Simulations of energetic-particle driven Alfvén eigenmodes in magnetically confined plasmas

Y. Todo[1]
[1] National Institute for Fusion Science, National Institutes of Natural Sciences
e-mail: todo@nifs.ac.jp

In burning plasmas, which is expected to be realized in ITER, energetic alpha particles born from deuterium-tritium (D-T) fusion reaction will play an essential role in heating the fuel plasma through particle collisions. Confinement of energetic alpha particles is crucial for the sustainment of high temperature needed for fusion reaction, which is higher than 10 keV. In the present magnetic confinement experiments on tokamak and stellarator/heliotron devices, auxiliary heating such as neutral beam injection (NBI) and ion-cyclotron-range-of-frequency (ICRF) wave heating generate fast ions. Confinement of the fast ions is also important for the present experiments.

Alfvén eigenmodes (AEs) are magnetohydrodynamic (MHD) oscillations in magnetically confined plasmas and excited by energetic particles (EPs) such as fast ions generated by NBI and ICRF heating. EPs are circulating inside the plasma along the magnetic field line and can destabilize AEs through resonant interaction. This is a kind of inverse Landau damping with MHD waves in 3-dimensional magnetically confined plasmas with complicated particle orbits and non-uniform spatial distribution. The spatial gradient of the EP distribution can drive AEs as well as the distribution gradient in velocity space. What is important is that this problem is a wave-particle interaction in an open system with source (fusion reaction, NBI, and ICRF) and sink (losses). This results in various types of time evolution, steady amplitude, frequency chirping, and recurrent bursts.

Validation studies of kinetic-MHD hybrid simulation code MEGA were conducted for DIII-D tokamak experiments where significant flattening of the fast-ion distribution associated with many AEs with low amplitudes were observed [1-3]. In the validation studies, realistic NBI as well as particle collisions and losses were implemented in the MEGA code. A novel method was developed to realize the simulation of the slowing-down time scale of fast ions [1]. The significantly flattened fast-ion pressure profile observed in the experiment was reproduced with the MEGA simulation [2]. In addition, the electron temperature fluctuation profiles which are brought about by the AEs are also well reproduced with the MEGA simulation for frequency, spatial profile, and amplitude. These results indicate that the MEGA code is a powerful tool for the understanding and the prediction of EP driven AEs and the EP transport.

Frequency chirping of EP driven instabilities is observed in fusion plasmas as well as in space plasmas. For example, recurrent bursts of EP driven geodesic acoustic modes (EGAMs) were observed with upward frequency chirping in the Large Helical Device (LHD) [4]. The MEGA code was applied to an LHD experiment where a secondary EGAM is suddenly excited during the upward frequency chirping of the primary EGAM [5]. The frequency of the secondary EGAM is just a half of that of the primary EGAM. This interesting phenomenon was reproduced with the MEGA simulation. It was found that the secondary EGAM is excited by a fractional resonance with the EPs that are resonating with the primary EGAM.

Bursting evolution of AEs were observed in many tokamaks and stellarators. The MEGA code was applied to examine the distribution formation process in the collisional slowing-down time scale of fast ions for various NBI power and collisional slowing-down time [6,7]. It was found that the intermittency of AEs rises with increasing NBI power and increasing slowing-down time. Figure 1 shows that with increasing volume-averaged classical fast ion pressure, the fast ion confinement degrades monotonically due to the transport by the AEs [6].

References
[1] Y. Todo *et al.*, Nucl. Fusion **54** (2014) 104012
[2] Y. Todo *et al.*, Nucl. Fusion **55** (2015) 073020
[3] Y. Todo *et al.*, Nucl. Fusion **56** (2016) 112008
[4] T. Ido *et al.*, Phys. Rev. Lett. **116** (2016) 015002
[5] H. Wang *et al.*, Phys. Rev. Lett. **120** (2018) 175001
[6] Y. Todo, New J. Phys. **18** (2016) 115005
[7] Y. Todo, Nucl. Fusion **59** (2019) 096048

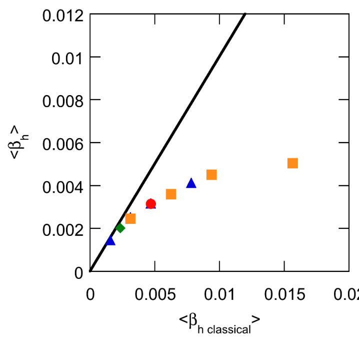

Figure 1 Volume-averaged fast ion beta versus volume-averaged classical fast ion beta. Fast ion confinement degrades with increasing classical fast ion beta [6].