Numerical Study of the Formation, Ion Spin-up and Nonlinear Stability Properties of Field-Reversed Configurations [1]

E. V. Belova, R. C. Davidson, H. Ji, M. Yamada, Princeton Plasma Physics Laboratory, Princeton; C. D. Cothran, M. R. Brown, Swarthmore College; and M. J. Schaffer, General Atomics, San Diego, USA

Abstract

Results of three-dimensional numerical simulations of the field-reversed configuration (FRC) using the HYM code are presented. Emphasis of this work is on the nonlinear evolution of magnetohydrodynamic (MHD) instabilities in kinetic FRCs [1]. Kinetic simulations show nonlinear saturation of the n=1 tilt mode. The n=2 and n=3 rotational modes are observed to grow during the nonlinear phase of the tilt instability due to ion spin-up in the toroidal direction. The ion toroidal spin-up is shown to be related to the resistive decay of the internal flux, and the resulting loss of weakly confined particles (with small toroidal angular momentum $|p_\phi| = |Rv_\phi - e/m\psi| \ll |\psi_0|$) from the closed-field-line region. Simulations with zero initial ion rotation demonstrate the formation of a rigid-rotor rotation profile in about 60-80 Alfvén times, depending on the plasma resistivity. The peak ion toroidal velocity is proportional to the ion diamagnetic drift velocity, and in the final state, the ions carry large fraction of the total current. The details of the ion toroidal spin-up determine the nonlinear evolution of the rotational instabilities.

Three-dimensional simulations of counter-helicity spheromak merging and the FRC formation show good agreement with results from the SSX-FRC experiment [2]. Simulations show formation of an FRC in about 30 Alfven times for typical experimental parameters. It is demonstrated that a relatively large plasma viscosity ($\mu > 2\,10^{-3}$) and the field line-tying effects can slow-down the reconnection, and are likely to be responsible for the incomplete reconnection of the toroidal field seen in the experiments. Growth rate of the n=1 tilt mode is shown to be significantly reduced compared to the MHD growth rate due to large plasma viscosity and field-line-tying effects. Several factors contribute to further reduction of the instability growth at later time ($t \gtrsim 20t_A$), including the nonlinear effects and the stabilizing effect of the strong toroidal flows (low-viscosity case), and the residual toroidal field (high-viscosity case).

[1] E.V. Belova et al., Phys. Plasmas **11**, in press (2004).

[2] C. D. Cothran et al., Phys. Plasmas **10**, 1748 (2003).

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