§7. Observations of Sustained Phase Shifted Magnetic Islands from Externally Imposed m/n = 1/1 RMP in LHD

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New observations in LHD show that the magnetic islands externally imposed by m/n = 1/1 resonant magnetic perturbation (RMP) can be maintained in an intermediate state with a finite phase shift away from the value present in vacuum. The magnetic island is maintained with a deviated phase of around 0.3π rad from the imposed RMP. The experimental observation implies that the plasma response can provide plasma currents that produce deviations away from the RMP's designed position and can be maintained at the unfavorable phase. In previous studies of the dynamics of the magnetic islands in LHD, it has been observed that those behaviors are clearly divided into two saturated states of growth ($\Delta\theta_{pl} = 0$) and healing ($\Delta\theta_{pl} = \pm\pi$ rad). Here, the $\Delta\theta_{pl}$ is the phase difference of the plasma response field (PRF). The intermediate state of $\Delta\theta_{pl}$ has been thought to be transient and not to be steadily maintained [1]. However, as shown in Fig. 1, a steady intermediate state lasting about 2 s is found before the unclear transition to growth of the island under the condition of imposing static RMP. From t ~ 4.5 s to 6.4 s, the $\Delta\theta_{pl}$ is maintained at $\Delta\theta_{pl} \sim -0.5\,\pi$ rad (Fig. 1 (d)). The effective perturbed field (EPF), obtained by superposing of the RMP and the PRF, is adopted to determine the exact island structure. The phase of EPF $\Delta\theta_{eff}$ is around -0.3 π rad (Fig. 1 (f)) and finite amplitude $\Delta\theta_{eff}$ appears (Fig. 1 (e)), which means that the phase of magnetic island is maintained with the deviation of 0.3 π rad from RMP. Island width is larger than the vacuum width indicated by dashed line in Fig. 1 (g). The electron temperature profiles and the Poincaré plots are shown in Fig. 2. In the intermediate state at t = 5.0 s, the local flattening region appears at one side of R ~ 4.2 m (arrow in Fig. 2 (a)) whereas it can be seen at both sides of R ~ 3.0 m and 4.2 m in the growth state at t = 7.5 s (arrows in Fig. 2 (b)). These locations of the local flattening correspond to the magnetic island. Theories based on the competition between electromagnetic torques and poloidal flow-induced viscous torques [2, 3] provide a prediction for the intermediate state. These two kinds of torques might be balanced to realize the steadily maintained intermediate state whereas the islands are put in growth or healing state in the case the balance is broken. The new finding of the intermediate state brings a distinct paradigm shift in which the magnetic island can be moved and maintained in a partial position of the phase. If the poloidal flow can be externally varied, the phase of the magnetic island can be also arbitrarily controlled, which may permit continued utilization of the island divertor concept.

[1] Y. Narushima, et al., (2011) Nuclear Fusion **51** 083030
[2] Y. Narushima, et al., (2014) Plasma Fus. Res. **9** 1202066
[3] Y. Narushima, et al., (2015) Nuclear Fusion **55** 073004

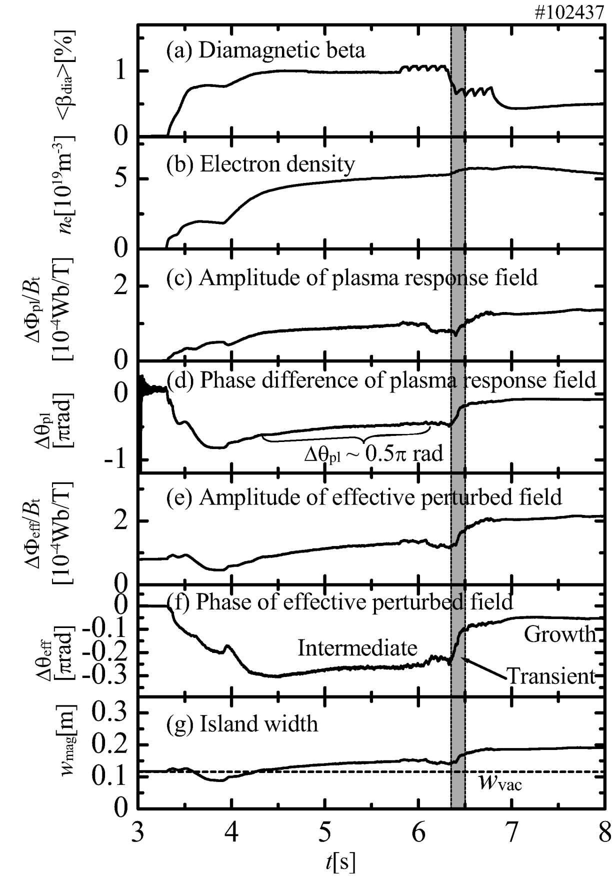

Fig.1 Waveform of (a) diamagnetic beta, (b) electron density, (c) amplitude of plasma response field (PRF), (d) phase of PRF, (e) amplitude of effective perturbed field (EPF), (f) phase of EPF, and (g) island width estimated from EPF. Intermediate state ($\Delta\theta_{pl}$ ~ -0.5 and $\Delta\theta_{eff}$ ~ -0.3 π rad) is maintained from t ~ 4.5 s to 6.35 s. After transition (t = 6.35 s - 6.5 s shadowed by gray), growth state ($\Delta\theta_{pl} \sim \Delta\theta_{eff} \sim 0$)

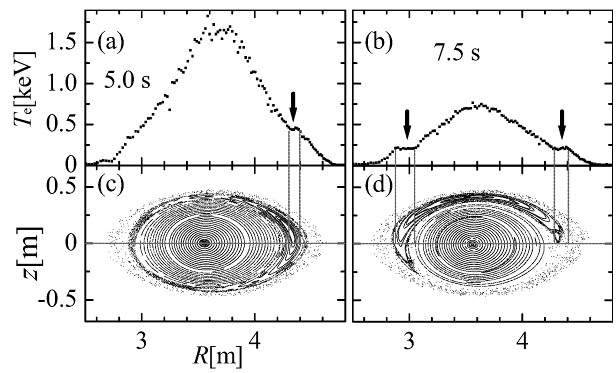

Fig. 2 Electron temperature measured by Thomson scattering. (a) In intermediate state (t = 5.0 s), local flattening region appears at R ~ 4.2 m. (b) In growth state (t = 7.5 s), local flattening regions appear at both sides (R ~ 3.0 m and 4.2 m). These positions of flattening region correspond to island structure in Poincaré plots