§11. Development of Macroscale Particle Simulation Code in a Toroidal System

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We developed an electromagnetic particle simulation code of a new full-implicit scheme to study MHD-scale phenomena in 3-dimensional toroidal fusion plasma, taking into accout particle effects. Electromagnetic field is temporally evolved through a full-implicit equation which guarantees consistency of the field with the charge and current density. The grid-size is not restricted by microscopic scales such as Debye length and skin depth. Furthermore, the time-step is not limited by plasma frequency.

We modify a macroscale simulation scheme which was proposed by Tanaka[1] making use of the guiding-center approximation both for ions and electrons. We consider the polarization drift to deal with MHD waves within the framework of the guiding-center approximation. The future electromagnetic field is solved implicitly, and the low-frequency electromagnetic waves with $\omega\Delta t \ll 1$ are properly reproduced, where ω is their characteristic frequency and Δt is the time step of the simulation.

As for the equation of motion, in addition to $\mathbf{E} \times \mathbf{B}$ drift, grad-B drift, and magnetic-curvature drift, the polarization drift is taken into account for perpendicular motion. For the parallel motion, the electric force and the mirror force are considered.

We numerically solved the Grad-Shafranov equation for the initial condition, and distributed the particles according to the solution. The aspect ratio is three. We set the density to be uniform for the initial condition, and realize the pressure gradient through the temperature gradient. The mass ratio of ion to electron is set to 1836. We use 1.6 million particles for electrons and ions, respectively. The numbers of grids in the cylindrical coordinate system are 65, 20, and 65 for $r-$, $\theta-$, and $z-$ directions, respectively. The grid sizes are $20c\omega_{\mathrm{pe}}^{-1}$ for Δr and Δz, and $2\pi/16$ for $\Delta\theta$. The time-step width is $2000\omega_{\mathrm{pe}}^{-1} \simeq 0.0146R/v_A$.

We tested our code against the MHD equilibrium of tokamak. We calculated up to $t = 30R/v_A$, and confirmed that the equilibrium is maintained. Furthermore, we analyzed the dispersion relation of shear Alfvén wave on each magnetic surface, and confirmed that it is consistent with the theory (Figure 1).

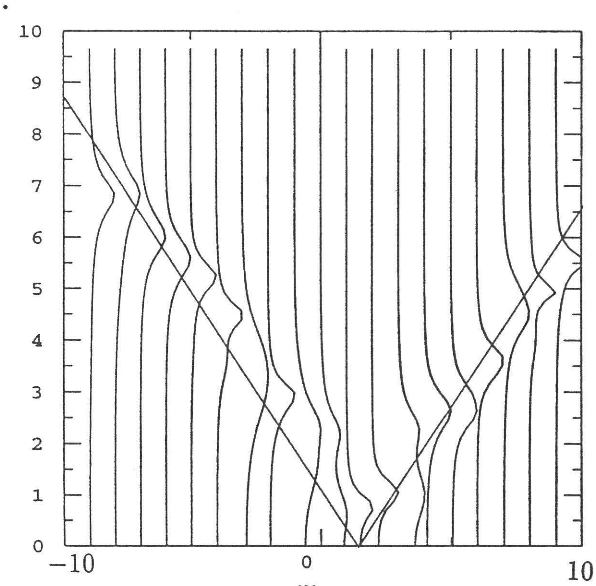

Fig. 1. The horizontal axis is the poloidal mode number, and the vertical axis is the frequency normalized by $\omega_A = v_A/R$. Each peak of a vertical line corresponds to the frequency of an $n = 1$ shear Alfvén wave in macroscale particle simulation. The V-shaped line is the theoretical dipersion relation $\omega = \omega_A|n - m/q|$ for the $q = 1.3$ magnetic surface.

References

1) Tanaka, M. : *J. Comp. Phys.* **107**(1993)124.