§ 2. Simulation of Fast Frequency Sweeping Mode in a JT-60U Experiment

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Instabilities with frequency chirping in the frequency range of Alfvén eigenmodes have been found with energetic neutral beam injection in JT-60U [1]. One type of instability appears with frequency inside the toroidal Alfvén eigenmode (TAE) gap and the frequency changes rapidly by 10-20 kHz in 1-5 ms. This type of instability is called the fast frequency sweeping (FFS) mode. Since the plasma profile changes in a much longer time scale, some nonlinear effects play an important role in the frequency change of the FFS mode during the interplay between the mode and the energetic ions created by the neutral beam injection.

Using the experimental q-profile, bulk pressure profile, and density profile we have carried out a particle-magnetohydrodynamic (MHD) hybrid simulation [2]. In this simulation the plasma is divided into to two parts, namely, energetic ions and bulk plasma. The bulk plasma and the electromagnetic field are described by the MHD equations. This approximation is reasonable under the condition that the energetic ion density is much less than the bulk plasma. The drift-kinetic description is employed for the energetic ions. To complete the equation system in a self-consistent way, we take account of the energetic ion effects on the bulk plasma in the MHD momentum equation. The δf particle simulation method is applied to the energetic ions. The major and minor radii are R_0=3.4m a=1.0m, respectively. The magnetic field at the magnetic axis is 1.2T. The bulk plasma and the beam ions are deuterium. Taking into account the FFS burst interval is less than 10ms whereas the slowing down time is of the order of magnitude 100ms, energetic ion pressure is assumed to be 20% of the classical distribution. Energetic ion distribution in the velocity space is a slowing down distribution with maximum velocity that is 80% of the injection velocity. This maximum velocity corresponds to the Alfvén velocity at the magnetic axis. Perpendicular velocity of energetic ions is neglected for simplicity.

Nonlinear evolution of the energetic ions and the MHD equation is followed until $\omega_A t = 3000$ where ω_A is the Alfvén frequency. An energetic particle mode (EPM) with the primary poloidal/toroidal mode number m/n=2/1 is destabilized. Figure 1 shows frequency and peak location of the EPM with the q-profile and n=1 local shear Alfvén frequency. Frequency of the EPM is close to the local shear Alfvén frequency.

Frequency of the toroidal electric field is analyzed. Time evolution of the frequency spectrum is shown in Fig. 2. The contour levels are 0.19, 039, and 0.59 of the maximum value. It is found that the frequency changes upwards by 8% (~4kHz) and downwards by 17% (~9kHz) of the frequency in the linear growth phase in 3000 Alfvén time (~2.4ms). This frequency change is close to the experimental results.

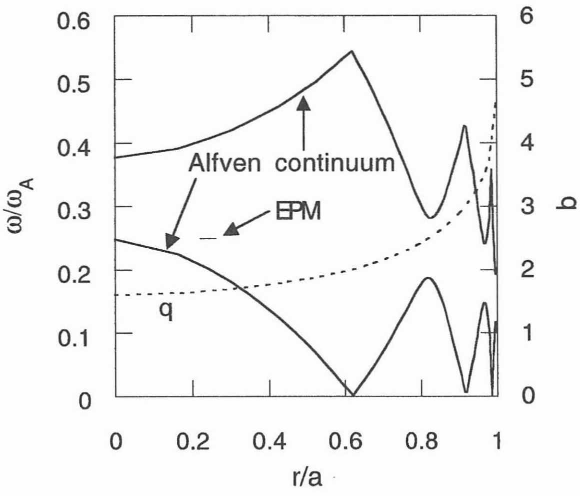

Fig. 1. Frequency and peak location of the EPM. Solid curves are the n=1 local shear Alfvén frequency and dashed curve is the q-profile.

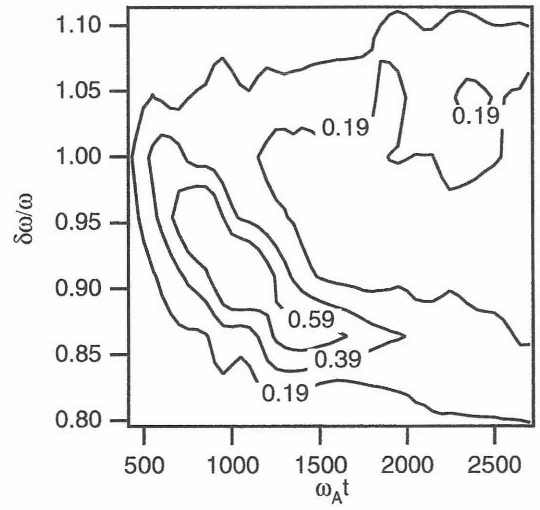

Fig. 2. Time evolution of the frequency spectrum. Contour levels are 0.19, 0.39, and 0.59 of the maximum value.

References

[1] K. Shinohara et al., Nucl. Fusion **41**, 603 (2001).
[2] Y. Todo and T. Sato, Phys. Plasmas **5**, 1321 (1998).