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§25. Simulation Study of Nonlinear Dynamics in Plasmas with Flows

Yoshida, Z., Numata, R., Furukawa, M., Hori, D., Ohsaki, S. (Graduate School of Frontier Sciences, The University of Tokyo), Hayashi, T.

Flows, which universally exist in plasmas, couple with magnetic fields and create various fascinating structures. Driven magnetic reconnection is a typical example of such flow-magnetic field coupled system.

In a high-temperature collisionless plasma, such as the solar corona, the rate of magnetic reconnection (diffusion) is so small that the ideal magnetohydrodynamics (MHD) model applies in a macroscopic scale. The reconnection speed, however, is much higher if a small scale structure is created. In a small scale, dissipation due to ion chaotic motion plays an important role. A theory of fast reconnection requires self-consistent explanations of the structure bridging the macro and micro scale hierarchies. The Hall-MHD model can describe such a "mesoscopic" hierarchy. The Hall term added to the Ohm's law as a singular perturbation introduces an intrinsic length scale, viz., the ion skin depth ℓ_{i}. The ℓ_{i} is the scale where ion exhibits chaotic motion. The chaos of particle orbit yields a collisionless resistivity (referred to as the chaos-induced resistivity) when the system of particles are viewed as a plasma.

In this study, we consider the Hall-MHD model including the chaos-induced resistivity. The Ohm's law is generalized as follows,

$$\boldsymbol{E} + \left(\boldsymbol{V} - \frac{\epsilon}{n}\nabla\times\boldsymbol{B}\right)\times\boldsymbol{B} = \frac{\eta}{R_{\mathrm{m}}}\nabla\times\boldsymbol{B} \qquad (1)$$

$$\eta(\boldsymbol{x},t) := 1 + \sum_j \alpha\exp\left(-\frac{1}{\epsilon^2}|\boldsymbol{x}-\boldsymbol{x}_j(t)|^2\right), \qquad (2)$$

where ϵ is the ratio of the ion skin depth to the system size, R_{m} is the magnetic Reynolds number, α is the magnitude of the chaos-induced resistivity, and $\boldsymbol{x}_j(t)$ is the position of the magnetic nulls. Because the magnetic nulls move as the field changes, the resistivity has dynamic inhomogeneous distribution.

We have performed simulations using the code developed in [1] to study the effect of the Hall term and the chaos-induced resistivity. The parameters for the simulations are summarized in Table. I. Figure 1 shows the reconnection rate at the center of the dissipation region. The reconnection rate for $\alpha \neq 0$ is significantly large compared with that for $\alpha = 0$.[2] We also observe that intermittent bursts of the reconnection rate occur corresponding to the sudden enhancement of the resistivity. Figure 2 shows the out-of-plane current distribution obtained by the Hall-MHD model with the chaos-induced resistivity. We see that the X-type structure is formed. The current sheet is formed in other cases. Only the Hall term or the chaos-induced resistivity does not lead the X-shaped configuration. We conclude that the Hall effect co-operates with the chaos-induced resistivity to yield such an X-type structure and leads the fast magnetic reconnection.

Table 1: Parameters for simulation. Taking $\alpha > 0$, the resistivity is enhanced ($\eta_{\max}$ is the maximum of the enhancement factor.)

Run	A	B	C	D	E	F
ϵ	0	0.1	0.1	0.1	0.05	0.05
α	0	0	1	0.1	0	1
($\eta_{\max}$)	1	1	3	1.2	1	3

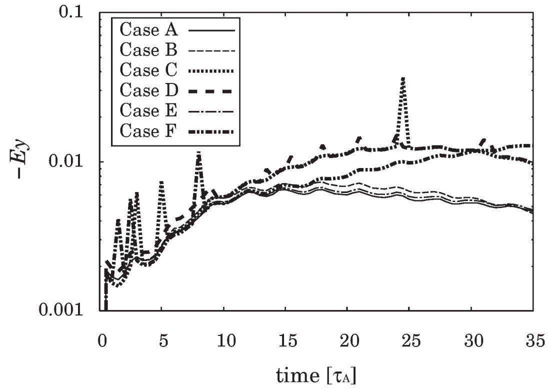

Fig. 1: Reconnection rate measured by the electric field at the center of the dissipation region.

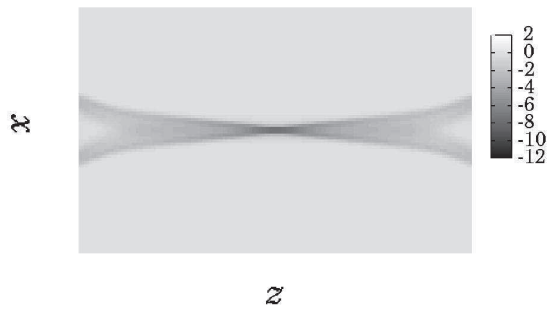

Fig. 2: X-type structure is obtained by using the Hall-MHD model with the chaos-induced resistivity.

References

1) Numata, R., Yoshida, Z., Hayashi, T. : J. Plasma and Fusion Res. SERIES 6 (2004) 130 ; Numata, R., Yoshida, Z., Hayashi, T. : Comput. Phys. Commun. 160 (2004) 291.

2) Numata, R., Furukawa, M., Yoshida, Z. and Hayashi, T. : submitted to Phys. Rev. Lett.