§2. Linear and Nonlinear Simulation Study on 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. Linear and nonlinear particle-MHD simulation codes [1, 2] are developed to analyze hybrid kinetic-MHD modes. The background plasma is described by an MHD fluid model, and the MHD equations are solved by a finite difference method. The particle simulation technique is used for the alpha particle component. 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.

In the linear particle-MHD simulation code [2], the particle weight is a function of the toroidal angle. This new technique reduces required particle number. 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.

Resonance condition between energetic alpha particles and TAE mode is investigated with this code. Resonance condition for each particle can be expected as

$$l=(\omega_0-n\omega_\varphi)/\omega_b \quad (1)$$

where ω_0, ω_φ, and ω_b are the eigenfrequency of TAE mode, toroidal precession rate, and bounce frequency, respectively. In Eq. (1) n is the toroidal mode number (=2 in this report) and l is an arbitrary integer. From simulation results l is plotted for resonant alpha particles in Figure 1. Figure 1 shows that the values of l are actually close to integers. It is interesting to note that trapped particles also resonate with TAE mode.

With the same initial condition nonlinear simulations are carried out. Alpha particles are lost being induced by TAE mode. For β_α=3%, the fraction of lost particles is 1.2%. Initial distribution of lost alpha particles is shown in Figure 2. They distribute around the passing/trapped boundary. Counter-passing particles are lost when they cross the passing/trapped boundary. Trapped particles are also lost if they are close to the passing/trapped boundary. As investigated in the linear simulation trapped particles also resonate with TAE mode.

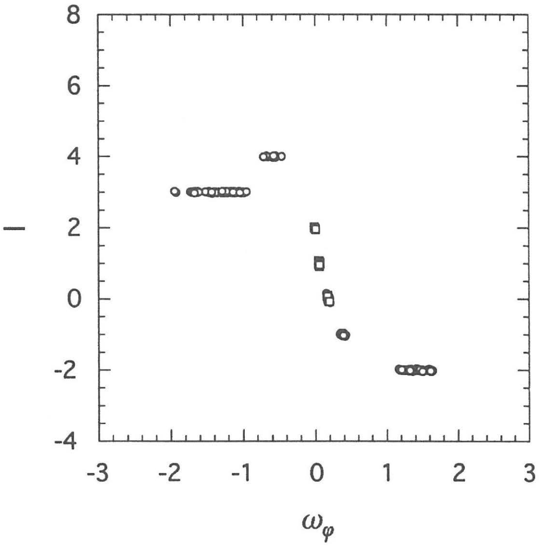

Fig. 1. Values of l which is defined by Eq. (1) are close to integers for resonant particles. Circles and squares denote passing particles and trapped particles, respectively. The horizontal axis is the toroidal precession rate.

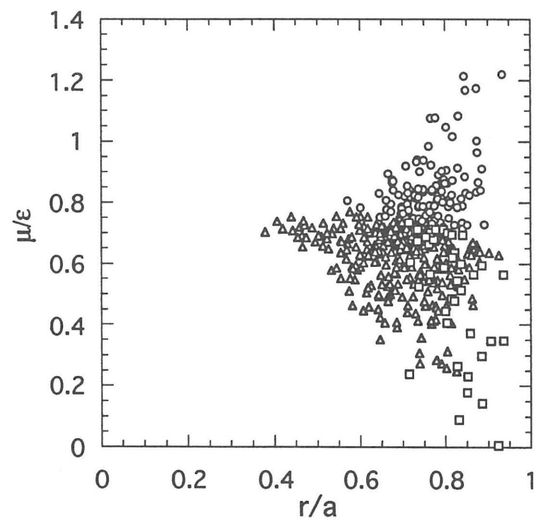

Fig. 2. Initial distribution of lost alpha particles in r-μ/ε plane. Triangles denote counter-passing particles which cross the passing/trapped boundary. Squares and circles represent the other passing particles and trapped particles, respectively.

References
1) Y. Todo, T. Sato, and The Complexity Simulation Group, IAEA Fusion Energy Conference CN-64/D2-3 (1996).
2) Y. Todo and T. Sato, *submitted to* J. Comput. Phys.