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Effects of Bursting MHD Activities on Energetic Ion Transport in CHS

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Abstract

In CHS, two types of global MHD modes exhibiting bursting amplitude modulation are newly observed in low density plasmas heated by co-injected neutral beams: (1) $m=3/n=2$ burst mode, and (2) toroidal Alfvén eigenmode. They are thought to be excited through resonant interaction between energetic ions and global MHD modes such as interchange modes and Alfvén eigenmodes. The frequency of these modes is rapidly shifted down during each burst. When the $m=3/n=2$ burst mode is excited in outward-shifted plasmas and grows up to the relative amplitude to the toroidal field $b_\theta/B_t \sim 6\times10^{-5}$, energetic ion loss is transiently enhanced.

Keywords:

MHD modes, fast ions, burst mode, Alfvén eigenmodes, fast ion loss flux, heliotron/torsatron

1. Introduction

In a toroidal plasma close to a fusion reactor condition, resonant interaction between energetic ions and MHD modes plays a crucial role in determining energetic ion confinement. Energetic ions generated by NBI or ICRF heating or D-T fusion reaction destabilize various types of global modes such as toroidal Alfvén eigenmodes (TAE modes)[1], kinetic ballooning modes[2] and fish-bone instabilities[3], and in turn suffer enhanced loss due to stochastic magnetic fields caused by these global modes.

In helical systems having appreciable level of magnetic field ripple, it is particularly important to clarify interactions between energetic ions and MHD instabilities and their effects on energetic ion confinement. In the CHS heliotron/torsatron with moderate (negative, *i.e.*, $q'<0$, $q=2\pi/\iota$ ($\iota/2\pi$: rotational transform)) magnetic shear, the low frequency burst modes with $m=2/n=1$ were observed already from the early experimental campaigns and are well-documented, except for interaction between energetic ions and MHD modes [4-6]. The $m=2/n=1$ burst modes are observed only in inward-shifted plasma heated by co-NBI, that is, the magnetic axis position in the vacuum field $R_{ax}\leq0.92$ m. Recently, two types of new MHD modes which might be excited by energetic ion population were observed: one is a newly observed $m=3/n=2$ mode which shows clear bursting character and is excited even in slightly outward-shifted plasmas (even in $R_{ax}\geq0.95$ m) only for the co-NBI case, and the other one is TAE mode [7].

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In this paper we focus on excitation conditions and characteristics of these modes, in particular, $m=3/n=2$ burst mode, and their effects on energetic ion loss.

2. Experimental Conditions and Results

These data shown below were obtained in plasmas heated by co-injected neutral beams at $B_t = 0.9$ T and low line averaged density $n_e \leq 2\times10^{19}$ m^{-3}, where the net plasma current is induced up to ~ 10 kA by NBI. The volume-averaged plasma beta of the bulk plasma is about 0.2 % and the beam beta is predicted to be 0.2–0.3 % from a shift of peak position of soft-X-ray emission [6]. Figure 1 shows typical time evolution of the $m=3/n=2$ burst type mode which is newly observed even in outward-shifted plasmas, where the co-injection NBI is applied from 35 ms to 135 ms and 53 GHz ECH is superimposed from 100–110 ms. This mode frequency is in 50–90 kHz. The frequency is relatively higher than that of the previously observed $m=2/n=1$ burst mode, and is considerably lower than the predicted TAE frequency and sometimes becomes insensitive to the electron density. Therefore, this mode can be distinguished from TAE mode as discussed in Ref. [7]. The amplitude of TAE mode as well as the $m=2/n=1$ and $m=3/n=2$ burst modes is often modulated, exhibiting bursting behaviors under high power NBI heating. Moreover, the frequency of these modes is rapidly shifted (that is, frequency "chirping") during each burst. Figure 2 shows expanded time evolution of the $m=3/n=2$ burst mode and TAE mode. As seen from Fig. 2, the frequency is rapidly shifted from 66 kHz to 38 kHz in 0.7 ms and 112 kHz to 93 kHz in 0.2 ms, in the $m=3/n=2$ burst and TAE modes, respectively. The relative fluctuation amplitude to the toroidal magnetic field reaches $b_\theta/B_t \sim 1\times10^{-4}$ and $\sim 3\times10^{-5}$ for respective modes.

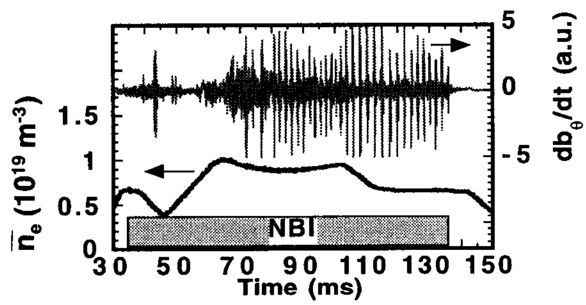

Fig. 1 Time evolution of the magnetic probe signal and line averaged electron density in a plasma with the newly observed $m=3/n=2$ burst mode, where the line averaged electron density at the center chord is ~ 1×10^{19} m^{-3}, $B_t=0.9$ T and $R_{ax}=0.97$ m.

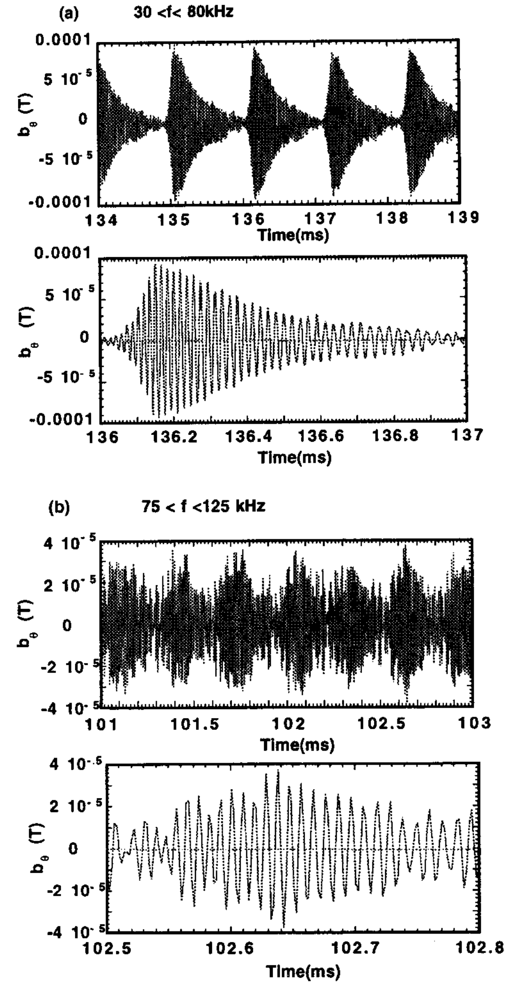

Fig. 2 Enlarged time evolution of magnetic fluctuations for the $m=3/n=2$ burst mode (a) and TAE mode (b) observed in $R_{ax}=0.95$ m configuration.

Recently, a probe for detecting energetic ion flux escaping toward the torus wall was installed in CHS [8]. In this experimental campaign, a signal from a scintillator installed inside the probe is monitored to investigate time behaviours of energetic ion loss flux to the wall. Figure 3 shows correlation between the $m=3/n=2$ burst mode and energetic ion loss flux for three cases: (a) and (b) at the configuration of $R_{ax}=0.95$ m and (c) for $R_{ax}=0.97$ m. As seen from Fig. 3 (c), energetic ion loss flux is transiently enhanced in the plasmas shifted outwards ($R_{ax}=0.97$ m), when the fluctuation amplitude grows up to a certain amplitude (~ 6×10^{-5} T). In the plasmas produced at slightly inward position ($R_{ax}=0.95$ m) than this case (Fig. 3 (c)), ion flux is not always enhanced (for instance, Figs. 3 (a) and (b)) associated with the burst mode. The relative amplitude of the observed magnetic bursts to the toroidal field and relative increment in energetic ion loss flux are summarized as a function of R_{ax} in Fig. 4. The observed transient increase in energetic ion flux caused by the burst mode may closely link to particle loss cone region in CHS.

3. Summary

In CHS two types of distinct MHD instabilities associated with energetic ion population are newly observed during co-injected NBI in a relatively low electron density and toroidal magnetic field. These modes exhibit bursting modulation of the amplitude and rapid frequency shift during each burst. In an outward shifted configuration of R_{ax}=0.97 m which is favourable for high beta plasma (deeper vacuum magnetic well), energetic ion loss flux is transiently enhanced during the m=3/n=2 magnetic burst with $b_\theta/B_t \geq 6\times10^{-5}$. On the other hand, measurable energetic ion loss will not be caused by the TAE mode, since the TAE mode is in the relatively lower level of $b_\theta/B_t \leq 3\times10^{-5}$ and is only observed in the $R_{ax}\leq$0.95 m configuration.

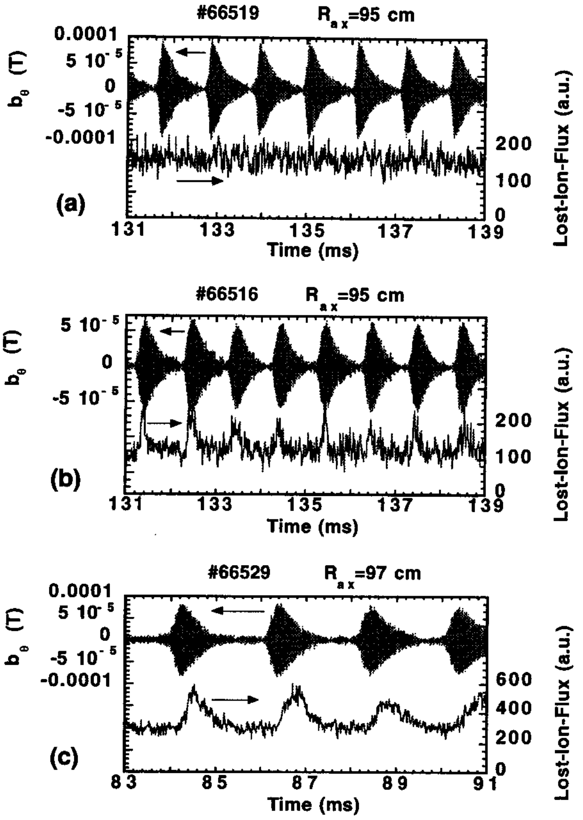

Fig. 3 Time evolution of the m=3/n=2 burst mode and energetic ion loss flux measured with a lost ion probe installed outside the last closed flux surface, for two configurations with R_{ax}=0.95 m (a and b) and 0.97 m (c).

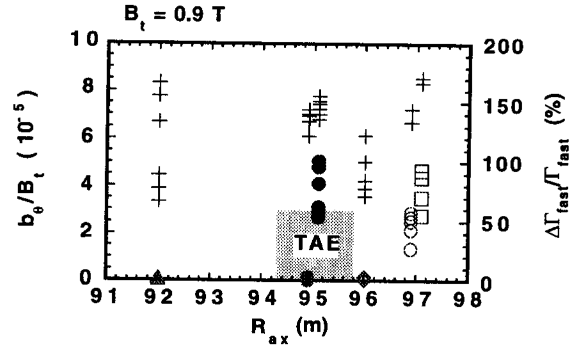

Fig. 4 The m=3/n=2 burst mode amplitude (shown by +) and the relative increment in energetic ion loss flux (shown by open and solid circles, squares, triangles and diamonds), as a function of the magnetic axis position in the vacuum magnetic field. The shaded region corresponds to the presence of TAE modes.

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