MHD instability driven by supra-thermal electrons in TJ-II stellarator

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Abstract

Coherent magnetic fluctuation (MHD instability) was observed in low density electron cyclotron resonance heating plasmas in TJ-II stellarator. The frequency is lower than the gap frequency of shear Alfven spectra. The mode excitation strongly depends on the condition of electron cyclotron resonance heating (ECRH), and it is concluded that the mode is destabilized by supra-thermal electrons. The mode frequency agrees with both Alfvenic and acoustic dependence.

Introduction

Energetic ion driven MHD instabilities such as fishbone (FB) modes and Alfven eigenmodes have been strongly studied both experimentally and theoretically, because they may potentially induce anomalous transport of the energetic particles which decrease plasma performance in fusion burning plasmas [1]. Recently, MHD instabilities driven by energetic electrons as well as energetic ions attract much attention because the Larmor radius normalized by minor radius is similar to the ones of the alpha particles in Deuterium-Tritium (D-T) burning plasmas such as ITER. Therefore the energetic electrons may be useful to investigate the alpha particle behavior interacting with MHD instabilities depending on their orbit velocity, precession frequency and rotating frequency. FB instability was destabilized by supra-thermal electrons in DIII-D tokamak [2], and studies related to energetic electron driven MHD instabilities have been carried out in not only tokamaks [3-5] but also helical/stellarators [6-10].

In TJ-II experiments, Alfven eigenmodes driven by energetic ions have been studied [11,12], and recently two types of coherent fluctuations were observed in electron cyclotron resonance heated (ECRH) plasmas. One is an electrostatic mode localized in the core region with a finite poloidal mode number [13]. The other is an electromagnetic mode (MHD instability) observed with Mirnov coils and bolometry. This paper discusses the first experimental results on the MHD instabilities driven by supra-thermal electrons in TJ-II

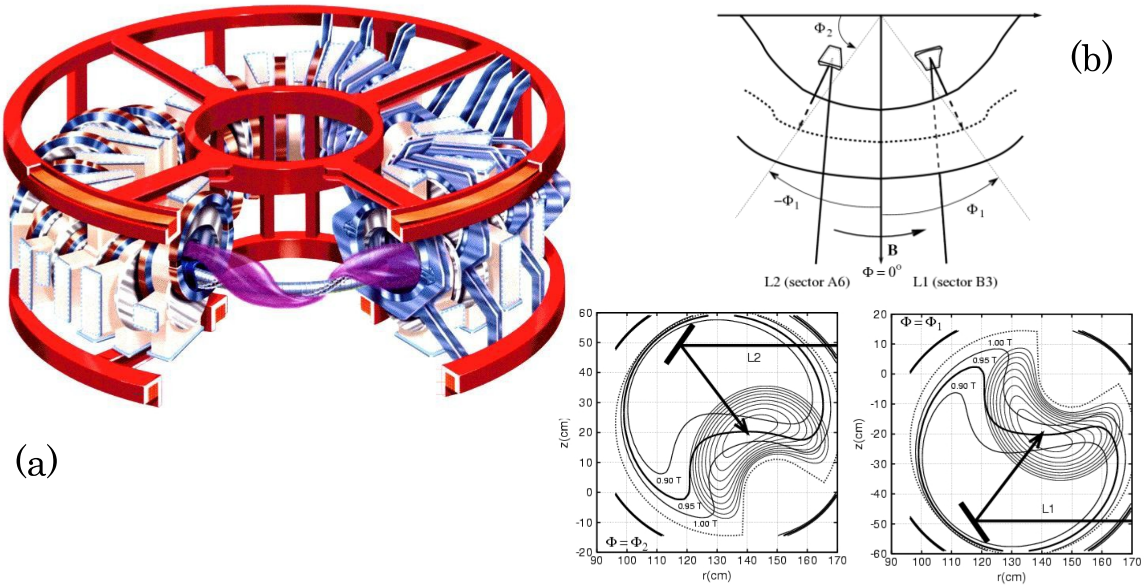

Figure 1. (a) Schematic of TJ-II stellarator and coil system. (b) Beam lines of ECRH system in TJ-II. The mirror located inside the vacuum vessel can control the microwave beam direction in poloidal and toroidal directions.

stellarator.

Experimental setup

The experimental stage is TJ-II stellarator having a high degree of magnetic configuration flexibility. The schematic view of TJ-II device and the shape of plasma are shown in Fig, 1(a). The major and minor radii are 1.5 m and 0.22 m, respectively. The strength of magnetic field is 1 T. In present experiment, the plasmas with low density of 0.1-1.0 x $10^{19}m^{-3}$ are produced and sustained by an ECRH. Two gyrotron generators with the frequency of 53.2GHz were installed in TJ-II. Figure 1 (b) shows the mirrors of ECRH system, which control the microwave beam direction into the plasma and the focal point of the microwave can be changed in the poloidal and toroidal directions. So far, supra-thermal electrons with the energy range of several 10 keV were successfully generated in the low density plasmas [14,15].

Observation of MHD instability in ECRH plasmas

The supra-thermal electron driven MHD instabilities were explored in low density plasmas heated by ECRH. Several coherent magnetic fluctuations were observed depending on some conditions such as magnetic field configuration, ECRH heating condition and so on. Here the properties of the observed modes with a high iota configuration (100_60_69) are presented.

Figure 2 shows frequency spectrum observed in a Mirnov signal and waveforms of ECRH, stored energy, electron density, plasma current, hard X-ray (HXR) and electron cyclotron

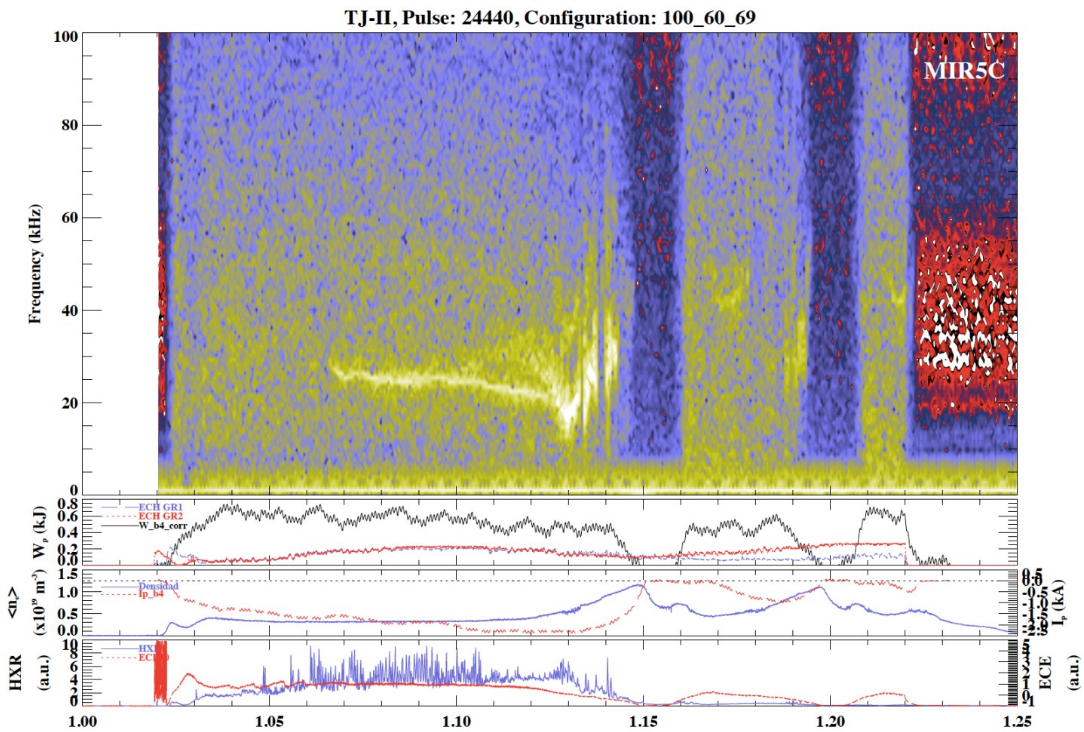

Figure 2. (upper frame) Frequency spectrum of a Mirnov coil signal. (second) time evolution of stored energy (Wp) and ECRH injection. (third) electron density and plasma current. (bottom) hard X-ray and ECE signals.

emission (ECE). The coherent fluctuation of magnetic field was observed simultaneously with the spikes appearing in the HXR signal. The frequency of the coherent mode ranges from 35 kHz to 15 kHz and is lower than the gap frequency of shear Alfven spectra. The mode frequency behaves in a different ways before and after t = 1.13 sec. In the first phase, the electron density is less than $0.5\mathrm{x}10^{19}\mathrm{m}^{-3}$ and slowly increases. The plasma current in the counter direction also slowly increases. The mode is continuously excited and the frequency slowly decreases. The bolometer array also detects this mode and the mode structure was obtained. The low frequency mode locates at around $\rho \sim 0.5$. The phase difference indicates the mode has even poloidal mode number. On the other hand, after t = 1.13 sec the electron density increases quickly, exceeds the cut-off density and then, the plasma collapses. The mode was excited intermittently, the mode frequency increases rapidly and then, the mode disappears, before the plasma collapse.

Mechanism of the mode excitation

A MHD mode was observed in ECRH heated plasmas with the standard configuration (100-44-64). This mode shows very similar property to that shown in Fig. 2. The mode was observed in the low density plasmas (less than $0.5\mathrm{x}\ 10^{19}\ \mathrm{m}^{-3}$) and the mode frequency is about 20 kHz. The bursting activity was also observed in HXR signals during the mode excitation.

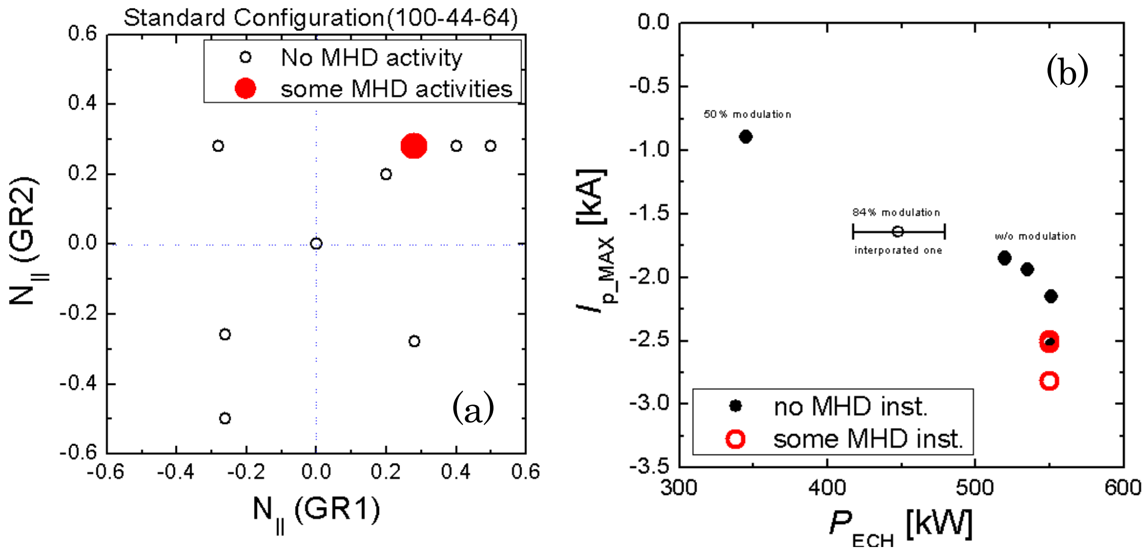

Figure 3. (a) Result of $N_{\parallel}$ scan experiment. Open circles indicate the condition of no MHD mode and large closed circle indicates the condition that MHD modes were observed. (b) The relation between the plasma current and ECRH power. The ECRH power was scanned using modulation technique.

In order to investigate the mode drive mechanism, the ECRH operation was changed. A focal point scan in the poloidal cross section was performed and no mode was observed with off-axis heating. The $N_{\parallel}$ scan was also performed in various combinations and summarized in Fig. 3(a). The low frequency mode was observed with only the condition of $N_{\parallel 1}$ = 0.28 and $N_{\parallel 2}$ = 0.28, where $N_{\parallel 1}=\cos(\theta_1)$ and $N_{\parallel 2}=\cos(\theta_2)$ determine the angle of both ECRH beams with respect to the magnetic field direction in vacuum for on-axis launching. In this case, $\theta_1=\theta_2=74^{\circ}$, where $\theta = 90^{\circ}$ corresponds to perpendicular injection. This indicates that the destabilization of the low frequency mode is sensitive to the distribution of supra-thermal electrons in real space and phase space. The ECRH power scan was also performed utilizing microwave modulation technique, and the plasma current and ECRH power are summarized in Fig. 3(b). The mode was observed only with the condition of high power (550 kW) and the plasma current (ECCD) over -2.5 kA in the counter direction. The ECCD current is related to the population of supra-thermal electrons. Therefore this result indicates that the mode destabilization is related to the population of supra-thermal electrons.

Moreover, the electron cyclotron emission (ECE) signals near the core region was observed to jump up significantly during the mode appearance. The significant jump of ECE signal indicates the existence of supra-thermal electrons, because high-energy tail components in energy distribution function produce intense emission. Therefore this is another evidence of supra-thermal electrons being related to the mode destabilization. It is concluded from these experimental results that the low frequency modes are destabilized by supra-thermal electrons.

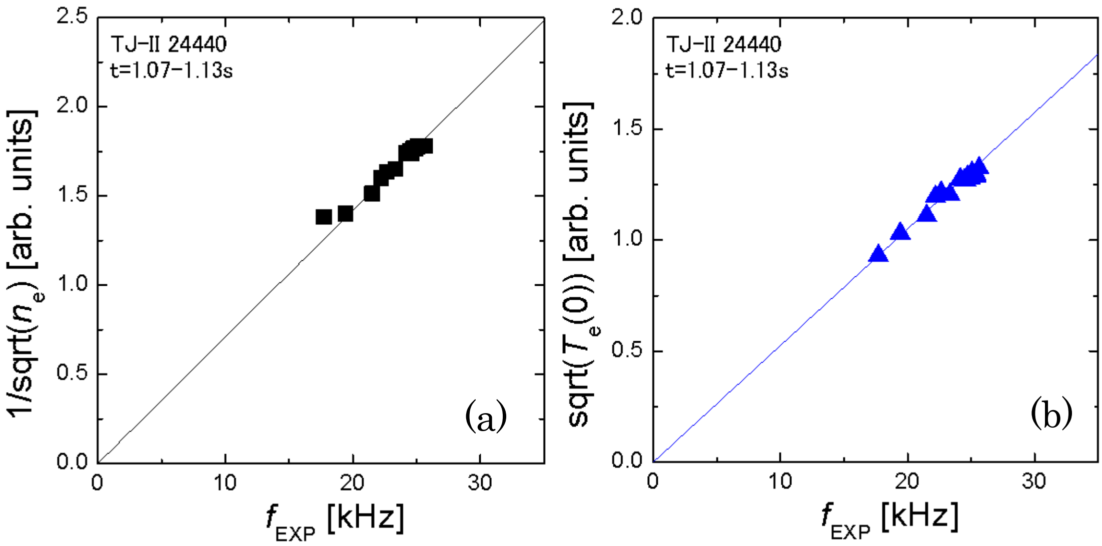

Figure 4 (a) The Alfvenic scaling ($1/\sqrt{n_e}$) and (b) the acoustic scaling ($\sqrt{T_e}$) agree well with the observed mode frequency.

Discussion and summary

In order to discuss the mode type, the mode frequency dependence is investigated for some cases. The observed frequency shown in Fig.2 (first phase) are compared with Alfvenic frequency dependence ($f_{\mathrm{Alf}} \propto {}^{1}/_{\sqrt{n}}$) and with acoustic frequency dependence ($f_{\mathrm{Ac}} \propto \sqrt{T_{\mathrm{e}}}$), which are shown in Fig. 4. The mode frequency dependence is consistent with both Alfvenic and acoustic scaling. It is due to the fact that the electron temperature well correlated to the density in this plasma. Thus, it is impossible to distinguish whether the observed mode is Alfvenic or acoustic. The preliminary analysis of the shear Alfven spectra shows that the gap frequency of shear Alfven spectra of this plasma is about 150 kHz (HAE gap), which is much higher than the observed frequency. It is speculated that there may be beta-induced Alfven eigenmodes (BAE) and beta-induced Alfven-acoustic eigenmode (BAAE) gaps frequency in the observed frequency range. However, further investigations of shear Alfven spectra is necessary for the mode identification.

The coherent magnetic fluctuations (MHD instabilities) have been observed in ECRH heated plasmas in a wide range of central iota value of $1.55 < \iota/2\pi < 1.71$. The mode frequencies are from 15 kHz to 50 kHz and lower than the gap frequency of shear Alfven spectra. The mode excitation is very sensitive to ECRH operation condition. There are many phenomenological evidences of the relation between supra-thermal electrons and the mode destabilization, such as large activity in HXR signals, large ECCD current, jump up of ECE signals near the core region and so on. It is concluded that the mode is destabilized by supra-thermal electrons. The frequency dependence agrees well both Alfvenic and acoustic scaling. However, further investigation is necessary for mode identification, which is left for a future study.

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