Abrupt onset of tongue deformation in LHD plasmas

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An abrupt onset of the new tongue-shaped deformation of magnetic surface in magnetized plasmas, which was conjectured in since the 1960s but has not been observed, is experimentally identified just before an abrupt onset of a large-scale collapse event. Two novel properties of the event are identified. First, the transition of symmetry of perturbation (rather than a growth of linearly unstable MHD modes) was found to be a key for the onset of abrupt collapse, i.e., the transition of symmetry gives a new route to the collapse from stable state. Second, as a phase-space response of ions, the distortion from Maxwell-Boltzmann distribution of epithermal ions was observed for the first time[1].

The tongue event is characterized by the toroidally, poloidally, and radially localized perturbation in the plasma which triggers the collapse and is observed in the magnetic probe arrays and ECE signals. Figure 1 shows the polar plots of magnetic field perturbation of toroidal magnetic probe and radial profiles of the plasma displacement measured with ECE during m/n=1/1 mode oscillations and during tongue events before the collapse. The perturbation of the magnetic field at the 'tongue' event is localized near the NBI port in toroidal angle (φ = 270°) and in the direction of $B \times \nabla B$ drift of ion in poloidal angle (θ = 90°), which is in contrast to the usual m/n=1/1 mode MHD modes as seen in fig.1(a)(b). The displacement of the plasma is also localized radially at $r_{eff}/a_{99} \sim 0.8$, which is further inside the location of $\iota/(2\pi)$ = (1/q) =1 rational surface at $r_{eff}/a_{99} \sim 0.9$, where the m/n = 1/1 MHD oscillations are localized as seen in fig.1(c)(d). It is clearly demonstrated that this abrupt event occurs with the tongue-shaped topology in a short time ($-100\ \mu s < \Delta t < 0$) and then the perturbation evolves into a rotating m/n = 1/1 mode. This clear localization of the perturbation field before the MHD oscillation indicates that this MHD oscillation is triggered by the MHD 'tongue' event rather than the growth of the MHD mode.

After the minor plasma collapse triggered by the 'tongue' event, the distortion from the Maxwell-Boltzmann of carbon ion is observed in the charge exchange spectroscopy. The distortion is characterized by the simultaneous decrease of co-traveling and increase of counter-traveling ions ('dent' and 'swell') in outer region of the magnetic field tongue. The 'dent' and 'swell' distortion is symmetric in the velocity space and appears in the same region in the plasma minor radius. This magnetic field tongue is observed in the low density discharge with perpendicular neutral beam injection, where a significant perpendicular pressure gradient by trapped ions exists in the plasma. This fact indicates that the distortion is due to the change in trapped ions rather than the passing particle, and decrease of co-traveling (increase of counter-traveling) is due to the abrupt flattening of trapped ions with the parallel velocity of v_{th} to $2.5v_{th}$. This is clear evidence for the distortion of epithermal ions in the plasma triggered by the magnetic field 'tongue' event.

The tongue of the magnetic field is clearly observed in the low density plasma with significant energetic ions injected by neutral beam. This is a new trigger mechanism of MHD burst different from the conventional picture where the instability of the MHD mode grows. A novel route, transition of symmetry, to trigger the onset of collapse of electron energy and MHD burst is identified. This mechanism is different from the conventional picture where the unstable MHD mode grows.

References

[1] K.Ida et. al., Sci. Rep. 6 (2016) 36217.

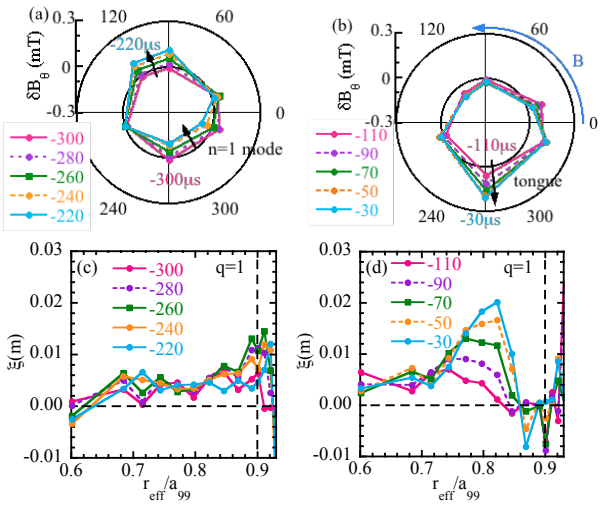

Fig.1 (a)(b) Polar plots of magnetic field perturbation of toroidal magnetic probe and (c)(d) radial profiles of the plasma displacement measured with ECE at Δt = -300, -280, -260, -240, -200 μsec [(a)(c) during m/n=1/1 mode oscillations] and at t = -110, -90, -70, -50, -30 μsec [(b)(d) during tongue events] before the collapse.