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Electromagnetically consistent model of complete reconnection

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The internal kink mode, with principal poloidal and toroidal mode numbers m=n=1, is thought to underlie the sawtooth crashes in tokamak plasmas. The expulsion of thermal energy from the core may be caused by magnetic reconnection in several ways, e.g. through stochastization of magnetic field lines, or complete magnetic reconnection of the plasma core [1]. Complete reconnection amounts to a heat loss mechanism simply by mixing of two plasma temperatures on reconnected flux surfaces. However, energetic particles in the core (from fusion or additional heating) can behave differently from the bulk plasma during a sawtooth crash. These particles are almost collisionless on the timescale of the crash and have drift orbits that deviate significantly from the field lines. These orbits are affected by the internal kink mode via the time-dependent magnetic field an electric field, with contributions specific to the m=1 kink motion and to the reconnection.

This point was made in [2] which presented a model for these magnetic and electric fields. In [3] that model was used to compute energetic particles orbits during sawtooth crashes. In [2,3], the magnetic and electric fields are computed self-consistently, satisfying Maxwell's and Ohm's laws. However, the model is short of a full MHD model: the plasma motion, while consistent with the electric and magnetic fields, is prescribed instead of based on the MHD force balance. This is evident from the fact that the mode has single helicity and hence magnetic surfaces exist in the nonlinear phase (full MHD dynamics in a torus produces multiple helicities and hence at least some level of field stochasticity).

The present paper uses the same assumptions, but adds to the earlier research by presenting explicit analytic expressions for the electric and magnetic fields. The model gives an electromagnetically self-consistent description of complete reconnection of a single-helicity m=1 mode in an arbitrary axisymmetric equilibrium with arbitrary q-profile (with q=1 surface, of course). It is shown that the single-helicity restriction gives rise to two distinctive phases in complete reconnection: first the m=1 shift of the core and reconnection, which leads to an m=1 deformed shape of the reconnected magnetic surfaces. The second phase is a reconnection-free m=1 motion that restores axisymmetry. Generally, these two phases cannot be mixed: reconnection cannot immediately yield an axisymmetric state.

The application to the modelling of energetic particle orbits during reconnection, to be published separately, will be briefly outlined. In particular, comparison with full-MHD simulations can reveal the specific role of magnetic stochasticity in the full MHD case.

References

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