§33. Simulation of Global MHD Phenomena by the Gyrokinetic PIC Code

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Full understanding of experimentally observed global magnetohydrodynamic (MHD) phenomena in high temperature tokamak plasmas, inevitably requires investigations by the kinetic theory and simulation. The electromagnetic gyrokinetic PIC (particle-in-cell) code is able to simulate these phenomena without the "closure" problem. However, it needs huge computer resources. In addition to the development of advanced algorithm, parallelization of gyrokinetic PIC codes on state-of-the-art massive parallel computers is the crucial subjects.

More than a decade ago, we developed a gyrokinetic PIC code, gyr3d,[1,2] in the three dimensional (3d) rectangular coordinate system. Recently we developed a gyrokinetic PIC code for MHD simulation, Gpic-MHD,[3] for cylindrical geometry. In addition to 3d Gpic-MHD with multi-helicities, we have 2d Gpic-MHD with a single helicity assumption.

To simulate larger scale and higher beta plasma, the extension of the split-weight scheme was proposed as the improvement of the conventional δf -scheme. We proposed an alternative algorithm, which uses the vortex equation and generalized Ohm's law along the magnetic field for the time integration of field quantities.[4,5] The basic algorithm is equivalent to solve reduced-MHD-type equations with kinetic corrections. The dominant kinetic term is the perturbed electron pressure estimated by particle dynamics. We verified that the 2d Gpic-MHD with the advanced scheme could successfully simulate the $m=1$ and $n=1$ kinetic internal kink mode in larger scale and higher beta tokamaks as shown in Fig.1.

The standard version of 3d Gpic-MHD with conventional δf -scheme has been used as the benchmark code to study parallelization performance of various massive-parallel computers. The 1d domain decomposed version uniformly breaks up the total simulation domain in the axial direction. Parallelization performance on Altix3700Bx2 was studies.[3] Recently, performance of 3d Gpic-MHD on SR16000 was studied.[6,7] The hybrid parallel programming model of thread parallel and process parallel is used. The total simulation domain is decomposed in 1d (axial) or 2d (radial and axial) directions. Replicas of field quantities are used to utilize logical cores larger than the number of subdomains. Each process treats one subdomain, which includes the approximately same number of particles. The highest speed of Gpic-MHD for the fixed number of logical cores was obtained for two threads, the maximum number of axial decomposition and optimum combination of the numbers of radial decomposition and replicas. Figure 2 shows "strong scaling" of FLOPS depending on the number of logical cores with $1025\times128\times128$ mesh with 8.192 billion particles.

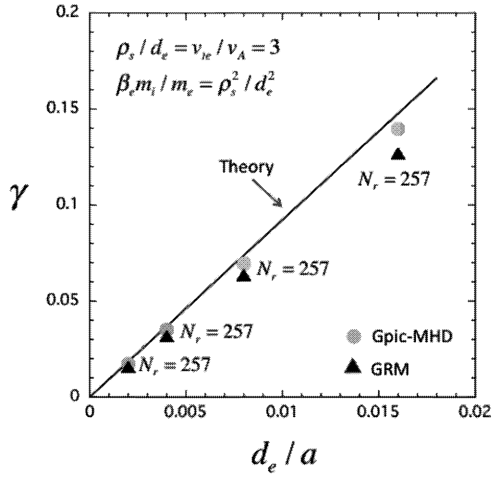

Fig. 1. Growthrates of the collisionless internal kink mode versus normalized skin depths.

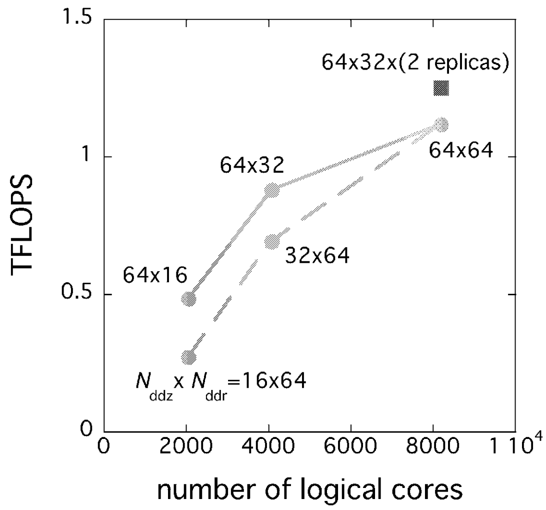

Fig. 2. FLOPS versus number of logical cores.

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2) Naitou, H. et al.: J. Plasma Fusion Res. **72** (1996) 259
3) Naitou. H. et al.: J. Plasma Fusion Res. SERIES **8** (2009) 1158
4) Naitou, H. et al.: Bull. APS 51th Annual Meeting of DPS **54** (2009) 35
5) Naitou, H. et al.: submitted to Plasma Science and Technology
6) Naitou, H. et al.: Plasma and Fusion Res. **6** (2011) 2401084
7) Naitou, H. et al.: accepted for publication in Progress in Nuclear Science and Technology