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Nonlinear evolution of the cylindrical tearing mode and its diamagnetic stabilization[1]

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The $m = n = 1$ tearing mode is widely believed to be responsible for sawtooth crashes in tokamaks, and more broadly, as a paradigm of fast reconnection in collisionless plasmas. Past research has demonstrated that the resistive MHD evolution of this mode fails to capture essential features of experimental observations. While there have been several reduced two-fluid models for the nonlinear evolution of the instability, which have elucidated conditions under which the instability exhibits near-explosive growth or is suppressed, the demonstration of this entire range of dynamics in a complete Hall (or extended) MHD simulation of a tokamak has remained a formidable challenge. This challenge has been overcome by the Magnetic Reconnection Code (MRC). The computational approach to solving these equations has to confront two major challenges: the development thin current sheets and thus a wide range of spatial scales, as well as the large range of time scales caused by fast dispersive waves that are much faster than the reconnection time scale. We have employed variable grids to efficiently resolve small scales, and implicit time stepping methods to step over the fast time scales which are not of physical interest while maintaining stability of the time integration. We obtained very good performance with a Newton-direct solver method, using a code generator to calculate the sparse Jacobian matrices. We used the MRC to produce realistic simulations of sawtooth crashes which are quantitatively comparable with experimental results. Our results include a comprehensive study of the sawtooth instability in resistive and extended MHD, and cover a whole range of near-explosive sawtooth crashes and their nonlinear stabilization. In this process, we have identified new physical mechanisms for nonlinear stabilization of sawtooth crashes. We will also present our latest results for the evolution of the $m = 1$ mode in a reversed field pinch configuration.

[1]Center for Integrated Computation and Analysis of Reconnection and Turbulence