Effect of plasma relaxation and dynamo on mean current and electric field in the reversed field pinches

V.V.Mirnov, C.C.Hegna, S.C. Prager

The University of Wisconsin-Madison, WI 53706
and the Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas

Abstract

Current–driven tearing instabilities are believed to dominate magnetic relaxation and energy transport in configurations such as the reversed field pinch (RFP) and spheromak. In the Madison Symmetric Torus (MST) RFP experiments, the amplitudes of fluctuations in magnetic field $\mathbf{B}^{(1)}$, flow velocity $\mathbf{v}^{(1)}$ and current density $\mathbf{j}^{(1)}$ follow a sawtooth cycle in their time dependence. During the sawtooth crash a surge occurs in the dynamo – a fluctuation-induced mean force in Ohm's law. It is observed that during the crash a substantial change occurs in the mean plasma current density profile and a very large change occurs in the mean electric field profile. We have performed a two-fluid quasilinear dynamo theory to determine how the effect of the dynamo is divided between local current density production and local electric field production. The spatial structure of the fluctuation induced two-fluid dynamo has been studied previously [1]. Both the MHD dynamo ($<\mathbf{v}^{(1)}\times\mathbf{B}^{(1)}>$) and the Hall dynamo ($<\mathbf{j}^{(1)}\times\mathbf{B}^{(1)}>$) contribute to the generalized Ohm's law, $<\mathbf{E}>_{||} - \eta<\mathbf{j}>_{||} = -(1/c)<\mathbf{v}^{(1)}\times\mathbf{B}^{(1)}>_{||} + (1/en^{(0)}c)<\mathbf{j}^{(1)}\times\mathbf{B}^{(1)}>_{||} = \varepsilon_{||}(x, t)$, where $\varepsilon_{||}(x, t)$ is the total electromotive force, $< >$ denotes mean (flux surface average) value, x is the distance from the mode-resonant surface. This equation does not determine $<\mathbf{E}>_{||}$ and $<\mathbf{j}>_{||}$ separately. To calculate these quantities we combine the two-fluid tearing mode theory with a one-dimensional temporal model based on Faraday's law for two cases: (a) $\varepsilon_{||}$ is an exponentially growing tearing mode, (b) $\varepsilon_{||}$ is a periodic function of time with experimentally observed sawtooth temporal profile and a spatial scale x_0. In case (a), the Hall dynamo contributes mainly to the parallel current on a short length scale while the broad MHD dynamo drives the electric field on the scales larger than the electron skin-depth δ. In case (b) at $x_0 >> \delta$, $\varepsilon_{||}(x, t)$ generates mostly a strongly oscillating electric field while a small fraction contributes to a smooth dc current. In the opposite limit, $x_0 << \delta$, all quantities oscillate strongly. In general, the self-inductance of the tearing layer prevents fast changes to the mean parallel current, thus, provides "stiffness" of the profiles with respect to perturbations.

Work supported by U.S.Department of Energy Grant No DEFG02-85E253212 and partially by the NSF Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas.

[1] V.V.Mirnov, C.C.Hegna, and S.C.Prager, Plasma Physics Reports **29** 612 (2003) (Sov. J.Plasma Physics - Fizika Plazmy)