§5. Multi-Phase Simulation of Fast Ion Profile Flattening due to Alfvén Eigenmodes in a DIII-D Experiment

Todo, Y., Van Zeeland, M.A. (General Atomics),
Bierwage, A. (Japan Atomic Energy Agency),
Heidbrink, W.W. (Univ. California, Irvine)

We have developed a multi-phase simulation that is a combination of classical and hybrid simulations for energetic particles interacting with an MHD fluid to simulate the nonlinear dynamics on slowing down time scales of the energetic particles [1]. The hybrid simulation code MEGA is extended with realistic beam deposition profiles, collisions, and losses, and is used for both the classical and hybrid phases. The code is run without MHD perturbations in the classical phase, while the interaction between the energetic particles and the MHD fluid is simulated in the hybrid phase. In a multi-phase simulation of DIII-D discharge #142111 [2], the stored fast ion energy is saturated due to Alfvén eigenmodes (AE) at a level lower than in the classical simulation. Figure 1 shows the time evolutions of stored fast ion energy and MHD kinetic energy. After the stored fast ion energy is saturated, the hybrid simulation is run continuously. We see in Fig. 1(b) MHD kinetic energy reaches a steady level after t=75ms. Figure 2 compares fast ion pressure profile among multi-phase simulation, classical simulation, and experiment. It is demonstrated that the fast ion spatial profile is significantly flattened due to the interaction with the multiple AEs with amplitude $v/v_A \sim \delta B/B \sim O(10^{-4})$.

The dominant modes found are toroidal Alfvén eigenmodes (TAE), which is consistent with the experimental observation at the simulated time. The n=1 and 2 modes have also a property like energetic particle mode such that their peak is located on the continuum. The amplitude of the temperature fluctuations brought about by the TAEs is of the order of 1% of the equilibrium temperature which is comparable to electron cyclotron emission measurements in the experiment. In the standard run, the amplitude of the TAE modes is $v/v_A \sim \delta B/B \sim 3\text{-}6 \times 10^{-4}$ for n=1-4, and the fast ion pressure profile is more flattened than that in the experiment. We expect that the half and third energy beam components, which are not included in the present simulations with the beam deposition power 4.95 MW, would increase the beam deposition power to 6.25 MW and make the fast ion pressure closer to the experiment.

We carried out two more multi-phase simulations with different dissipation coefficients. Significant flattening of fast ion spatial profile takes place over a range of one order of magnitude for the dissipation coefficients. The kinetic energy of the MHD fluctuations is roughly in proportion to the inverse of the dissipation coefficients. This is consistent with the result that the significant flattening of fast ion spatial profile takes place for all the dissipation coefficients. The physics model in this study does not include kinetic damping of AE modes such as radiative damping and thermal ion Landau damping. The dissipation coefficients enable us to control the damping rate, and we can adjust dissipation coefficients to match the experimental fast ion profile.

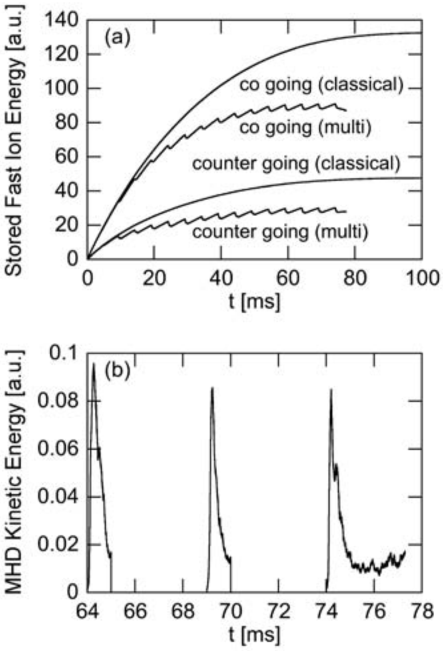

Fig. 1 Time evolutions of (a) stored fast ion energy in multi-phase and classical simulations and (b) MHD kinetic energy in the multi-phase simulation.

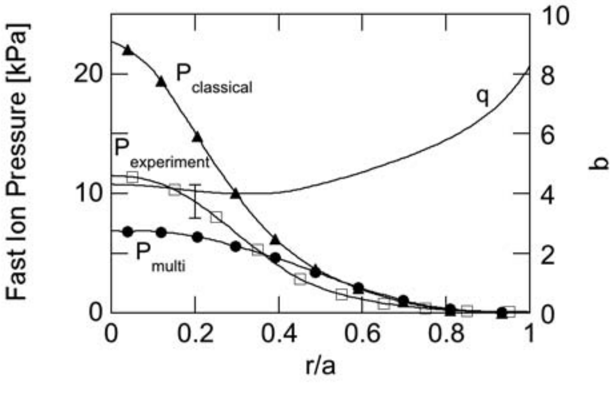

Fig. 2 Comparison of fast ion pressure profile among multi-phase simulation (circle), classical (triangle) simulation, and experiment (square) with an error bar shown in the figure.

1) Todo, Y. *et al.*: to appear in Nucl Fusion **54** (2014).
2) Van Zeeland, M. A. *et al.*: Nucl. Fusion **52** (2012) 094023.