§15. Particle Simulations of Collisionless Magnetic Reconnection: Roles of Electron Inertia

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The origin of electrical resistivity - an ad hoc assumption of magnetic reconnection in MHD studies, has remained the major questions of plasma physics for more than two decades. As the most possible candidate, the electron inertia was theoretically invoked without a proof [1,2]. For the purpose of its proof, particle simulations have been performed here using the low-frequency (implicit) particle simulation code of two-dimensions [3]. For the physical model, a coalescence of two flux bundles carrying the same directional current is used with /without a background "toroidal" magnetic field [4,5].

The toroidal electric field is generated by magnetic induction in a broad region containing the X-point, and an elongated current sheet whose width is a few electron skin depths, $L_B \cong 3c/\omega_{pe}$, is formed (Fig.1). The toroidal current and electric field undergo the same exponential growth at the X-point before reconnection sets in, as shown in Fig.2; they saturate to maintain the Ohm's law-like relationship $E_t \propto J_t$ when magnetic reconnection has started. Sub-Alfvenic plasma outflow off the reconnection region is generated in the poloidal plane which spreads within the dual fans originating at the X-point. The parallel distribution functions of electrons shows a significant toroidal acceleration without thermalization, which results in their streaming and transport along the magnetic field line. Absence of the Joule heating is consistent with that the simulations are carried out in collisionless plasmas [5].

The electron transport due to the parallel streaming is proved to enhance the reconnection rate a few times by comparing the runs that either (a) permits or (b) prohibits the streaming [5]. In fact, the reconnection rate in Fig.2 (case (a)) is $d\Psi/dt \sim -0.23\Psi^{(0)}\tau_A^{-1}$, whereas it reduces to $-0.09\Psi^{(0)}\tau_A^{-1}$ for the case (b). Moreover, the finite Larmor radii of ions do not play roles in determining the reconnection rate [4,5] for the linear reconnection regime with $\Delta\Psi \sim t$.

Thus, the series of the simulations reveal that the collisionless reconnection is mediated by rapid pump-out (limiting) of the X-point current in which transit electron acceleration under the finite inertia takes a decisive role.

References

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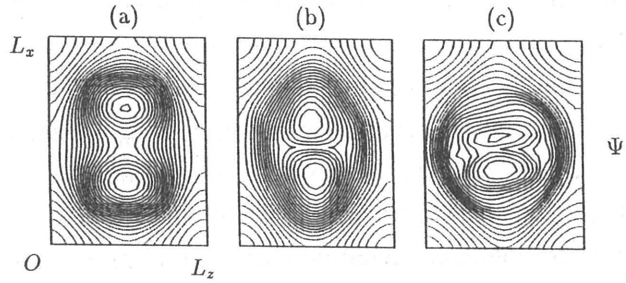

Fig. 1. The poloidal magnetic flux function Ψ for the initial time, just before, and after the commencement of reconnection.

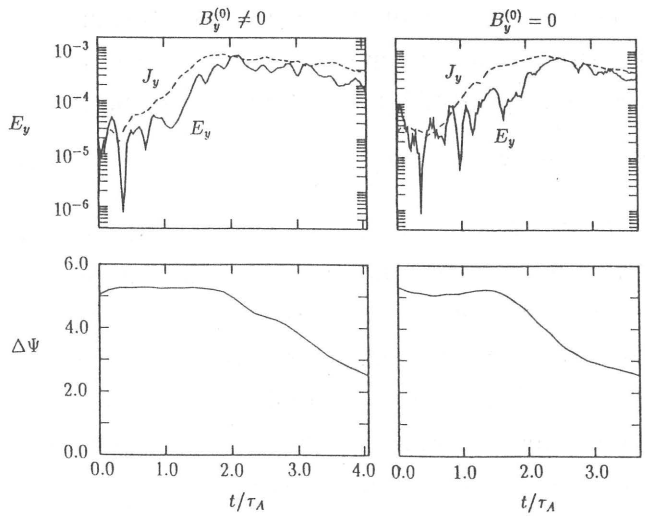

Fig. 2. Time histories of the toroidal electric field E_y (solid) and current J_y (dashed) in the upper panel; that of the isolated poloidal flux $\Delta\Psi$ (solid) in the lower panel. The ambient toroidal magnetic field is either absent (right,[4]) or present (left,[5]).