§1. Particle Simulation Study of Merging Process of Two Spheromaks

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In order to investigate physics of magnetic reconnection such as kinetic triggering mechanism, plasma heating, particle acceleration and so on, merging experiments of spheromaks and spherical tokamaks have been performed in many experimental plasma devices such as TS-3 and MAST [1]. On the other hands, various particle and magnetohydrodynamic (MHD) simulations have been carried out for the same purpose in simple slab geometry. As a result, common pictures of magnetic reconnection have been extracted from the experiments and numerical simulations. However, their close comparison did not be done due to big gaps between the simulation models and the experimental devices as yet. In this study multi-scale simulation model is developed in the cylindrical system for realizing more close comparison between experimental and simulation results and extracting more fruitful common pictures of magnetic reconnection.

Suppose that plasmas are confined in a conducting vessel with a central conductor. Simulation domain is implemented on a (256×2048) space grid in two-dimensional cylindrical coordinates (r,z), assuming that physical quantities are axially symmetric ($\partial/\partial\phi = 0$). The simulation model is based on the domain decomposition method [2] in which particle-in-cell (PIC) model is applied to a central reconnection region, while transfer process of two spheromaks outside the reconnection region is described by MHD model. Reconnection region, where two spheromaks can merge, has a disk structure with the width of several ion Larmor radii along the geometric axis.

Two-dimensional low-beta equilibrium solution, which satisfies Grad-Shafranov equation, is adopted for an initial profile. The equation of state satisfying the adiabatic condition with the ratio of specific heats $\gamma(=5/3)$ is assumed in an initial profile. Two spheromaks with opposite magnetic helicity and opposite average velocity are located far from the reconnection region, as shown in Fig. 1. In the MHD region the frozen-in condition is satisfied inside the plasma, i.e., $\mathbf{E}+\mathbf{v}\times\mathbf{B}=\mathbf{0}$. Two spheromaks behave as an incompressible fluid outside the reconnection regions and approach to each other as time goes on. For the PIC simulation we have typical following parameters; total number of particles $N_{pt} = 20480000, \beta = 0.01, \omega_{pe}/\omega_{ce} = 2, R_{in} = 0.2R_l$, $M_i/M_e = 100, Z_l/R_l = 8, \rho_i/R_l = 0.058$, where Z_l R_l , R_{in}, and ρ_i are axial and radial sizes of simulation domain, radius of central conductor, and typical ion Larmor radius, respectively.

Figure 1 shows the mass density profile (color maps) and magnetic flux profile (lines) at initial (top) and reconnection (bottom) phases for the reconnection region with the width of four Larmor radii along the geometric axis. Two spheromaks with opposite magnetic helicity collide in the central reconnection region at $\omega_{ce}t = 805$. Toroidal current with opposite sign to that of the spheromak current, namely, reconnection current is generated near the contact surface of two spheromaks, as shown in Fig. 2. The reconnection current drives the change in magnetic field topology and plasma heating (see top panel of Fig. 2). We also observed the generation of quadra-pole structure in toroidal magnetic field through the Hall effect. These results are consistent with the previous experimental and simulation results [1, 3].

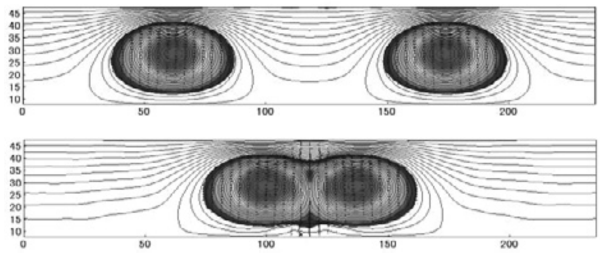

Fig.1 Mass density profile (color maps) and magnetic flux profile (lines) at initial (top) and reconnection (bottom) phases.

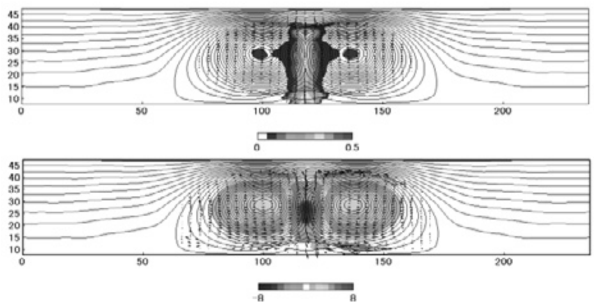

Fig.2 Ion temperature profile (top) and toroidal current density profile (bottom) at $\omega_{ce}t = 805$.

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