Penetration and amplification of resonant perturbations in 3D ideal-MHD equilibria

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abstract

Understanding 3D ideal-MHD equilibria, as described by the ideal force-balance equation, $\nabla p = \mathbf{j} \times \mathbf{B}$, is fundamentally important for understanding both tokamaks & stellarators. Edge-localized modes are believed to be ideal, peeling-ballooning modes; and a 'hot-topic' of current research is to suppress these modes using resonant magnetic perturbations (RMPs).

However, the nature of ideal-MHD equilibria in 3D geometry is profoundly affected by resonant surfaces, which beget a non-analytic dependence on the boundary. And, in order to preserve quasi-neutrality, non-physical infinite currents arise in equilibria with continuously-nested magnetic surfaces and smooth pressure & transform profiles.

These difficulties are not fundamental flaws in ideal-MHD, which remains perhaps the most successful, relevant yet simplest model of plasma dynamics. It is just that, until recently, self-consistent tractable solutions to the ideal-MHD equilibrium equation for arbitrary 3D geometry had not been discovered.

Recently, for the first time, we computed the 1/x and delta-function current-densities, and we realized that self-consistent solutions demand locally-infinite shear at the resonant surfaces. We introduced a new class of solutions that admit additional delta-function current-densities that produce a discontinuity in the rotational-transform that removes the singularities. Our equilibrium solutions can be computed both perturbatively and using fully-nonlinear equilibrium calculations (with the SPEC code), and we present precise verification calculations.

Most importantly, our solutions yield predictions that are in sharp contrast to previous predictions, with direct implications for understanding the penetration of RMPs: in ideal-MHD, a resonant perturbation penetrates past the rational surface and into the core of the plasma; and the perturbation is magnified by pressure inside the resonant surface, increasingly so as stability limits are approached.