Development of electromagnetic particle code using adaptive mesh refinement technique: Application to the Earth magnetotail

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It is widely believed that magnetic reconection plays an important role in the magnetospheric substorm and the solar flare. However, physical processes around the diffusion region are not well understood. Recently, it has been suggested that multi-scale coupling process should be important in the reconnection triggering and the anomalous plasma heating and acceleration around the diffusion region. Now, it is necessary to conduct a self-consistent large-scale simulation including phenomena with various scales to describe multi-scale coupling. However, a realization of such a simulation with an ordinary PIC technique is still difficult because electron-scale phenomena are very localized in ion-scale or MHD-scale system.

To overcome this difficulty, we have developed a new electromagnetic particle code with adaptive mesh refinement (AMR) technique. The AMR technique dynamically subdivides the cells that satisfy a refinement criterion and effectively achieves high-resolution simulations. Actually, it is only in the vicinity of the central current sheet where high-resolution simulations are required and we can reduce the number of cells in the lobe region where plasma density is low so that both the electron Debye length and a characteristic scale length are large. With AMR technique, it is expected to realize self-consistent multi-scale simulations.

One of the main problems in developing the electromagnetic particle code using the AMR is decrease in the number of particles per cell in the refined regions. Especially, in the vicinity of the X-line, high-resolution simulations are required because the kinetic effects of electrons are expected to be important. However, the number density of plasma in such a region is low due to inflow of the tenuous plasma in the lobe region, so that the number of particles per cell is decreased and the numerical noise is increased. In order to solve the problem, we subdivide particles (superparticles) residing in the subdivided cells and control the number of particles per cell. As a result, we find that the number of particles in the vicinity of the X-line is enough to describe the electron-scale structures, for example, the double-peak current sheet due to the meandering motions of electrons. We also confirm that the width of the electron diffusion region, the outflow velocity of electrons, and the intensity of the inductive electric field are consistent with those in other reconnection simulations conducted by full particle codes, even though in our code the most refined cells are distributed only around the X-line so that the numbers of cells and particles are greatly reduced. Thus we conclude that we have realized effectively high-resolution simulations on the evolution of the plasma sheet by the use of the AMR technique and the particle splitting-coalescence algorithm.

In this paper, we will describe the AMR technique and the particle splitting-coalescence algorithm used in our code, and discuss the efficiency of our code in case of simulations of the plasma sheet evolutions comparing with the conventional particle codes.