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Validation and extension of kinetic-magnetohydrodynamics hybrid simulation for the prediction of burning plasmas

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Magnetohydrodynamics (MHD) is a one-fluid plasma model which is coupled with the electromagnetic field equations. MHD explains well the macroscopic behavior of laboratory, space, and astrophysical plasmas. However, MHD is an unfinished framework for magnetically confined fusion plasmas, because the MHD pressure equation assumes sufficiently high collision frequency which is not valid for the high-temperature plasmas. One typical example that requires an extension of MHD is energetic-particle driven instabilities. Kinetic-MHD hybrid simulations for energetic particles interacting with an MHD fluid are useful tools to understand and predict energetic particle driven MHD instabilities.

In this talk, recent progress of kinetic-MHD hybrid simulations of energetic-particle driven instabilities and MHD instabilities in magnetically confined plasmas is presented focusing on validation with experiments. We use MEGA code which is a kinetic-MHD hybrid simulation code for energetic particles interacting with an MHD fluid and has been recently extended with kinetic thermal ions [1,2].

The kinetic-MHD hybrid simulation was extended to the multi-phase simulation in order to simulate the energetic ion distribution formation process with neutral beam injection, collisions, losses, and transport due to the Alfven eigenmodes (AEs) with the energetic ion finite Larmor radius effect and the MHD nonlinearity retained [3]. The multi-phase simulation is a comprehensive simulation which deals with both the AEs and the energetic ion transport as self-consistently and realistically as possible.

Validation studies of MEGA code have been conducted for many tokamak (JT-60U/SA, DIII-D, TST-2, EAST, AUG, JET) and stellarator/heliotron (LHD, Heliotron J, CFQS, W7-X) plasmas. The spatial profiles and the frequencies of AEs were reproduced for a DIII-D experiment as well as the significant flattening of energetic ion pressure profile [4]. MEGA code was also validated on the bursting evolution of energetic-particle driven instabilities in JT-60U and LHD plasmas [5-7]. The frequency chirping and the sudden excitation of energetic-particle driven geodesic acoustic modes observed in LHD were also reproduced [8]. The LHD plasmas are stable in the experiments against pressure driven MHD instabilities beyond the theoretical threshold. The extended MEGA simulations with kinetic thermal ions revealed that the trapped thermal ions stabilize the instability and successfully solved the mystery of the “supercritical stability” of the LHD plasmas [9].

The successful validation studies indicate that MEGA is a useful tool for the prediction of burning plasmas. MEGA was also applied to ITER plasmas. For the steady-state scenario with 9MA plasma current, beta-induced Alfvén eigenmodes (BAEs) with low toroidal mode number (n=3, 5) were found to become dominant in the nonlinear phase as shown in Fig. 1 although many toroidal Alfvén eigenmodes (TAEs) with n~15 are most unstable in the linear growth phase [10]. In this talk, new simulation results of energetic-particle driven instabilities in ITER burning plasmas with kinetic fuel ions will be presented and compared with the previous results.

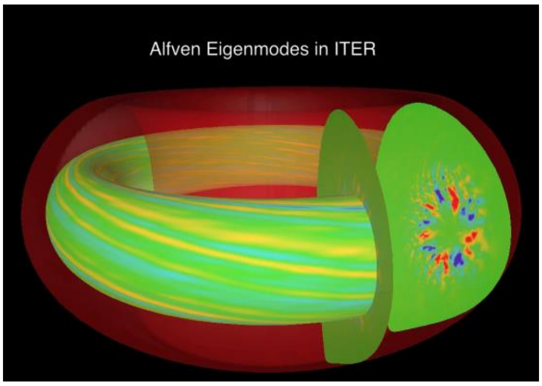

Figure 1. Alfven eigenmodes in ITER [10].

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