Theoretical description of explosive magnetic reconnection in collisionless two-fluid models

M. Hirota[1], Y. Hattori[1] and P. J. Morrison[2]

[1]Institute of Fluid Science, Tohoku University, Sendai, Miyagi 980-8677 Japan

[2]Department of Physics, Institute for Fusion Studies, University of Texas at Austin, Austin, TX 78712, USA

A mechanism for explosive magnetic reconnection is investigated by analyzing nonlinear and non-quasi-steady evolution of collisionless tearing instabilities in two-fluid models. For simplicity, we revisit the effects of electron inertia and electron temperature that bring in two microscopic scales; the electron skin depth d_e and the ion-sound gyroradius ρ_s, respectively. It is known that an elongated current sheet with Y-shaped ends is formed in the presence of only electron inertia ($d_e \neq 0, \rho_s = 0$), whereas the X-shaped current sheet is formed when the effect of electron temperature is taken into account $\rho_s \gtrsim d_e$. Although several pioneering works [1,2] have attempted to explain the explosive growth of the nonlinear tearing mode, we note that their predictions do not agree quantitatively with our high-resolution simulation results. In previous work [3], we have considered only the effect of electron inertia (namely, the Y-shape) and estimated the explosive growth rate by using a new variational method. This theory is also generalized to the case of the X-shape in the present work.

The concept of our variational method is inspired by the ideal MHD Lagrangian theory, in which the magnetic energy is considered to be part of the potential energy of the dynamical system. If an ideal fluid displacement keeps decreasing the magnetic energy, it is likely to grow by gaining the corresponding amount of the kinetic energy, and the most unstable displacement would decrease the magnetic energy most effectively. This argument assumes that the two-fluid effects are locally essential for changing the topology of magnetic field lines, but their impact on the global energy balance is negligible. By choosing a proper fluid displacement as a trial function, we can estimate the growth rate of the displacement, which is indeed explosive and agrees with the simulation results.

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