Observation of Hysteretic Magnetic Island Response to Resonant Magnetic Perturbation in LHD*)

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The hysteretic magnetic island response to an externally applied resonant magnetic perturbation (RMP) field is observed in the LHD. Thresholds of the amplitude of the RMP for the growth/healing transition of the magnetic island differ. In the case that the RMP is ramped up, that field is initially shielded and the magnetic island is healed. After that, when the increasing RMP exceeds a threshold, that field penetrates into the plasma and the magnetic island appears. In the case that the RMP is ramped down, the threshold of the RMP for island healing is smaller than that for growth.

Keywords: magnetic island, resonant magnetic perturbation, hysteresis, Large Helical Device

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Understanding magnetic island behavior is an important issue from the viewpoint of MHD stability and/or plasma confinement in magnetically confined plasmas. In the Large Helical Device (LHD) plasmas, serious disruption never occurs even if the magnetic island grows whereas a disruptive phenomenon is triggered by the growth of a magnetic island in tokamak plasmas. In the LHD the island growth merely triggers a minor collapse when the magnetic shear becomes low [1]. Furthermore, the growth of the magnetic island at the peripheral region induces a detached state [2], which implies an advantage in utilizing a magnetic island.

The magnetic islands show a spontaneous behavior of growth/healing during the discharge, in which the saturated island states are affected by the plasma parameters of plasma beta β, collisionality ν, and poloidal flow ω_{pol} [3,4]. Through those studies, the plasma parameter effect on the magnetic island has been clarified under a stationary resonant magnetic perturbation (RMP) field with an $m/n = 1/1$ Fourier mode (here, m/n is the poloidal/toroidal Fourier mode number).

We conducted the experiment with a time-varying RMP to clarify the RMP effect on the magnetic island dynamics. In this study, the plasma is heated by NBI and typical parameters are line averaged density $\bar{n}_e = 2\times10^{19}\,\mathrm{m}^{-3}$, central electron temperature $T_e(0) = 1.3\,\mathrm{keV}$, and diamagnetic beta $\langle\beta_{\mathrm{dia}}\rangle = 0.9\%$, respectively. The resonant magnetic perturbation is imposed by the perturbation coil system which had been originally used as a correction coil system to compensate the natural error field [5]. Ten pairs of coils made of normal conductors set at the top and the bottom of the LHD (Fig. 1) can produce the magnetic field with an $m/n = 1/1$ and/or 2/1 mode. In this study, to make the magnetic island with an $m/n = 1/1$, the perturbation field is imposed by RMP coils (shown by red in Fig. 1). In addition, the other RMP coils (shown by gray in Fig. 1)

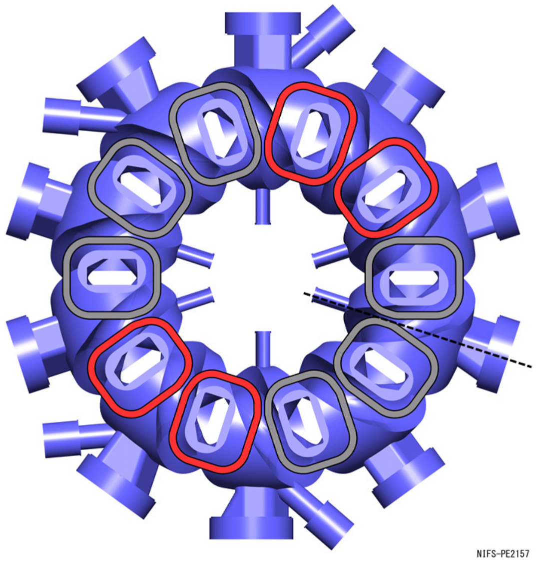

Fig. 1 Top view of the vacuum vessel and the resonant magnetic perturbation coil system of the LHD. Coils for $m/n = 1/1$ are colored red. Coils for $m/n = 2/1$ are colored gray. The dashed line indicates sight line of Thomson scattering measurement.

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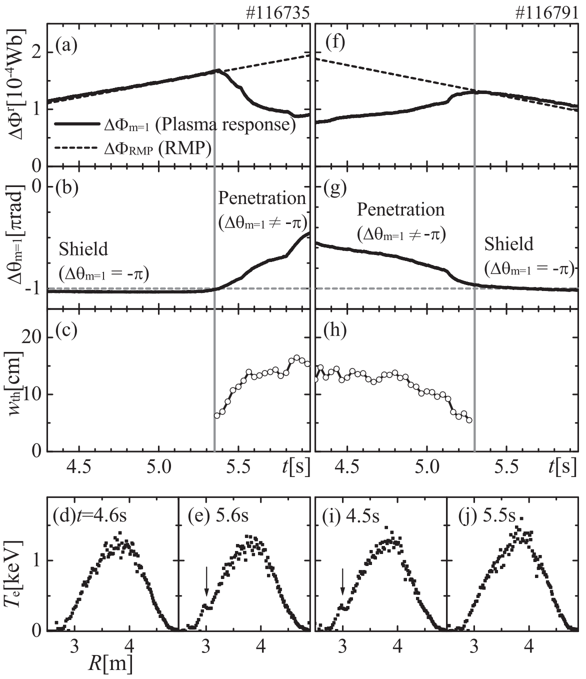

Fig. 2 Time evolution of (a, f) plasma response field (solid) and RMP (dashed), (b, g) phase shift $\Delta\theta$, (c, h) flattening width of T_e, and (c, d, g, h) T_e prolife. (Left) Case of RMP ramp up. (Right) Case of RMP ramp down.

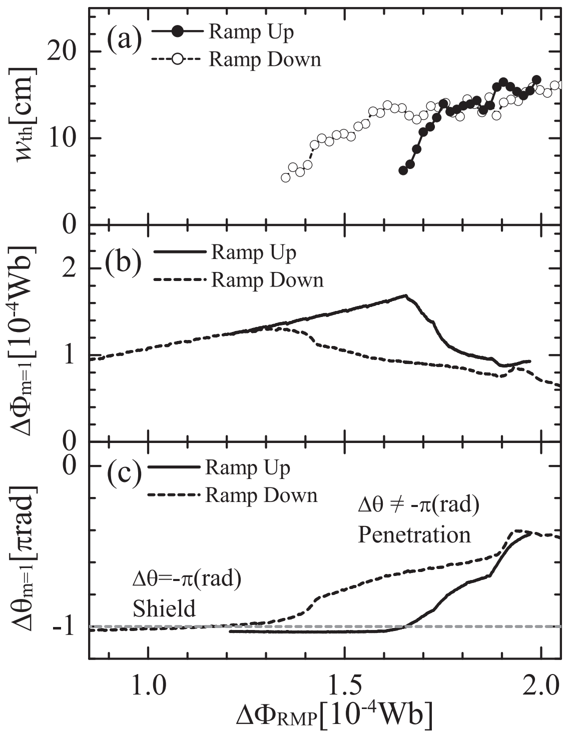

Fig. 3 Trajectories of (a) w_{th}, (b) $\Delta\Phi_{m=1}$ and (c) $\Delta\theta_{m=1}$ with respect to $\Delta\Phi_{RMP}$. Solid and dashed lines indicate RMP ramp up case and ramp down case, respectively.

are also used to cancel the toroidal coupling component of $m/n = 2/1$. The coil current is swept with the rate of 380 A/s during the plasma discharge. The relationship between magnetic island and magnetic diagnostics had been reported in [6], in which the magnetic diagnostics can detect the detailed behavior of the magnetic island.

Typical waveforms of the plasma response field ($\Delta\Phi_{m=1}$), RMP field ($\Delta\Phi_{RMP}$), phase shift ($\Delta\theta_{m=1}$), and radial profiles of electron temperature T_e are shown in Fig. 2. Here, the behavior of the RMP can be distinguished by $\Delta\theta_{m=1}$; the RMP penetrates (is shielded) when $\Delta\theta_{m=1} \neq |\pi|$ ($\Delta\theta_{m=1} = \pm\pi$). In the case that the RMP is ramped up during the discharge (Figs. 2 (a-e)), the phase shift $\Delta\theta_{m=1}$ keeps $-\pi$ (rad) and the plasma response field $\Delta\Phi_{m=1}$ linearly increases like $\Delta\Phi_{RMP}$ until $t = 5.35$ s (Figs. 2 (a, b)). This condition ($\Delta\Phi_{m=1} = \Delta\Phi_{RMP}$ and $\Delta\theta_{m=1} = -\pi$ (rad)) means that the plasma response field compensates the RMP field. As a result, the magnetic island shows healing. The T_e profile does not show the local flattening region (Fig. 2 (d)). After $t = 5.35$ s when the RMP reaches $\Delta\Phi_{RMP} = 1.6 \times 10^{-4}$ (Wb), the phase shift departs from $\Delta\theta = -\pi$ (rad), which means that the RMP penetrates into the plasma and the local flattening appears in the T_e profile at $R = 3$ m (Fig. 2 (e)). The time evolution of the width of the flattening region of the T_e profile, w_{th}, indicates an increment of the width of the island (Fig. 2 (c)). In the ramping-down RMP case (Figs. 2 (f)-(j)), the RMP field penetrates until $t = 5.3$ s. In this period the local flattening appears in the T_e profile at $R = 3$ m (Fig. 2 (i)) and its width, w_{th}, decreases with time (Fig. 2 (h)). After $t = 5.3$ s when the RMP reaches $\Delta\Phi_{RMP} = 1.3 \times 10^{-4}$ (Wb), the phase shift reaches $\Delta\theta = -\pi$(rad) and the plasma response field, $\Delta\Phi_{m=1}$, decreases linearly with ramped $\Delta\Phi_{RMP}$, which means that the RMP is shielded. As a result, the magnetic island disappears. The T_e profile does not show the local flattening region (Fig. 2 (j)). The sudden disappearance/appearance of the magnetic island had been reported in [4] in which the poloidal flow has an important role. Figure 3 shows the trajectories of w_{th}, $\Delta\Phi_{m=1}$ and $\Delta\theta_{m=1}$ with respect to $\Delta\Phi_{RMP}$. When the RMP is ramped up (solid lines in Fig. 3), the magnetic island appears at $\Delta\Phi_{RMP} = 1.6 \times 10^{-4}$ (Wb). The explanation of the decrease in the plasma response field, $\Delta\Phi_{m=1}$, at $\Delta\Phi_{RMP} > 1.6 \times 10^{-4}$ (Wb), is left to future research. On the other hand, when the RMP is ramped down (dashed lines in Fig. 3), the magnetic island disappears at $\Delta\Phi_{RMP} = 1.3 \times 10^{-4}$ (Wb).

These experimental observations indicate that the threshold for the shielding is larger than that for the penetration, which shows the hysteretic magnetic island response to an externally applied resonant magnetic perturbation field.

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