§20. Structure of Ion Dissipation Region of Driven Reconnection in An Open System

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Magnetic reconnection plays an important role in plasmas, and leads to the fast energy release from magnetic field to plasmas and the change of magnetic field topology. We develop a three-dimensional PArticle Simulation code for Magnetic reconnection in an Open system (PASMO) [1,2]. Ions become un-magnetized and execute a complex thermal motion called meandering motion in the ion dissipation region. The complex meandering (chaotic) motion leads to the growth of off-diagonal components of pressure tensor term, which is a main cause to break ion frozen-in condition in the vicinity of magnetic neutral sheet [3]. In this paper we investigate the role of the meandering motion in the formation of ion dissipation region by examining particle simulation results of collisionless driven reconnection based on the following simple model.

Figure 1 shows the spatial profiles of magnetic field (B_x and B_y) at the steady state. Because B_x and B_y change linearly in the vicinity of the reconnection point ($x = 0$ and $y = 0$), the magnetic field can be written as

$$B_x = B_x^{'} y, B_y = B_y^{'} x, \qquad (1)$$

where $B_x^{'}$ and $B_y^{'}$ are constant. Using these equations, the local ion Larmor radius ρ_L is written as

$$\rho_L(x) = \frac{mv_\perp}{eB_y} \simeq \frac{mv_{th}}{eB_y^{'} x}, \qquad (2)$$

$$\rho_L(y) = \frac{mv_\perp}{eB_x} \simeq \frac{mv_{th}}{eB_x^{'} y}, \qquad (3)$$

where v_{th} is the thermal velocity. The spatial size L_{mi} of the meandering motion is determined from the location which satisfies the relation [1]

$$L_{mi} = \rho_L(L_{mi}). \qquad (4)$$

If the size of the dissipation box is equivalent to the meandering motion amplitude, the length x_c and width y_c are obtained from Eqs. 1, 2, 3 and 4 as

$$x_c^2 = \frac{m_i v_{th}}{eB_y^{'}}, \qquad (5)$$

$$y_c^2 = \frac{m_i v_{th}}{eB_x^{'}}. \qquad (6)$$

These x_c and y_c are shown in Figs. 1 and 2.

Next we discuss the relation between the width y_c of dissipation region and the ion pressure tensor Π^i. Figure 2 shows the profiles of terms of the force balance equation for ion

$$E_z + (u^i \times B)_z = \{\frac{\partial}{\partial t} + (u^i \cdot \nabla)\} u_z^i + \frac{1}{en^i} \nabla \cdot \Pi^i, \qquad (7)$$

where u^i is ion flow velocity. It is found that the pressure tensor term $\frac{1}{en^i}\frac{\partial \Pi_{yz}}{\partial y}$ mainly supports the electric field E_z around the reconnection point ($x = 0$). Let us consider writing down $\frac{1}{en^i}\frac{\partial \Pi_{yz}}{\partial y}$ as a function of y. The pressure tensor Π_{yz}^i is approximately given by

$$\Pi_{yz}^i \sim \int dv\ m^i v_y v_z f^i, \qquad (8)$$

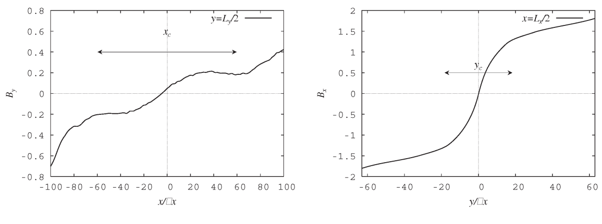
where f^i is the distribution function. Because the velocity v_y and v_z are given by $E \times B$ drift and thermal velocity v_{th} in the outside of dissipation region ($|y| > y_c$) respectively,

$$\Pi_{yz}^i \sim \frac{m^i n^i E_z B_x v_{th}}{B_x^2 + B_y^2}. \qquad (9)$$

Because B_x also changes linearly in $|y| > y_c$ (Fig. 1(b)), we can substitute Eq. 1 into Eq. 9. The pressure tensor term in Eq. 7 is given by

$$\frac{1}{en^i}\frac{\partial \Pi_{yz}^i}{\partial y} = -\frac{1}{en^i}\frac{m^i n^i E_z B_x' v_{th}(B_x'^2 y^2 - B_y^2)}{(B_x'^2 y^2 + B_y^2)^2}. \qquad (10)$$

This analytic solution is drawn in Fig. 2. It is clear that the tendency of this solution is in agreement with that of the simulation result. When we substitute y_c into y in Eq. 10 and ignore the term B_y because $B_x \gg B_y$, Eq. 10 is reduced to $-E_z$. In concluding, we can make sure that the ion orbit effect controls the physics in the ion dissipation region from this simple analysis.



(a) B_x. (b) B_y.

Fig. 1. Spatial profiles of magnetic field at the steady state ($t\omega_{ce} = 806$). (a) B_x along y direction and (b) B_y along x direction. L_x and L_y are the simulation box sizes.

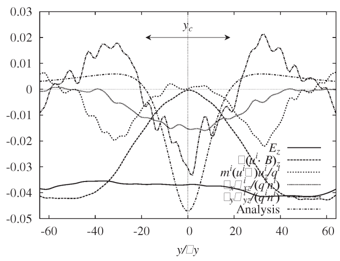


Fig. 2. Width of dissipation region and spatial profiles of force balance at the steady state.

Reference
1) Pei, W. et al.: Phys. Plasmas, **8**, 3251 (2001).
2) Ohtani, H. et al: LNCL.
3) Ishizawa, A. and Horiuchi, R. : PRL, **95** 045003-1 (2005).