§7. Abrupt Drop of Toroidal Flow Due to Stochastization of Magnetic Field

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The effect of stocahstization of magnetic field to the plasma flow is one of the crucial issue to understand the mechanism of edge localized mode (ELM) suppression by magnetic perturbation in toroidal plasmas. This is because the reduction of plasma flow (toroidal flow, poloidal flow, and zonal flow) due to stocahstization of magnetic field should have a strong impact both on MHD stability and transport at the pedestal. The topological bifurcation from nesting magnetic flux surface to stochastic magnetic field (stochastization) has been observed, when the magnetic shear at a rational surface becomes weak after the neutral beam direction is reversed from co-injection to counter-injection in LHD. Because the current diffusion time is longer than the duration of the discharge, the edge rotational transform decreases due to the non-inductive current driven by the neutral beam, while the central rotational transform even increases due to the return current after the reversal of the neutral beam direction. As the magnetic shear decreases, the formation of a magnetic island or stochastic region starts to develop and their size increases as the magnetic shear decreases. Since the stochastization needs the overlapping of a secondary magnetic island with a different mode number, the bifurcation to the stochastization is observed only when the magnetic shear is medium $s = 0.5 \sim 0.6$. As the magnetic shear decreases further ($s < 0.4 \sim 0.5$), the fundamental magnetic island grows and stochastization disappears (only the single mode magnetic island appears)[?]. In the previous experiment, the stochastization can be identified by the fast radial propagation of heat pulse driven by modulated electron cyclotron heating (MECH).

Figure 1 shows the time evolution of toroidal rotation at the magnetic axis ($R = 3.71$m) and of the magnetic axis ($R = 3.53$m and 3.35m) in the discharge where the direction of the NBI is switched from co-injection to counter-injection at t = 5.3s. The toroidal rotation changes its sign from positive (co-direction) to negative (counter-direction) associated with the switch of the NBI direction with the time scale momentum transport of 0.3sec. Although the counter-NBI is kept to be injected until the end of the discharge (t = 5.3 - 7.3s), abrupt decrease of toroidal rotation is observed at t = 6.0s, which indicates the stochastization of magnetic field. The damping of toroidal rotation due to the stochasitization of magnetic field is much faster than the momentum transport time scale. In the later time of the discharge, the magnetic field shear decreases furthermore and the second topology bifurcation from the stochastic magnetic field to the nesting magnetic flux surface with magnetic islands takes place at t =6.7s. Then the toroidal rotation at the magnetic axis starts to recover. Figure 2 shows the radial profile of toroidal rotation velocity and ion temperature before (t=5.64s) and after (t=6.44s) the stochastization of magnetic field. The flattening of profiles are observed both in the ion temperature and toroidal rotation. The radial profile of toroidal rotation is much more peaked than that of ion temperature because of the toroidal viscosity which increases sharply towards the plasma edge in LHD. It should be also noted that the ion temperature profile is slightly peaked at the plasma center, which is in contrast to that the electron temperature profile shows complete flattening.

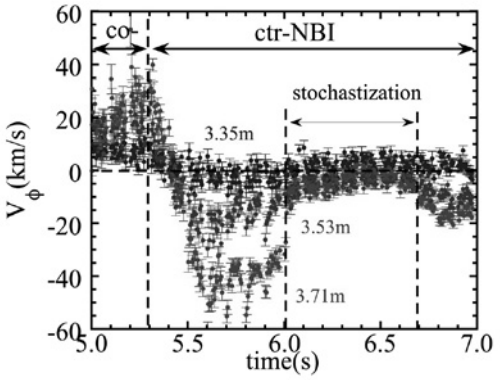

Fig. 1: (a) Time evolution of toroidal rotation velocity in the discharge where the direction of the NBI is switched from co-injection to counter-injection at t = 5.3s. The stochastization of magnetic field takes place at t = 6.0s

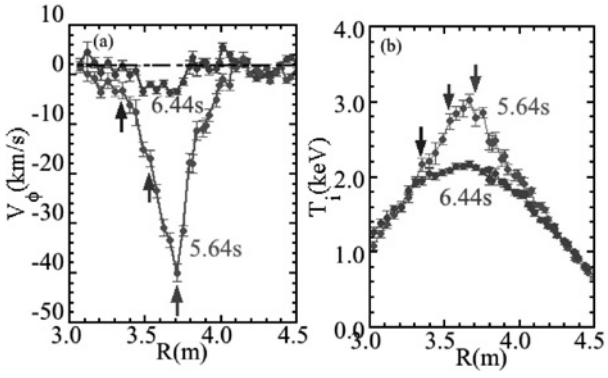

Fig. 2: Radial profile of (a) toroidal rotation velocity and (b) ion temperature before (t=5.64s) and after (t=6.44s) the stochastization of magnetic field. The three locations plotted in figure 1 are indicated with arrows.

1) K.Ida et. al., New J. Phys. **15** (2013) 013061.