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Extended MHD Modeling of Tearing-Driven Magnetic Relaxation[1]

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Driven plasma pinch configurations are characterized by the gradual accumulation and episodic release of free energy in discrete relaxation events. The hallmark of this relaxation in a reversed-field pinch (RFP) plasma is flattening of the parallel current density profile effected by a fluctuation-induced dynamo emf in Ohm's law. Nonlinear two-fluid modeling of macroscopic RFP dynamics has shown appreciable coupling of magnetic relaxation and the evolution of plasma flow. Accurate modeling of RFP dynamics requires the Hall effect in Ohm's law as well as first order ion finite Larmor radius (FLR) effects, represented by the Braginskii ion gyroviscous stress tensor. New results find that the Hall dynamo effect from $< \mathbf{J} \times \mathbf{B} > /\mathbf{ne}$ can counter the MHD effect from $- < \mathbf{V} \times \mathbf{B} >$ in some of the relaxation events. The MHD effect dominates these events and relaxes the current profile toward the Taylor state, but the opposition of the two dynamos generates plasma flow in the direction of equilibrium current density, consistent with experimental measurements. Detailed experimental measurements of the MHD and Hall emf terms are compared to these extended MHD predictions. Tracking the evolution of magnetic energy, helicity, and hybrid helicity during relaxation identifies the most important contributions in single-fluid and two-fluid models. Magnetic helicity is well conserved relative to the magnetic energy during relaxation. The hybrid helicity is dominated by magnetic helicity in realistic low-beta pinch conditions and is also well conserved. Differences of less than 1% between magnetic helicity and hybrid helicity are observed with two-fluid modeling and result from cross helicity evolution through ion FLR effects, which have not been included in contemporary relaxation theories. The kinetic energy driven by relaxation in the computations is dominated by velocity components perpendicular to the magnetic field, an effect that had not been predicted.

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