§2. Particle-MHD Simulation Study on Nonlinear Evolution of the Toroidal Alfvén Eigenmode

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In fusion reactors, successful confinement of alpha particles is required for self-sustained operation. The alpha particles born from D-T reactions can destabilize the macroscopic modes such as the toroidal Alfvén eigenmode (TAE mode) and the fishbone mode. Nonlinear behaviors of such hybrid kinetic-MHD modes and alpha particles are one of the major physics uncertainties for fusion reactors. We have developed two simulation codes, Vlasov-MHD code1) and particle-MHD code, to analyze hybrid kinetic-MHD modes. In both simulation codes the background plasma is described by an MHD fluid model, and the fully nonlinear MHD equations are solved by a finite difference method. The particle simulation technique is used for the alpha particle component in the particle-MHD code, while the drift kinetic equation is solved by a finite difference method in the Vlasov-MHD code. The contribution of the alpha particle current is extracted from the total current in the MHD momentum equation to take into account the effects of alpha particles on the background plasma in a self-consistent way. Nonlinear kinetic effects such as the particle trapping by a finite-amplitude wave which suppresses the Landau damping can be followed by these codes. The Vlasov-MHD code has an advantage that it is free from numerical noises of particle discreteness, though it demands larger computer power than the particle-MHD code. On the other hand, the δf method2) has been developed to reduce the numerical noises in particle simulations. We employ it in the particle-MHD code.

Particle-MHD simulations are carried out with more relevant conditions to fusion burning plasmas in order to confirm the saturation by particle trapping which is elucidated by the Vlasov-MHD simulation1). The initial alpha particle distribution is the slowing-down distribution which is isotropic in the velocity space with the maximum energy of 3.5 MeV. The magnetic field strength at the magnetic axis is 5T, the number density of the background plasma is 10^{20}m^{-3}, the minor radius is 0.9m, and the aspect ratio is 3. With different beta values of alpha particles (β_α) three simulation runs are carried out.

We focus on the n=2 mode as well as the Vlasov-MHD simulation1). Excitation and saturation of the most unstable TAE mode is observed [Fig. 1], and the spatial flattening of the alpha particle distribution takes place. For the volume average β_α of 0.33%, the saturation level is 1.6×10^{-3} with the linear growth rate of 1.1×10^{-2} ω_A and the mode frequency of 0.35 ω_A. We have confirmed two more evidences for that the particle trapping is the saturation mechanism:
a) the saturation level is in proportion to the square of the linear growth rate,
b) the toroidal canonical momenta of resonant particles show oscillatory behaviors after saturation, though they monotonically decrease (or increase) in the linear growth phase.

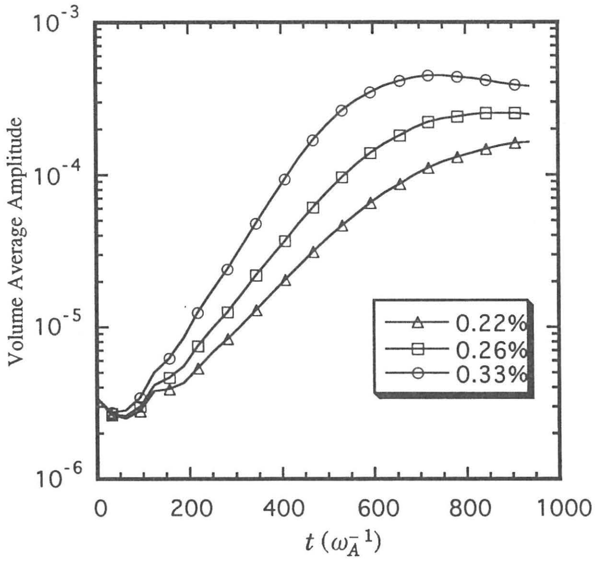

Fig. 1. Time evolution of the volume average amplitude of the TAE mode with three volume average β_α, 0.22%, 0.26%, and 0.33%.

References
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2) Parker, S. E. and Lee, W. W.: *Phys. Fluids* **B5**, (1993) 77.