A theoretical model of steady-state magnetic reconnection in a collisionless incompressible plasma based on the Grad-Shafranov equation solution

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The problem of steady-state magnetic reconnection in an infinite current layer in a collisionless, incompressible, nonresistive plasma, except of the electron diffusion region, is examined analytically using the electron Hall magnetohydrodynamics approach. This method of plasma description is considered to be applicable in the nearest vicinity of the electron diffusion region, where the electric current is formed by electrons. The scale of this region is defined by the proton inertial length (proton skin-depth) whereas the diffusion region size is controlled by the electron inertial length. It was found that this approach allows to reduce the problem to the magnetic field potential finding, while last one has to satisfies the Grad-Shafranov equation. The obtained solution demonstrates all essential Hall reconnection features, namely protons acceleration up to the Alfven velocities, the forming of Hall current systems and the magnetic field structure. The reconnection rate as well as other reconnection characteristics depend on the electron diffusion region size only, not on its internal processes. No reconnection is possible when the electron diffusion region is absent. It turns out that the necessary condition of steady-state reconnection to exist is the electric field potential jump across the electron diffusion region and separatrixes presence. The magnitude of this jump has to be proportional to the external magnetic pressure. Besides, the powerful mechanism of electron acceleration in the direction of theX-line is required. It is to accelerate electrons up to the electron Alfvén velocity value inside the diffusion region and on the separatrixes. This is a necessary condition for steady-state reconnection as well.