§1. Simulation Study of Energetic Particle Driven Instabilities in LHD and Tokamaks

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We studied two subjects, 1) high-frequency energetic particle driven geodesic acoustic mode (EGAM) in LHD, and 2) validation of comprehensive magnetohydrodynamic hybrid simulations for Alfvén eigenmode (AE) induced energetic particle transport in DIII-D plasmas. For subject 1, we clarified the excitation condition and the properties of the high-frequency EGAM observed in LHD[1]. In this article, we focus on subject 2.

A multi-phase simulation[2], which is a combination of classical simulation and hybrid simulation for energetic particles interacting with a magnetohydrodynamic (MHD) fluid including neutral beam injection, slowing-down, and pitch angle scattering, was applied to DIII-D discharge #142111 where the fast ion spatial profile is significantly flattened due to multiple Alfvén eigenmodes (AEs). The large fast ion pressure profile flattening observed experimentally was successfully reproduced by these first of a kind comprehensive simulations[3]. Temperature fluctuations due to three of the dominant toroidal Alfvén eigenmodes (TAEs) in the simulation results were compared in detail with electron cyclotron emission measurements in the experiment. It was demonstrated that the temperature fluctuation profile and the phase profile are in very good agreement with the measurement, and the amplitude is also in agreement within a factor of two[3]. This level of agreement validates the multi-phase hybrid simulation for the prediction of AE activity and alpha particle transport in burning plasmas.

For the prediction of AE activity and energetic particle transport in burning plasmas, validation of simulations on the present experiments are important and indispensable. We have improved the simulation model from that used in Ref. 2 on two aspects; (1) we use an extended MHD model with thermal ion diamagnetic drift, and take account of the equilibrium toroidal flow; (2) we employ a more realistic beam deposition profile and power with the half and third beam energy components in addition to the full energy component. The total beam deposition power is increased to 6.25MW from 4.95MW used in Ref. 2.

Figure 1 compares the fast ion pressure profiles among the multi-phase simulation and the classical simulation, and the experiment. The fast ion pressure profile in the experiment is inferred from the Motional Stark Effect (MSE) constrained equilibrium reconstruction and the subtraction of the thermal pressure. We see in Fig. 1 that significant flattening of fast ion pressure profile takes place in the multi-phase simulation. Figure 2 compares the electron temperature fluctuations for the $n = 3$ TAE with those observed with the ECE measurements in the experiment. We see very good agreement in Fig. 2(a) for amplitude profile and absolute amplitude. We have also a remarkable agreement in phase profile shown in Fig. 2(b). The spatial variation of the phase indicates the shearing profile of electron temperature fluctuation in the poloidal plane. The shearing tail at the edge region is leading the rotation of the TAE.

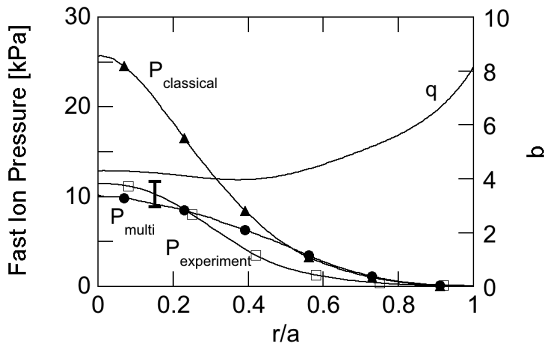

Fig. 1. Comparison of fast ion pressure profile among multi-phase simulation (circle), classical (triangle) simulation, and experiment (square) with an error bar shown in the figure.

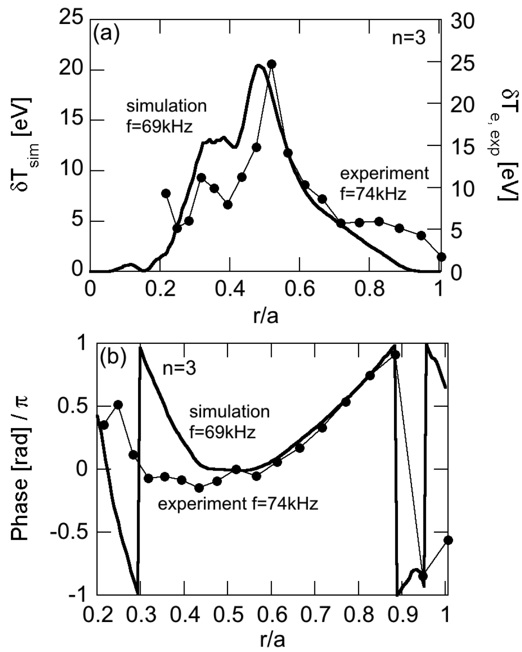

Fig. 2. Comparison of (a) electron temperature fluctuation profile and (b) the phase profile for $n = 3$ between simulation and experiment. Left vertical axis is for simulation, while right for experiment in panel (a).

1) Wang, H. *et al.*: 25th IAEA-FEC, 13-18 October 2014, St. Petersburg, Russian Federation, TH/P1-12.
2) Todo, Y. *et al.*: Nuclear Fusion **54** (2014) 104012.
3) Todo, Y. *et al.*: to appear in Nuclear Fusion **55** (2015).