§15. Hysteresis of Plasma Response Field in Transition to Detached and to Reattached Plasma

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Sustaining a detached plasma is important for the reduction in heat load on the divertor. The externally controlled methods such as gas puffing at divertor region etc. had been studied for maintaining detached plasmas. In the recent LHD experiments, a resonant magnetic perturbation (RMP) is utilized to establish the detached plasma  $^{(1, 2)}$ , which is one of the candidates to reduce the divertor heat load. The finite plasma response field has been detected when the RMP is imposed, and its behavior has been investigated from the viewpoint of the magnetic island dynamics<sup>(3)</sup>. It has reported that a parameter of the phase difference,  $\Delta \theta$  (defined as the phase difference between the plasma response field and the RMP), changes from antiphase ( $\Delta \theta = -\pi$ ) side to in-phase ( $\Delta \theta = 0$ ) side while the plasma transits from the attached to the detached state. Finally, when the  $\Delta \theta$  reaches at certain critical value,  $\Delta \theta_{crit}$ , the plasma enters the detached state as shown in Fig.1. When we make the electron density increase and decrease during a single discharge, a re-attach phenomenon was observed after the detached state is established. Figure 2 shows the time evolution of the ion saturation current of Langmuir probe on the divertor  $I_{sat}$ , plasma response field  $\Delta \Phi^{\rm r}$  and phase difference  $\Delta \theta$ . Before t = 5.15s the plasma is attached as shown in Fig.2(a), in which the finite  $I_{sat}$  is detected and the phase difference  $\Delta \theta$  moves toward  $\Delta \theta = 0$ maintaining below a threshold as shown in Fig.2(c). When the attached plasma enters to detached state at t = 5.15s, the  $I_{\rm sat}$  drops to fairly low level signal. At that time, the  $\Delta \theta$ indicates  $\Delta \theta = -0.36\pi$  rad. During the detached state, at t =5.15 – 6.85s, the  $I_{\rm sat}$  signal shows almost constant at extremely low level. When the plasma experiences the reattach at t = 6.85s, the  $I_{sat}$  suddenly increases. At that time, the  $\Delta\theta$  indicates  $\Delta\theta = -0.23\pi$ rad. The critical  $\Delta\theta$  for detach and re-attach are different, which shows the hysteresis. This experimental observation implies that the structure of the magnetic confinement field is different for each transition.

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2) M. Kobayashi, S. Masuzaki, I. Yamada, Y. Narushima, C. Suzuki, N. Tamura, et.al., (2012) 24th IAEA Fusion Energy Conference CN-197 EX/4-4 San Diego, USA

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Fig.1 Time evolution of phase difference  $\Delta \theta$  (solid lines) for the case of transition from attached to detached state. Open circles indicate the point when the detached plasmas are established. Gray dashed lines indicate the threshold of  $\Delta \theta$  for detachment.



Fig.2 Time evolution of (a) ion saturation current of divertor probe, (b) plasma response field and (c) phase shift. Attached plasma transits to detached state at t = 5.15s. Reattach occurs at t = 6.85s.