35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-1.056 (2008)

Energetic-particle modes driven by supra-thermal electrons in second harmonic ECRH plasmas of the Compact Helical System

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1. Introduction

Fast-particle-driven MHD instabilities such as the fishbone (FB) mode and toroidicity-induced Alfvén eigenmodes (TAEs) are one of key physics issues in magnetically confined fusion plasma experiments because those instabilities may lead to anomalous transport of alphas in a future burning plasma. In existing toroidal devices, experiments concerned with this subject have been so far performed by use of beam ions, perpendicular fast ion produced by ICRH and alphas born from D-T reactions. It should be pointed out that compared with alphas in ITER, in existing experiments, those ions mentioned above are fairly energetic, having much higher ratio of Larmor radius to minor radius and also showing significant shift of banana orbits from flux surfaces [1]. Supra-thermal electrons are also capable of destabilizing those modes since excitation of those modes depends on precessional drift frequency of particle, not on mass [2]. They are characterized by small dimensionless orbit, similarly to alphas in reactor-relevant plasmas. In this point of view, it could be mentioned that instabilities driven by supra-thermal electrons are relevant to alpha-particle-driven modes in burning plasmas. After the FB mode excited by supra-thermal electrons produced by 2nd harmonic ECRH was first found in the DIII-D [3] and Compass-D [4], FB modes associated with supra-thermal electrons have been observed in several tokamaks [5,6]. In regard to helical system, global AEs were excited due to supra-thermal electrons in the weak magnetic shear stellarator HSX with 2nd harmonic ECRH [7]. In this paper, we report bursting MHD instabilities in low-density plasmas with 2nd harmonic ECRH in CHS.

2. Energetic-particle modes in second harmonic ECRH plasmas

Figure 1a) shows bursting recurrent MHD instabilities in fairly low-density plasmas (n_e<0.5×10^{19} m^{-3}) of inward shifted configuration (R_{ax}/B_t=0.949 m/0.97 T) with high-power off-axis ECRH (P_{ECRH}~275 kW). The focused X-mode wave of which frequency is 54.5 GHz and power is up 300 kW was perpendicularly injected into the CHS vacuum chamber from the upper diagnostic port at the vertically elongated poloidal cross section. The wave frequency was 2nd harmonic because B_t ranged from 0.88 T to 1 T. The resonance layer was located at the place between a pair of helical winding coils, i.e. bottom of helical magnetic field ripple (see Figure 1b)). In such a heating scheme, helically trapped energetic electrons are primarily created. The Mirnov coil array indicates that the observed mode has a structure of m=2/n=1, propagating poloidally in parallel to the ion-diamagnetic direction and toroidally in parallel to the direction of helical field coil current equivalent to plasma current in tokamak in a viewpoint of increasing the rotational transform. Here, m and n stand for the poloidal and toroidal mode numbers, respectively. The mode is characterized by the rapid frequency downshift from ~70 kHz to ~50 kHz in the time scale of ~1 ms. It is noted that strong MHD activities can be seen in inward shifted configurations (R_{ax}≤0.949 m) that provide improved orbit of trapped particle compared with that in outward shifted configurations. The X-ray detector suggests that an appreciable amount of perpendicular supra-thermal electrons exists in plasmas of n_e less than 0.5×10^{19} m^{-3} whereas they do not at n_e of 1×10^{19} m^{-3}. It should be noted that the direction of toroidal precession drift of helically trapped electrons matches the toroidal direction of the observed mode propagation. Figure 2 shows shear Alfvén continua for n=1 and n=2 modes of the discharge shown in Fig. 1. It is obvious that the observed mode frequency is much lower than the TAE gap frequency. In addition, the mode shows the periodic recurrence accompanied with the rapid frequency down shift. Instabilities observed

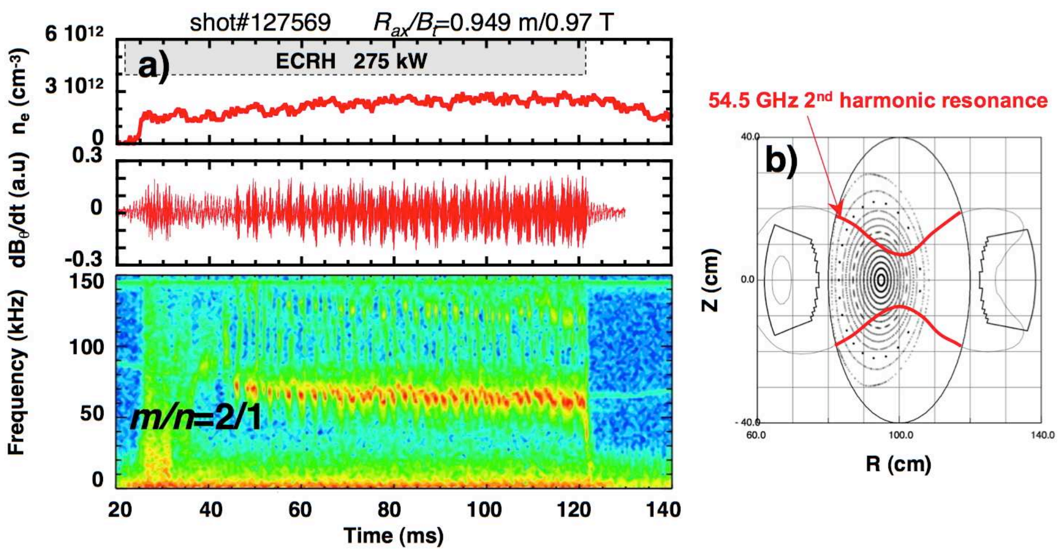

Figure 1a) Bursting MHD instabilities (m/n=2/1) in a low n_e 2nd harmonic ECRH plasma of CHS. Time traces of n_e, dB_θ/dt and its spectrogram are shown. 1b) 2nd harmonic resonance layer position for the wave of 54.5 GHz.

in CHS ECRH plasmas could be therefore classified into the energetic-particle mode (EPM).

The FB mode excited by trapped fast ions propagates poloidally in parallel to the ion-diamagnetic drift velocity and toroidally in parallel to the precession velocity of deeply trapped ions in tokamak [8]. In tokamak plasmas with ECRH, the strong bursting MHD activities have been observed when the resonance layer position was placed on the high field side. In such a heating condition, barely trapped electrons are primarily generated. The toroidal precession direction of those electrons is the same as that of ions trapped deeply in the low field side because of the drift reversal and those electrons can excite the FB instability potentially [2]. The bursting instabilities observed in 2nd harmonic ECRH plasmas of CHS propagate poloidally in parallel to the ion-diamagnetic direction and toroidally in parallel to the co-direction. This mode behavior is the same as the ion FB mode excited in tokamak and is also the same as EPM driven by tangentially co-injected beam ions in CHS. As mentioned before, helically trapped electrons are primarily produced in our condition. The direction of toroidal precession drift of helically trapped supra-thermal electrons matches that the toroidal direction of observed mode propagation. It looks that helically trapped supra-thermal electrons produced by ECRH play a dominant role in the mode excitation. In the case of EPM excitation by trapped particles, it may be expected that the mode frequency would be $\omega \approx \omega_d$, where ω and ω_d are the mode frequency and the bounce-averaged toroidal precessional drift frequency of trapped particles, respectively [9]. We have estimated toroidal precessional frequency f_d of deeply, helically trapped electrons by solving formulae for the particle drift in the r and θ directions in a model helical magnetic field given by Mynick *et al*. [10]. Figure 3a) shows examples of helically trapped orbits of energetic electrons. Estimated f_d of helically trapped electrons is shown in Figure 3b). It can be seen that if energies of trapped electrons are about 70 keV, the mode frequency matches f_d of those electrons.

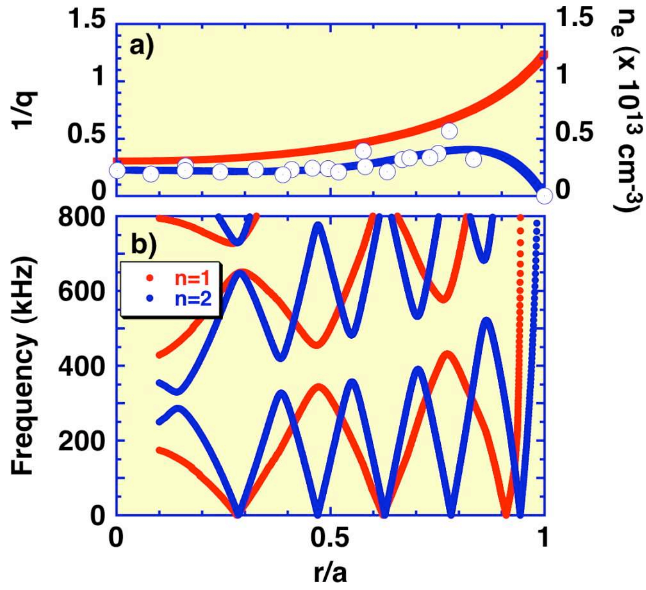

Figure 2a) Profiles of rotational transform ($1/q$) and n_e for the discharge shown in Fig. 1. 2b) Shear Alfvén continua (2D) for n=1 and n=2 modes.

In summary, bursting MHD instabilities were destabilized in fairly low n_e 2^{nd} harmonic ECRH plasmas without neutral beams in CHS. The mode of which frequency is lower than the TAE gap frequency is characterized by frequency downshift, rotating poloidally parallel to the ion-diamagnetic direction and toroidally in parallel to the co-direction. The direction of the toroidal precession of helically trapped electrons is the same as the co-direction. The observed mode is supposed to be due to helically trapped supra-thermal electrons produced by 2^{nd} harmonic ECRH.

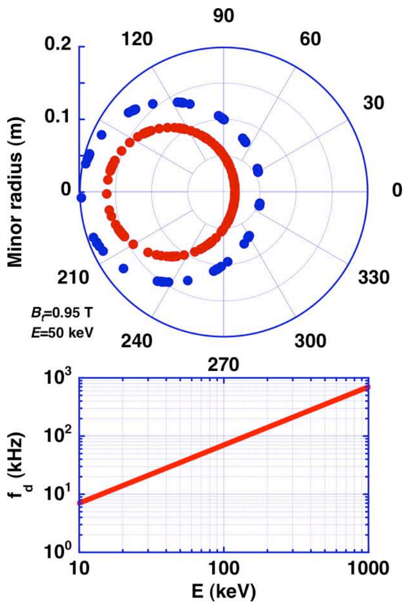

Fig. 3a) Bounce-averaged orbits of helically trapped electrons with energy of 50 keV. 3b) Toroidal precession frequency of helically trapped electrons as a function of energy

Acknowledgements

This work is supported by Grant-in-Aid from MEXT for Exploratory Research No. 20656150 and for Scientific Research on Priority Areas No. 16082209. This work is also supported by the JSPS-CAS Core-University Program in the field of "Plasma and Nuclear Fusion".

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