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# Transition of magnetic island behavior affected by external perturbation field and poloidal flow in LHD

# LHDにおける磁気島遷移現象に対する外部摂動磁場とポロイダルフローの影響


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Dynamics of magnetic islands in helical plasmas has been studied by means of resonant magnetic perturbation (RMP) to clarify its effect on the MHD stability and confinement. In the Large Helical Device (LHD) experiments, thresholds of the amplitude of the RMP for the healing/growth transition of the magnetic island depend on the magnetic axis position $R_{ax}$. The RMP threshold for growth of the island increases as the magnetic axis position $R_{ax}$ increases. Furthermore, the threshold of RMP for healing is smaller than that for growth, which means hysteresis in the critical RMP at a healing/growth transition. These phenomena are considered by the correlation with RMP and poloidal flow.


## 1. Introduction

Generally, an error field which can generate the magnetic island should be removed or suppressed for a good confinement of toroidal plasmas; nested flux surfaces are required. A serious disruption, however, never occurs even if the magnetic island grows in the Large Helical Device (LHD) plasmas. The magnetic islands intrinsically disappear as they are stabilized during a plasma discharge under certain conditions [1, 2] and the grown magnetic island merely triggers a minor collapse when the magnetic shear becomes low [3]. In the LHD, the RMP coils make a vacuum magnetic island with $m/n$ = 1/1 (here, $m/n$ is the poloidal/toroidal Fourier mode number) structure. It is worthwhile to obtain the control method of the magnetic island. Therefore, the study of the dynamics of magnetic islands has been a critical issue. This article is composed as follows. In the following section, the experimental observations are shown. Section 3 gives a summary.

## 2. Experimental result

Recent study has found that the dynamics of the magnetic island is affected by the poloidal plasma rotation [4]. Figure 1 shows the minor radius profile of electron temperature ($T_e$,) and poloidal flow ($\omega_{pol}$). The negative sign of $\omega_{pol}$ indicates the electron diamagnetic direction. The resonant surface of $\iota/2\pi$ = 1 lies at $r_{eff}$ = 0.55m. The local flattening of the $T_e$ profile indicates the existence of the magnetic island as shown in Figs. 1 (b) (c). After that, the island disappears (Fig. 1 (d)). During the magnetic island healing, the absolute value of the poloidal flow $|\omega_{pol}|$ lying at $r_{eff}$ = 0.6m increases with time and its profile becomes wide. This experimental result means that the magnetic island dynamics is correlated with the poloidal flow.

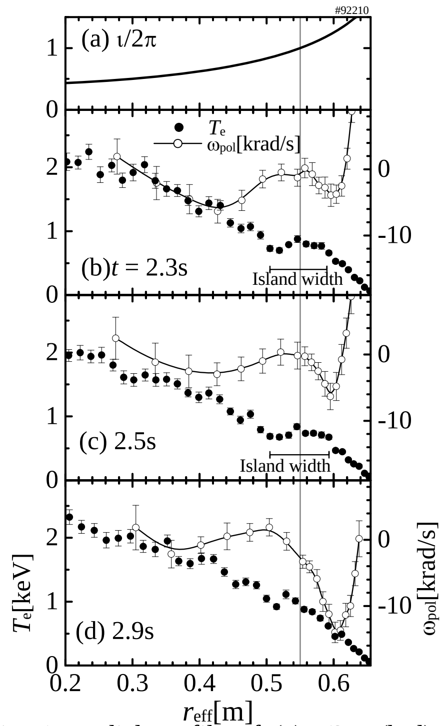


Fig. 1. Radial profile of (a) $\iota/2\pi$, (b-d) $T_e$ (closed), and $\omega_{pol}$ flow (open).

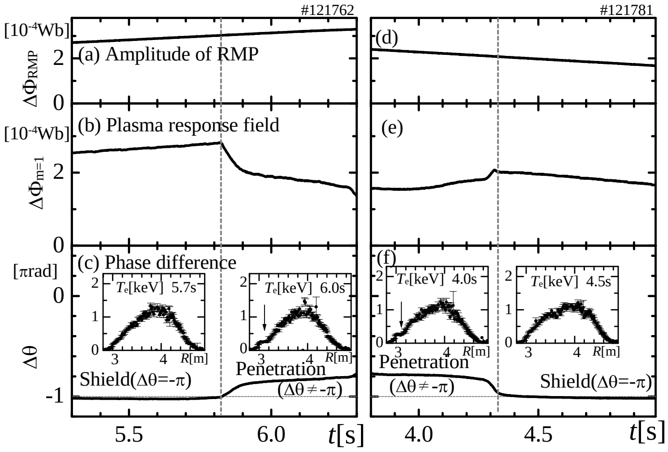


Fig. 2. Time evolution of amplitude of RMP $\Delta\Phi_{RMP}$ (a, d), amplitude of plasma response field $\Delta\Phi_{m=1}$ (b, e) and phase difference $\Delta\theta$ (c, f). (Left) RMP ramp-up case. (Right) Ramp-down case. Electron temperature profiles are shown in (c, f).

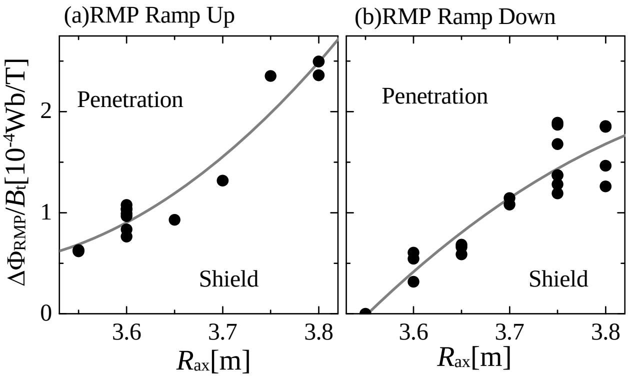


Fig. 3. Magnetic axis $R_{ax}$ dependence of critical $\Delta\Phi_{RMP}$ for ramp-up case (a) and ramp-down case (b), respectively. The region above (below) the gray fitted line corresponds to penetration (shield).

Figure 2 shows typical waveforms of an $m/n$=1/1 amplitude of RMP $\Delta\Phi_{RMP}$, amplitude of plasma response field of resonant Fourier mode $\Delta\Phi_{m=1}$, and phase difference between RMP and the plasma response field $\Delta\theta$ in the configuration with $R_{ax}$ = 3.75m. Here, $\Delta\Phi_{RMP}$ and $\Delta\Phi_{m=1}$ have the unit of [Wb] because they are detected by non-planar flux loops [5]. In the ramp up case (left), the phase difference $\Delta\theta$ is $\Delta\theta = -\pi$ (rad) (which means the RMP is shielded) until $t$ = 5.83s (Fig. 2 (c)). In this period the plasma response field $\Delta\Phi_{m=1}$ increases linearly with ramped $\Delta\Phi_{RMP}$, which compensates the RMP field. As the result, the magnetic island shows healing. The $T_e$ profile does not have the local flattening region (imposed in Fig. 2 (c)). After $t$ = 5.83s, the phase difference leaves from $\Delta\theta = -\pi$ (rad) which means the RMP penetrates into the plasma and the local flattening appears in the $T_e$ profile at $R$ = 3.1m (imposed in Fig. 2 (c)). In the ramp down case (right), the $\Delta\theta$ deviates from $\Delta\theta = -\pi$ (rad) until $t$ = 4.3s (Fig. 2 (f)) and local flattening of $T_e$ (imposed in Fig. 2 (f)) indicates the island formation. And then the RMP is shielded after $t$ = 4.3s and local flattening disappears (imposed in Fig. 2 (f)). The dependence of the critical normalized $\Delta\Phi_{RMP}$ on the magnetic axis position $R_{ax}$ is shown in Fig. 3. The critical $\Delta\Phi_{RMP}$ increases with $R_{ax}$ in both cases. This experimental observation means that the magnetic configuration with larger $R_{ax}$ tends to possess a robustness to the external imposed error field to retain the nested flux surfaces. It is also found that the critical $\Delta\Phi_{RMP}$ for the case of ramp-up (Fig. 3 (a)) is larger than that of the ramp-down case (Fig. 3 (b)). The nature of hysteresis provides that once the magnetic island can be suppressed at a certain critical value by reduction of $\Delta\Phi_{RMP}$, there is latitude to maintain that situation. These pictures correspond to the experimental fact that magnetic islands are likely to be healed at larger $R_{ax}$.

## 3. Summary

The magnetic island has shown the dynamical behavior which the transition is triggered by change of RMP/poloidal flow. It was observed that the RMP thresholds depend on magnetic axis position $R_{ax}$. Furthermore, it was found that the threshold of RMP for healing is smaller than that for growth, which means hysteresis of the critical RMP. Hysteresis can be thought to be originated from the ion polarization current effect [6]. The poloidal flow is important to understand the dynamics of magnetic island [7, 8] from the view point of the drag force via the viscosity. The theoretical calculation [9] predicts that neoclassical poloidal viscosity NPV increases with $R_{ax}$ in LHD plasmas. The large NPV brings the large viscous torque on the magnetic island, which has a role to make magnetic island be healed. These pictures correspond to the experimental fact that magnetic islands are likely to be healed at larger $R_{ax}$.

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