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アルフベン固有モードによる高速イオン分布異常平坦化のシミュレーション研究

Simulation study of anomalous flattening of fast ion profile due to Alfvén eigenmodes

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MEGA is a hybrid simulation code for energetic particles interacting with a magnetohydrodynamics (MHD) fluid [1]. In this work, MEGA is extended with realistic beam deposition profile, collisions, and losses to simulate self-consistently the nonlinear dynamics of Alfvén eigenmodes (AE modes) and energetic particles. A multi phase simulation, which is a combination of classical simulation and hybrid simulation, is developed to investigate the evolution in the fast ion slowing down time scale (~100ms) that is longer than the typical time scale of AE instability (~1ms). In the classical simulation, no MHD perturbation is considered. Relaxation of the fast ion distribution takes place due to the AE modes in the hybrid simulation while the beam injection, collisions, and losses are considered in both the simulations. The classical and hybrid simulations are alternately performed for 4ms and 1ms, respectively. This combination is repeated for the stored fast ion energy to reach to a steady level.

A multi phase simulation is carried out for DIII-D discharge #142111 [2]. The stored fast ion energy evolution is compared between the classical and the multi phase simulations in Fig. 1(a). We see the stored energy is reduced in the multi phase simulation than in the classical simulation. Figure 1(b) shows the time evolution of MHD kinetic energy. After t=74ms, the hybrid simulation is continued until the end of the run. We see the MHD kinetic energy is at a steady level after t=75ms. The steady fast ion pressure profiles are compared in Fig. 2 among the classical and multi phase simulations, and the experiment. We see the fast ion pressure profile is significantly flattened in the multi phase simulation. This profile is maintained with a balance among the beam injection, collisions, and the transport by the AE modes with amplitude $\delta B/B \sim O(10^{-4})$. The dominant AE modes are toroidal Alfvén eigenmodes (TAE modes), which is consistent with the experiment. The amplitude of the temperature fluctuations brought about by the TAE modes is of the order of 1% of the equilibrium temperature. This is also consistent with the electron cyclotron emission measurements in the experiment.

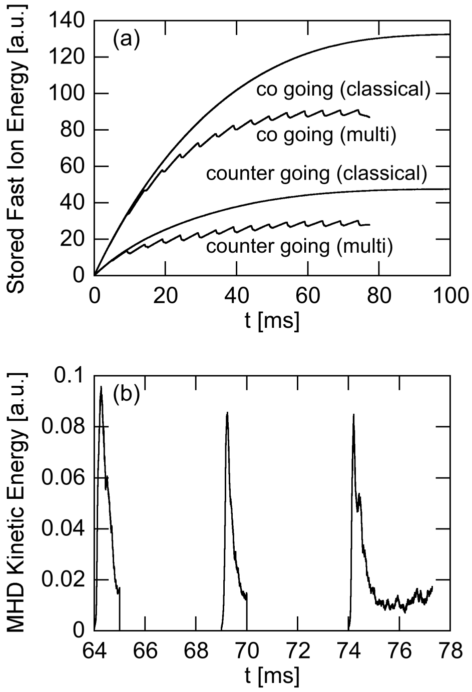

Fig. 1

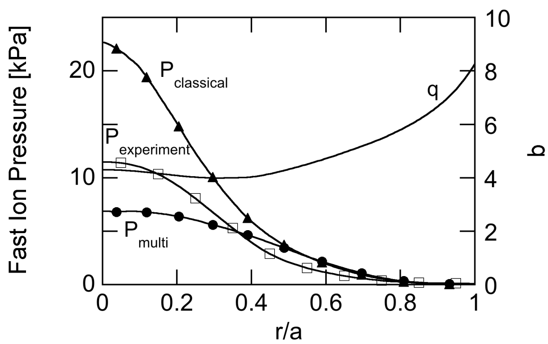

Fig. 2

[1] Y. Todo *et al.*, Phys. Plasmas **5**, 1321 (1998).
[2] M. A. Van Zeeland *et al.*, Phys. Plasmas **18**, 056114 (2011).