§7. MHD Infrastructural Code for Plasma Simulation: MIPS

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Magnetohydrodynamics (MHD) is a basic model of macroscopic behaviors of plasmas. MHD model is generally used for theoretical and computational analyses of fusion plasmas. For the purpose of promotion of collaborative simulation research, we have composed the MHD Infrastructural code for Plasma Simulation (MIPS). The MIPS code can be used for MHD simulation of toroidal plasmas and can be employed as a basis of extended-MHD simulations.

Recently, the Message-Passing-Interface (MPI) is the de facto standard of parallel programming language for computers with distributed memory. The MIPS code is parallelized with MPI so that the collaborators can immediately start MHD simulations on massively parallel computers. The collaborators can also refer to and use the parts of the MIPS code in order to reduce the time to compose and parallelize simulation codes.

The coordinates employed in the MIPS code are the cylindrical coordinates (R, φ, z). MHD equations described below are solved with the MIPS code.

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \mathbf{v})$$

$$\rho \frac{\partial}{\partial t}\mathbf{v} = -\rho\omega \times \mathbf{v} - \rho\nabla(\frac{v^2}{2}) - \nabla p + \mathbf{j} \times \mathbf{B} + \frac{4}{3}\nabla[\nu\rho(\nabla \cdot \mathbf{v})] - \nabla \times [\nu\rho\omega]$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

$$\frac{\partial p}{\partial t} = -\nabla \cdot (p\mathbf{v}) - (\gamma - 1)p\nabla \cdot \mathbf{v} + (\gamma - 1)[\nu\rho\omega^2 + \frac{4}{3}\nu\rho(\nabla \cdot \mathbf{v})^2 + \eta\mathbf{j} \cdot (\mathbf{j} - \mathbf{j}_{\mathrm{eq}})]$$

$$\mathbf{E} = -\mathbf{v} \times \mathbf{B} + \eta(\mathbf{j} - \mathbf{j}_{eq})$$

$$\mathbf{j} = \frac{1}{\mu_0}\nabla \times \mathbf{B}$$

$$\omega = \nabla \times \mathbf{v}$$

Here, μ_0 is the vacuum magnetic permeability, γ is the adiabatic constant, and $\mathbf{j}_{\mathrm{eq}}$ is the equilibrium current density. The spatial derivatives are calculated with a finite difference method of 4th-order accuracy. Runge-Kutta method of 4th order is used for the time integration.

The MIPS code was benchmarked on the ballooning modes in LHD. Viscosity and resistivity are $\nu = \eta/\mu_0 = 10^{-6}v_A R_0$ in the benchmark simulation. The results of the MIPS code were compared with those of the MHD linear analysis code CAS3D. The equilibrium analyzed was constructed with the HINT code in the rotating helical coordinates. The equilibrium data computed with the HINT code was transformed onto the cylindrical grid points of the MIPS code. The numbers of the grid points are (128, 640, 128).

The linear growth rates of the ballooning modes are compared between MIPS and CAS3D in Fig. 1. We see good agreement for low toroidal modes n≤7, while the MIPS simulation gives lower growth rates for n≥8 than the CAS3D analysis. The numbers of the poloidal grid points used in the MIPS code are not enough to resolve the spatial profiles of the higher-n ballooning modes. The spatial profiles of the ballooning mode with n=-3 are compared in Fig. 2. Good agreement between the MIPS simulation and the CAS3D analysis is seen again in Fig. 2. Then, we conclude that the MIPS code is a useful tool for simulation study of MHD instabilities in LHD.

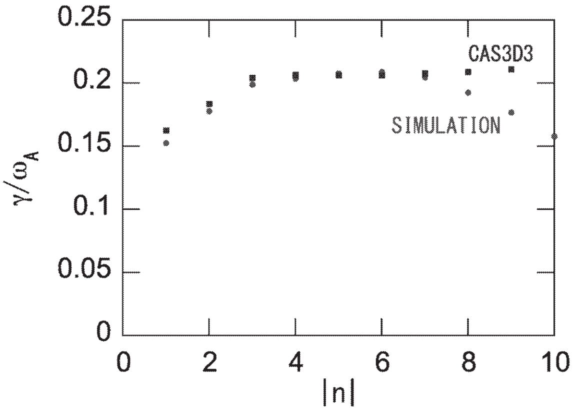

Fig. 1. Comparison of ballooning mode growth rate between MIPS (red circles) and CA3D (blue squares) for different toroidal mode numbers.

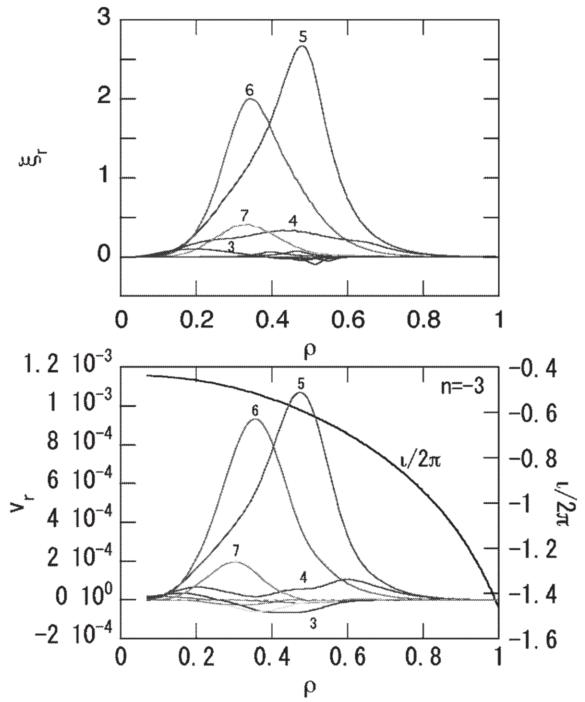

Fig. 2. Comparison of spatial profiles between the CAS3D analysis (top) and the MIPS simulation (bottom) for the ballooning mode with toroidal mode number n=-3.