§9. MHD Infrastructure Code MIPS

Todo, Y., Nakajima, N., Sato, M., Miura, H.

Magnetohydrodynamics (MHD) is a basic model for macroscopic behaviors of plasmas and is generally used for theoretical and computational analyses of fusion plasmas. The MHD simulation code, MIPS (MHD Infrastructure for Plasma Simulation) can be applied to toroidal plasmas and can be employed as a basis of extended-MHD simulations. We performed the benchmark test of the MIPS code[1] on the ballooning instability in the Large Helical Device (LHD). Recently, we have implemented into the MIPS code an extended-MHD model presented by Hazeltine and Meiss. It is interesting to investigate how the ballooning modes are affected with the ion finite Larmor radius effects that are retained in the Hazeltine-Meiss model. We compared the results to the MHD results.

The coordinates employed in the MIPS code are the cylindrical coordinates (R, φ, z). The numbers of the grid points are (128, 640, 128). The MIPS code is parallelized with the Message-Passing-Interface (MPI). The computational performance of the MIPS code using 32 cores of POWER6 processor (5.0 GHz) on the Plasma Simulator of NIFS (HITACHI SR16000) is 82Gflops. This is 13% of the theoretical peak performance. The linear growth rates of the ballooning modes in the MIPS simulation are compared with the CAS3D analysis in Fig. 1. The growth rate is normalized by the Alfvén frequency $\omega_A = \mathrm{v}_A / R_{\mathrm{axis}}$. We see good agreement for low toroidal modes n≤7, while for n≥8 the MIPS simulation gives lower growth rates than the CAS3D analysis. The numbers of the poloidal grid points used in the MIPS code may not be enough to resolve the spatial profiles of the higher-n ballooning modes. The finite viscosity and resistivity assumed in the simulation is another factor of the lower growth rate for higher-n modes. Good agreement was found also in the spatial profiles of the ballooning modes between the MIPS simulation and the CAS3D analysis. Then, we can conclude that the MIPS code is a useful tool for simulation study of MHD instabilities in LHD.

The extended-MHD model presented by Hazeltine and Meiss was implemented in the MIPS code. The electron and ion pressure are assumed equal to each other. The Hazeltine-Meiss model looks similar to the MHD equations. However, we should note that the ion finite Larmor radius effects are retained in the Hazeltine-Meiss model. The ballooning mode growth rate and real frequency in the LHD plasma investigated with the MHD and Hazeltine-Meiss models are shown in Fig. 2. Two cases of hydrogen plasma were investigated with the Hazeltine-Meiss model for different ion number densities n_i=1.6×10^{19}m^{-3} and n_i =4×10^{18}m^{-3}. We see in Fig. 2 the reduced growth rate and the finite frequency for the Hazeltine-Meiss model. The difference from the MHD results is greater for the lower density case and higher mode numbers. For the lower density case with n_i =4×10^{18}m^{-3}, the most unstable mode is n=-3 and the growth rate of the middle- and higher-n (|n|≥4) modes are significantly reduced. For the moderate density case with n_i =1.6×10^{19}m^{-3}, the most unstable mode is n=-5 and the growth rate of the higher-n (|n|≥6) modes are more reduced than the lower-n modes. We can say that the most unstable toroidal mode number of the ballooning instability in LHD hydrogen plasma is reduced with the Hazeltine-Meiss model to $|n| \leq 5$ for ion number density $n_i \leq 10^{19}\,\mathrm{m}^{-3}$.

Let us consider what yields the difference from the MHD model. It was predicted that the ion diamagnetic drift has the stabilizing effect on the MHD instabilities and gives the MHD instability a finite frequency of a half of the ion diamagnetic drift frequency ω_{*i}[2]. The stabilizing effect is stronger for higher ω_{*i} and the instability is stabilized when ω_{*i} is twice the ideal MHD growth rate. The results shown in Fig. 2 indicates that the ion diamagnetic drift effects reduce the growth rate of the short wavelength modes so that the modes with the diamagnetic drift frequency comparable to the ideal MHD growth rate ($\omega_{*i} \sim \gamma_{\mathrm{MHD}}$) are most unstable.

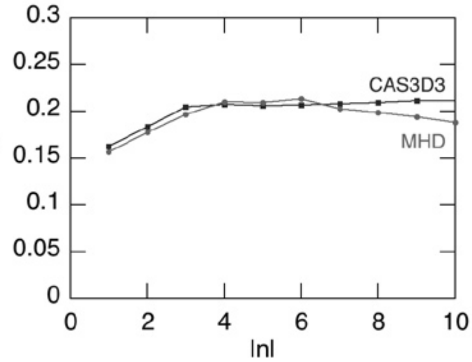

Fig. 1. Comparison of ballooning mode growth rate between MIPS (red circles) and CA3D (blue squares) for different toroidal mode numbers.

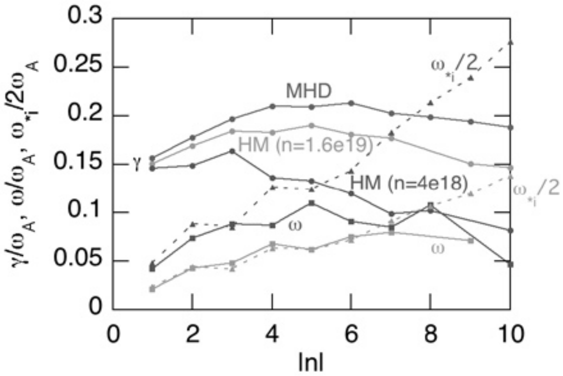

Fig. 2. Growth rate and frequency of the ballooning instabilities in LHD vs. toroidal mode number. Results simulated with the MHD model is shown in red while the Hazeltine and Meiss model results for hydrogen plasma are shown in orange (n_i=1.6×10^{19}m^{-3}) and green (n_i =4×10^{18}m^{-3}). Dashed curves represent $\omega_{*i}/2$.

1) Y. Todo *et al.*, *Simulation study of ballooning modes in LHD*, to appear in Plasma Fusion Res. **5** (2010).
2) N. Nakajima *et al.*, Nucl. Fusion **46**, 177 (2006).