§2. Bifurcation Physics of Magnetic Islands and Stochasticity Explored by Heat Pulse Propagation Studies in LHD

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Heat pulse propagation is a useful tool to investigate the magnetic topology and transport in the toroidal plasma. Recently, the heat pulse propagation has been applied to identify the stochastization of magnetic field in helical and tokamak plasmas. Originally, the heat pulse propagation technique has been used to estimate heat conductivity of plasmas. The heat pulse propagation has been recognized to be a powerful tool to study the magnetic topology as well as transport and it is applied to the plasma with magnetic islands or stochastic magnetic field [1]. The heat pulses are produced by the modulation electron cyclotron heating (MECH) with a frequency of 30 $\sim$ 50 Hz.

Time scales of the transition between two states in the bifurcation phenomena of magnetic topology and transport are important parameters in understanding the mechanism of the bifurcation. Figure 1(a)(b) show the contour of the modulation amplitude ($\delta T_e/T_e$) and the delay time (τ_d) of a fundamental component of the heat pulse in space and time in the discharges with forward and backward transitions from magnetic island to stochastic magnetic field and vise-versa in LHD plasmas. Here the running FFT with a time window length of 240ms, which corresponds to six periods of the MECH, and a time shift of 0.5ms was performed to obtain the time evolution of the amplitude and phase delay profiles. The Hanning window was used as the window function, whose half width of the half maximum is 0.5 times the window length. Therefore, the effective time resolution is 120ms that corresponds to 3 periods of the MECH. The transition of topology bifurcation is more clearly observed in the contour of the delay time. The small peak of the delay time at $t = 5.85$ sec and $t = 6.45$ sec indicate the appearance of magnetic inlands, while a large area of small delay time (close to zero) at $t = 5.94$ - 6.32 sec indicate the stochastization of the magnetic field. It is interesting that the region of the stochastic magnetic field shows abrupt expansion at $t = 6.14$ sec as the location of rational surface of $q = 2$ ($\iota/(2\pi) = 0.5$) moves outwards. The outward movement of rational surface is consistent with the jump of magnetic island location from $r_{\rm eff}/a_{99}$ ~ 0.3 (at $t = 5.85$ sec) to $r_{\rm eff}/a_{99} \sim 0.4$ (at $t = 6.45$ sec).

The time scale of the transition is evaluated from the time derivative of the delay time at the transition from magnetic island to stochastic field (t = 5.95 sec) and the transition from magnetic island to stochastic field (t = 6.35 sec) as seen in Fig.1(c)(d). The transition time defined by the 1/e width of the peak of time derivative delay time ($d\tau_d/dt$) are 120 ms and 160 ms for the transition from magnetic island to stochastic field and vise-versa, respectively. This is not the time scale of local stochastization of magnetic field at the rational surface but the time scale of radial expansion of the stochastic region from the rational surface to the magnetic axis as seen in the radial propagation of the onset time of the flow damping [?]. Therefore, the transition time scale from magnetic island to stochastic field discussed here is determined by the speed of radial expansion of the stochastic region from the rational surface to the magnetic axis and depends on the change in $\iota/(2\pi)$ profiles.

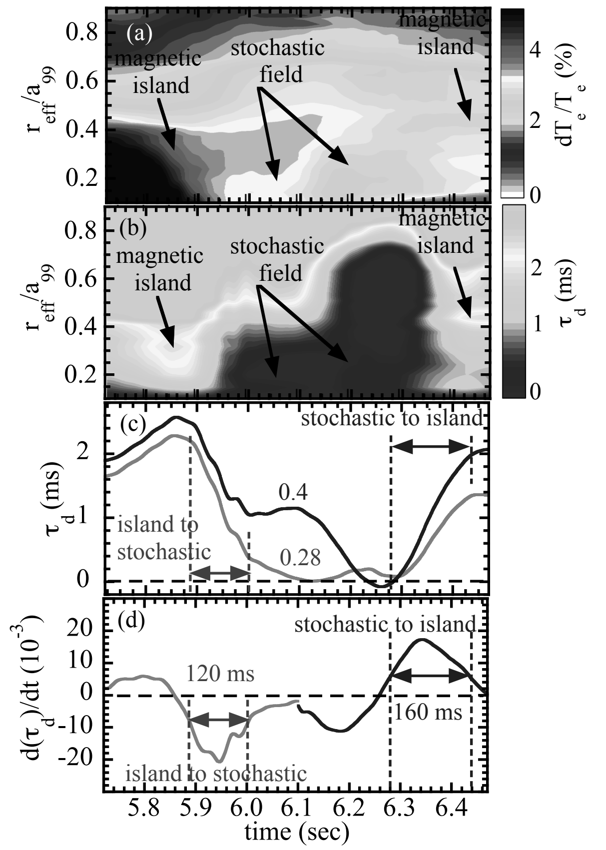

Fig. 1: Contour of (a) temperature modulation amplitude ($\delta T_e/T_e$) and (b) delay time of a fundamental component of a heat pulse in space and time for the discharges with the transition from magnetic island to stochastic magnetic field and stochastic magnetic field to magnetic island, (c) time evolution of the delay time at $r_{\rm eff}/a_{99} = 0.28$ and 0.4, and (d) time derivative of delay time for the transition from magnetic island to stochastic magnetic field and the transition from stochastic field to magnetic island in LHD plasmas.

1) K.Ida, et. al., submitted to Nuclear Fusion.