21aC2-2

External control of energetic-ion-driven MHD instabilities by ECH/ECCD in Heliotron J plasmas

ヘリオトロンJプラズマにおけるECH/ECCDを用いた高速イオン励起MHD不安定性の外部制御

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Energetic-ion-driven magnetohydrodynamics (MHD) instabilities such as Alfvén eigenmodes (AEs) and energetic particle modes (EPMs) have been studied in neutral beam injection (NBI) heated Heliotron J plasmas. We clarified the characteristics of the observed EPMs such as mode structure and observation region. We demonstrated that EPMs could be controlled by means of both positive and negative magnetic shear induced by electron cyclotron driven plasma current.

1. Introduction

Energetic-ion-driven MHD instabilities, which could enhance the transport and induce the loss of energetic ions such as alpha particles in a D-T fusion reactor, are being extensively studied in many toroidal plasmas. The methods to control the energetic-ion-driven MHD instabilities are required for a fusion reactor, but they have not been established yet. While several methods are proposed to control the modes, electron cyclotron heating (ECH)/electron cyclotron current drive (ECCD) are an ideal tools to control a MHD instabilities since they can provide highly localized EC waves with a known location and good controllability. The effect of ECH/ECCD on the energetic-ion-driven MHD instabilities is investigated in tokamaks and helical systems such as Heliotron J [1], DIII-D, LHD and TJ-II. In a linear theory, the changes in electron density and temperature by ECH and in plasma current by ECCD can affect both growth rate and damping rate of the energetic-ion-driven MHD instabilities through the changes in (i) pressure gradient of energetic ions, (ii) structure of shear Alfvén continuum and (iii) electron Landau damping. Since Heliotron J has low magnetic shear in vacuum and therefore the magnetic shear can be controlled by ECCD, we have investigated the effect of continuum damping, whose rate is related to the magnetic shear, on the observed EPMs.

2. Characteristics of EPM in Heliotron J

The observed energetic-ion-driven MHD instabilities were identified as global AEs (GAEs) and EPMs by comparing with shear Alfvén spectra in Heliotron J plasmas. In the low-density plasma ($\langle n_e \rangle \leq 1.0\mathrm{x}10^{19}$ m^{-3}), EPMs only are observed because the energetic ions are too slow to resonate with the GAEs. The bursting EPMs cause energetic ion loss from the confinement region under certain experimental conditions. Figure 1 (a) shows that typical observation of EPMs in low-density plasma heated by both ECH and NBIs. Purple curves in Figs. 1 (c)~(f) indicate time evolution of plasma stored energy, electron density, plasma current and amplitude of observed EPMs with m=2/n=1 (m, n: the poloidal and toroidal mode number), respectively. Figure 2 shows the density dependence of frequency and amplitude of the observed EPMs with m=2/n=1. The frequency was not proportional to Alfvén velocity. Then this characteristic means that the

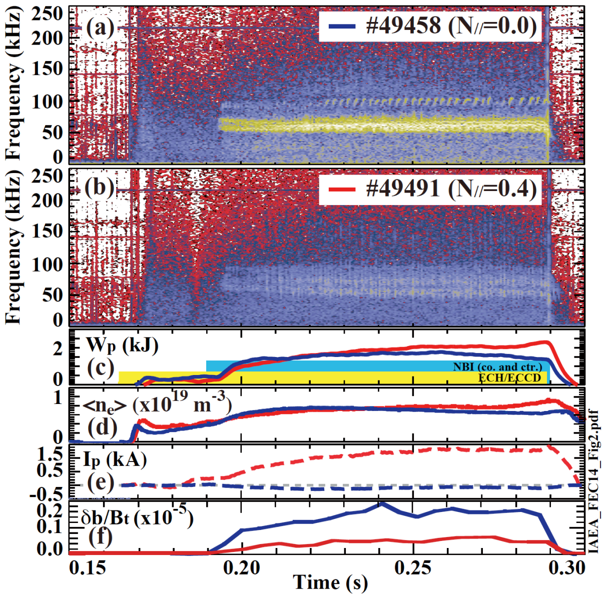

Fig. 1. Time evolution of typically observed EPMs in plasma (a) without ECCD and (b) with ECCD, and (c) plasma stored energy, (d) electron density, (e) plasma current and (f) amplitude of observed EPMs with n=1.

observed modes are not AEs. EPMs are localized at the plasma edge region (normalized minor radius ρ~0.8) where the observed frequency of EPMs coincides with that of shear Alfvén continuum. We observed the movement of EPMs from the local density fluctuations measured with a beam emission spectroscopy. As the increasing of plasma current, the EPMs slightly moves outward. This movement of EPMs can be explained by the shift of shear Alfvén continuum with m=2/n=1 due to the change of plasma current.

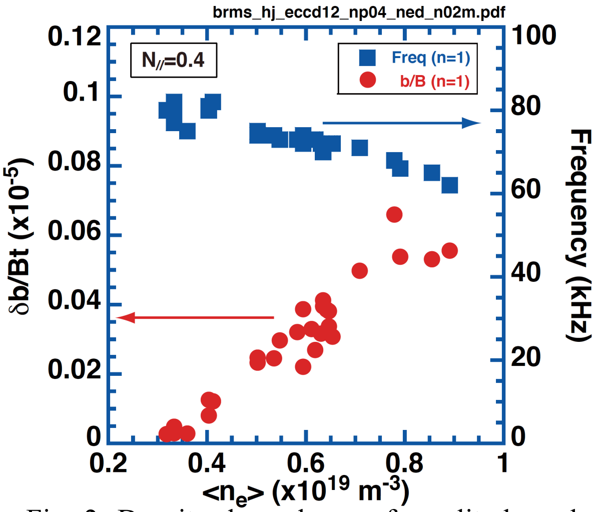

Fig. 2. Density dependence of amplitude and frequency of observed m=2/n=1 EPMs in NBI-heated Heliotron J plasmas.

3. Control of EPMs by ECCD

We attempted to control the observed EPMs by means of the magnetic shear modified by EC driven plasma current. It is expected that the continuum damping is the main damping mechanism of EPMs and that the continuum damping rate is related to the local magnetic shear. Typical observation of EPMs in the case of $N_{//}$=0.4 corresponding to ECCD case are shown in Fig. 1 (b). We fixed the plasma parameters except plasma current in these experiments, as shown in Figs. 1. (c) and (d). Therefore, electron and ion Landau damping, energetic ion beta were also fixed in these experiments. Clear reduction of amplitude of the observed EPMs is shown in Fig. 1 (b). Plasma current I_p can be controlled in the range of $-1.5 < I_p < 2.5$ kA by ECCD by changing EC wave parallel refractive index $N_{//}$ from 0.0 to 0.5 and magnetic field direction. The amplitude of the observed m=2/n=1 EPMs obviously decreased with an increasing absolute value of plasma current $|I_p|$ produced by EC driven current, as shown in Fig. 3. The EC driven plasma current profile estimated by TRAVIS code indicates that EC driven plasma current locally flows at the plasma core and enhances the magnetic shear at the plasma edge where the EPMs are excited. We demonstrated that the mitigation of EPM amplitude is observed in the increase in both positive and negative shear.

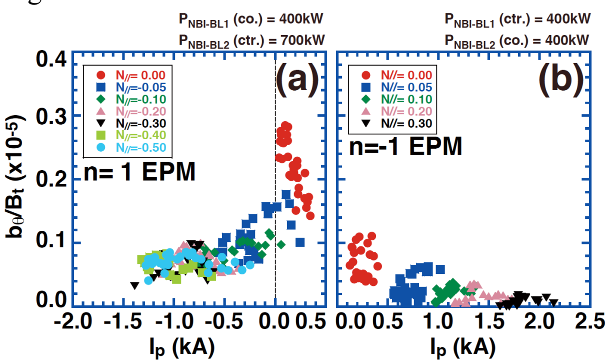

Fig. 3. Effect of plasma current corresponding to EC-driven current on amplitude of observed n=1 EPMs.

Acknowledgments

The authors are grateful to the Heliotron J group for their arrangement of the experiments. This work is performed with the support and under the auspices of the NIFS Collaborative Research Program (NIFS10KUHL030), and the Collaboration Program of the Laboratory for Complex Energy Processes, IAE, Kyoto University.

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