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An open boundary condition in the AMR-PIC simulations of magnetic reconnection

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One of the main issues on magnetic reconnection processes is the mechanism breaking the frozen-in condition around the x-line and providing the electric resistivity in collisionless plasmas. It has been recognized empirically in magnetohydrodynamic simulations that the Petschek-type fast reconnection can be achieved only when an intense resistivity arises locally near the x-line. However, the generation mechanism of the resistive effects in collisionless plasmas is poorly understood in the kinetic framework. In 2D reconnection, it has been demonstrated by kinetic simulations that the momentum transport due to the Speiser-type motion of the electrons around the x-line gives rise to the so-called inertia resisticity which results in the electron viscosity term in the generalized Ohm's law. Although the electron viscosity gives sufficient dissipation for supporting the reconnection electric field under the thin current layer on the order of the electron inertia length, such a thin current sheet has been observed neither in the laboratory experiments nor in the geomagnetosphere. Recent 3D particle-in-cell (PIC) simulations with the adaptive mesh refinement (AMR) have revealed that an electromagnetic turbulence in the current density direction gives rise to significant anomalous dissipation in association with plasmoid formations and enhances the effective width of the current sheet. However, the observations in space and laboratory have shown even wider current sheet during the fast reconnection, which implies the existence of more intense turbulence. It is reasonable to expect that, in a much larger system in the current density direction, the plasmoid formations are more three dimensional, which results in more turbulent current sheet.

The previous AMR-PIC simulations of magnetic reconnection have employed the periodic boundary condition in the outflow direction and the conducting wall condition in the upstream direction. These boundary conditions have an advantage that the implementation is easy, but they require very large system size for one to investigate the quasi-steady reconnection processes. Furthermore, the particles split around the x-line accumulate eventually in the downstream region, so that the number of the super-particles in the system increases as reconnection goes on. In order to achieve more efficient simulations of quasi-steady reconnection, we have developed an open boundary condition for the AMR-PIC model both in the downstream and upstream directions. The open boundary condition allows the particles and magnetic flux to leave the system in the downstream direction and to enter the system in the upstream direction. There are two advantages of using the open boundary condition: the first is to enable us to shrink the system size drastically in the reconnection plane, and the second is that the total number of the super-particles in the system is decreased. As a result, the redundant computer resources can be used to increase the system size in the out-of-plane direction. We expect that by using the open boundary condition one can obtain one order larger system size in the current density direction.

In this paper, we show initial results of the 2D AMR-PIC simulations of magnetic reconnection under the open boundary condition. It is described that the initial current sheet plasma is removed from the system and quasi-steady reconnection is achieved. By comparing to the results of the previous AMR-PIC simulations, we will discuss the efficiency by using the new boundary condition.

Keywords: magnetic reconnection, AMR-PIC model, open boundary, turbulence