considered to be related to direction and profile of plasma current mainly driven by NBI. In Co-NBI plasmas, the beam-driven

current increases the rotational transform, thereby the $m/n = 2/1$ rational surface will be vanish. No evidence for the presence of $m/n = 2/1$ MHD activity in Co NBI plasmas is observed by the magnetic measurement system.

Fig. 1. Comparison of (a) T_e profiles just before MECH injection, (b) phase delay of heat pulse and (c) amplitude of heat pulse between Co- and Ctr- NBI plasmas

Fig. 2. Two-dimensional heat transport model based on growth of $m/n = 2/1$ island structure. The nested closed flux surfaces and $\chi_{\perp} \ll \chi_{\parallel}$ are assumed inside the island.