§5. First Observation of Fishbone-like Modes Driven by Helical-Ripple Trapped Fast Ions on LHD

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Strong and repetitive fishbone(FB)-like bursting instabilities, which are excited by the perpendicular neutral beam injection (NBI), have recently been observed in high-Ti plasmas obtained at higher toroidal field in the Large Helical Device (LHD). The FB-like bursts locate around the rotational transform $\iota/2\pi=1$ in the edge region and propagate in the electron diamagnetic drift direction poloidally and counter-going direction toroidally. The initial frequency of the burst is in the range of 7-8 kHz and rapidly chirps down to ~4kHz in ~2ms with strongly distorted waveforms shown in Fig 1. The initial frequency is found to be close to the characteristic frequencies of the toroidal and poloidal precession motions of helical-ripple trapped fast ions. The 'precursor' excited before the burst is found to propagate in the electron diamagnetic drift direction having ~3kHz in the plasma frame, and have a typical m=1 resistive interchange (RIC) type mode structure. The transition from the usual RIC to the FB-like burst is observed in a plasma with relatively low power of perpendicular NBI.

Large amplitude FB-like modes as shown in Fig.2(a) decrease the stored energy. However, interesting effects are observed, i.e., FB-bursts significantly impact on toroidal and poloidal plasma rotations. The poloidal rotation is changed from the ion-diamagnetic direction to the electron diamagnetic drift one by each large burst, which suggests non-ambipolar transport of energetic ions. The toroidal rotation of C^{6+} ions in the co-direction inside the $\iota/2\pi=1$ flux surface is clearly slowed down by the bursts. However, the rotation outside $\iota/2\pi=1$ flux surface simultaneously increases in co-direction for the change inside $\iota/2\pi=1$ flux surface, as seen from Fig 2(b). After that, the toroidal rotation in the whole edge region is slowed down within a few milliseconds. During the bursts, C^{6+} temperature at the plasma edge region is noticeably increased, accompanying the increase in electron density around $\iota/2\pi=1$ flux surface and a noticeable reduction of Hα light emission as shown in Fig 2(c). The impacts on the bulk hydrogen plasma performance induced by this new instability are not clear but are still under discussions.

A likely candidate instability of the FB-like mode observed in LHD is thought to be RIC destabilized by the poloidal and toroidal precession motions of helical-ripple trapped fast ions. Although MHD wave is different, in many ways, FB like modes in LHD are similar to energetic wall mode (EWM) in JT-60U [1] or off-axis FB modes observed in DIII-D [2, 3], which is thought to be external kink modes destabilized by trapped energetic ions.

[1] G. Matsunaga et al., Phys. Rev. Lett. 103, (2009) 045001
[2] M. Okabayashi et al., Phys. Plasmas 18, (2011) 056112
[3] W. W. Heidbrink et al., Plasma Phys. Control. Fusion 53 (2011) 085028

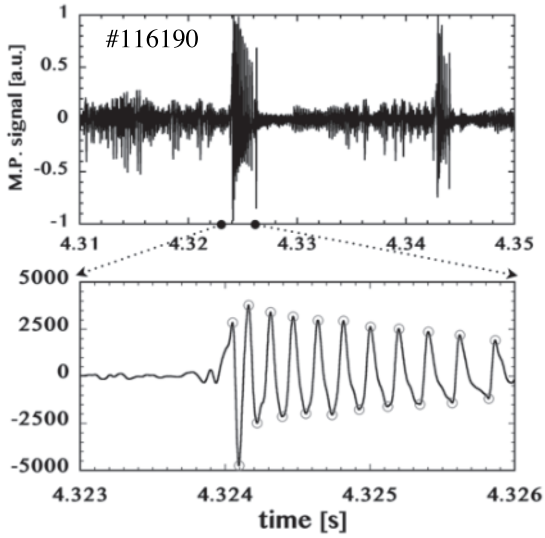

Fig 1: The typical waveforms of FB-like bursting instabilities observed in Magnetic Probe.

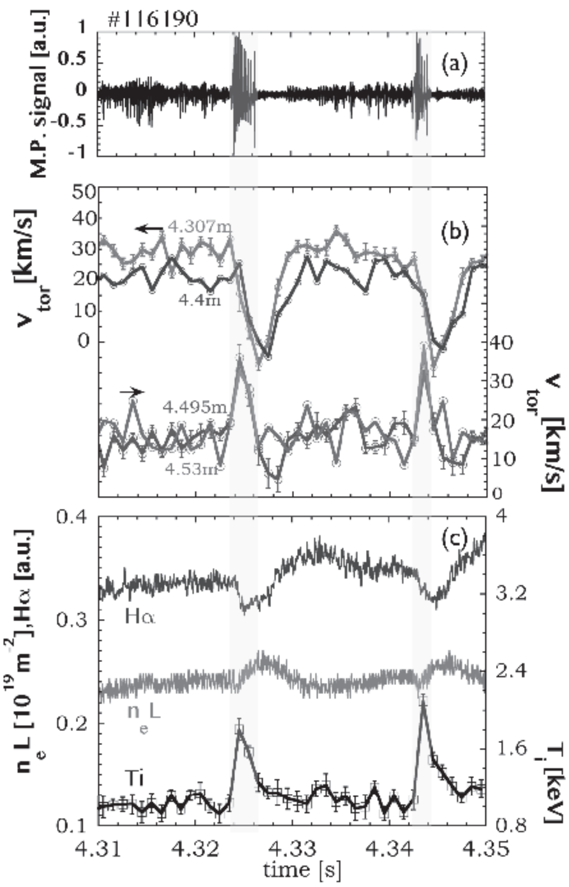

Fig 2: (a) The waveforms of FB-like bursting instabilities in Magnetic Probe signal. (b) The plasma toroidal rotation just inside $\iota/2\pi=1$ flux surface is significantly slowed down. Simultaneously, toroidal rotation is enhanced outside $\iota/2\pi=1$ flux surface. (c) The rapid rise of C^{6+} temperature at the plasma edge region is observed accompanied with noticeable reduction of Hα light emission and increment of electron density around $\iota/2\pi=1$ flux surface.