Multiregion Relaxed MHD toroidal states with flow

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The action-based formulation[1] of Multiregion Relaxed MHD (MRxMHD) encompasses both steady-flow statics, and dynamics on a slower timescale than Taylor relaxation. We consider the case of a toroidal plasma laminated into multiple nested annular toroidal relaxation regions, separated by interfaces supporting current sheets. Unlike ideal MHD, Taylor relaxation allows reconnection at resonant surfaces to occur within these regions. However, the physical applicability of the model depends on the interfaces between them being ideal, i.e. *stable* against reconnection for times much longer than the relaxation timescale.

It has been postulated[2] that plasma flow may stabilize such current sheets even if they occur on surfaces that resonate with boundary perturbations in 3D geometries such as stellarators, or tokamaks with resonant magnetic perturbation (RMP) coils. This motivates the extension, now under development, of the 3D-MRxMHD-based *equilibrium* code SPEC[3] to allow plasma flow with reasonably general flow profiles. However, it is not clear[4] that stationary 3D states with other than rigid-rotation flow exist, motivating development of a 3D MRxMHD *initial value* code to model oscillatory states and nonlinear instabilities.

The formulation of Ref. 1 describes the plasma in each region as an ideal Euler fluid, which is too general for practical purposes as it allows all the turbulent complexity of such a fluid. This motivates developing a Taylor-like relaxation model[5] for fluids, based on minimizing total energy with constant mass, entropy and fluid helicity (or, equivalently, minimizing fluid helicity at constant mass, entropy and energy). This leads to a compressible Beltrami equation, $\nabla \times \mathbf{v} = \alpha_0 \exp\,(-v^2/2\tau)\mathbf{v}$, where α_0 and τ are constant in each region, τ being the square of the isothermal sound speed in that region. The simplest case is $\alpha_0 = 0$, i.e. the flow has *zero vorticity*, but, because our relaxation regions are not simply connected, non-trivial rotation profiles can still be treated.

References:

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