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Studies of energetic-ion-driven MHD instabilities in low magnetic shear helical plasmas

低磁気シアヘリカルプラズマにおける高速イオン励起MHD不安定性研究

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Energetic-ion-driven MHD instabilities such as Alfvén eigenmode (AE) have been studied in the three-dimensional magnetic configurations with low magnetic shear and low toroidal field period that are the features of advanced helical devices. Comparison of experimental results obtained from Heliotron J and TJ-II with numerical studies indicates that most unstable AEs are global AE (GAE) in advanced helical devices with low rotational transform and helicity-induced AE (HAE) in that with high rotational transform, respectively.

1. Introduction

Most of existing and/or planned advanced helical devices have a low magnetic shear in combination with a magnetic well, by which pressure-driven MHD instabilities particularly at low order rational surface can be avoided or would be stabilized, and a low toroidal field period N_p to obtain good transport and MHD stability. To clarify the energetic-ion-driven MHD instabilities such as Alfvén eigenmode (AE) is important because they would enhance the anomalous transport of energetic ions and/or expel them from the plasma before their thermalization. The existence and stability of energetic-ion-driven MHD instabilities are characterized by the magnetic configuration through the shear Alfvén spectra. The effect of magnetic configuration upon energetic-ion-driven MHD instabilities should be investigated in each magnetic configuration. Low magnetic shear and three-dimensional magnetic configuration with low toroidal field period significantly affect on the shear Alfvén spectra. They differ not only from that of tokamaks but also helical devices with high magnetic shear and high toroidal field period.

For our study, we have experimentally and numerically investigated the energetic-ion-driven MHD instabilities in Heliotron J [1] and TJ-II [2]. Both devices have low magnetic shear and low toroidal field period N_p=4 to obtain high MHD stability. The rotational transform of Heliotron J can be varied in the range of $\iota/2\pi$=0.45~0.65 which is different from that of $\iota/2\pi$=0.9~2.0 of TJ-II. We are also able to study the effect of rotational transform value on the energetic-ion-driven MHD instabilities through the comparison between Heliotron J and TJ-II results.

2. Alfvén eigenmode in helical plasmas

In helical plasmas, the magnetic field strength is varied not only in the poloidal direction but also in the toroidal direction. This variation of magnetic field strength on the magnetic surface leads to the formation of frequency gap in the shear Alfvén continua at the intersection point of two continua with different parallel wave number $k_{//(m,\ n)}$ and $k_{//(m+\mu,\ n+\nu Np)}$ where n and m are the toroidal and poloidal mode number, and μ and ν are the integer, respectively [3]. The AEs can be excited in these frequency gaps. The frequency gap for toroidicity-induced AE (TAE), which is often observed in many tokamaks and helical devices with high magnetic shear, is formed by the coupling of poloidal harmonics with mode number m and m+1 corresponding with the case of μ=1 and ν=0. However, the shear Alfvén continuum of m cannot intersect with that of m+1 because of low magnetic shear in advance helical devices. This means that TAE does not exist. Meanwhile, global AE (GAE) which can exist just below and/or above the shear Alfvén continua, could be destabilized by the presence of super-Alfvénic ions. Moreover, the variation of magnetic field in the toroidal direction leads to the toroidal mode coupling. Both toroidal and poloidal mode couplings generate the helicity-induced AE (HAE) gap. Figure 1 shows the calculated shear Alfvén continua of the mode family N_f=1 for Heliotron J plasmas. The shear Alfvén spectra with (m+μ, n+νN_p) are superposed on and/or coupled with that of (m, n). There are no low n TAE gaps that are more dangerous than high n TAE. HAEs are appeared in the frequency range above 500 kHz under this experimental condition of Heliotron J. We found the GAE, of which frequency lying just above the shear Alfvén spectra of m=2/n=1, as shown Fig.1. Numerical simulation indicates the most important AEs are not TAE and HAE but GAE in Heliotron J.

3. Experimental result in iota scan experiments

In NBI heated Heliotron J plasmas, MHD instabilities are observed. The observed mode is identified as GAE because the frequency and radial structure of the mode agree well with the calculated GAE characteristics. We performed iota scan experiment where the rotational transform is scanned in the range of ι/2π = 0.47~0.63. Figures 2 (a) and (b) respectively show the GAE frequency of numerical calculation and experiment as a function of rotational transform. We found a few GAE of which frequcny and radial structure are slightly different from those in the numerical simulations. Experimental results show the GAE frequency increases with an increase of the rotational transform. This is the same tendency as that in numerical simulations. No low frequency GAE (f<50kHz) was observed in experiment although a GAE with low frequency is found in numerical simulations. This result might be explained by taking into account the coupling of sound wave with shear Alfvén wave. On the other hand, HAEs are mainly observed in the TJ-II iota scan experiment. It is conculded that most unstable AEs are GAE in advance helical devices with low rotational transform and HAE in that with high rotational transform, respectively.

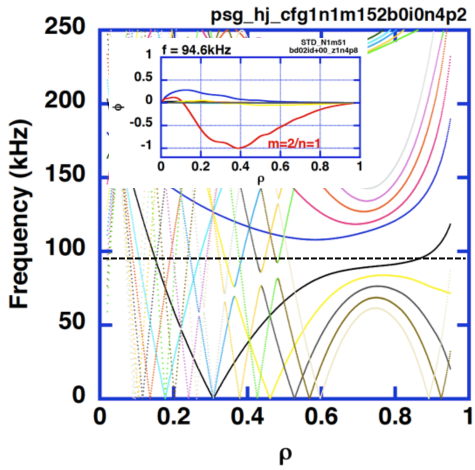

Fig.1. Example of shear Alfvén spectra including continua and eignfunction for N_f=1 of Heliotron J.

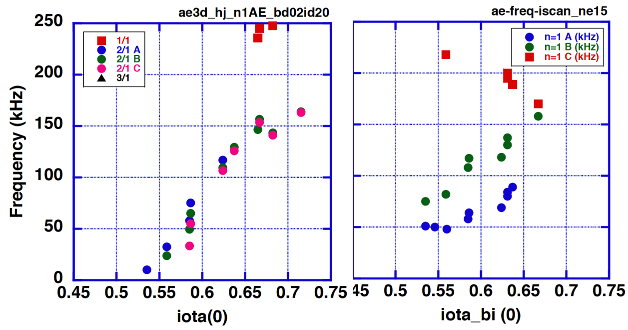

Fig.2. Frequency of GAE obtained from (a) a numerical simulation and (b) the experiment.

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