3D MHD equilibria with current sheets, magnetic islands, and chaos in stellarators and tokamaks

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Abstract. Two outstanding questions regarding MHD equilibria in toroidally confined plasmas are: how to reliably compute 3D MHD equilibria (1) in the ideal limit where current sheets are predicted to form at resonant rational surfaces, and (2) in partially relaxed plasmas where flux-surfaces, islands, and chaos coexist? The first question is of fundamental importance for MHD theory and has potential experimental implications. In fact, it has been observed experimentally that under certain conditions self-healing of islands can occur and thus current sheet formation is expected on small scales [1]. Moreover, the understanding of the ideal plasma response to resonant magnetic perturbations (RMPs) in tokamaks is incomplete and still under debate [2]. The second question is clearly vital for a proper description of the magnetic field that is consistent with the established pressure and current profiles. In particular, the β-limit in stellarators is most likely set by equilibrium degradation rather than stability [3]. In order to address these questions, a theory based on a generalized energy principle, referred to as *multi-region, relaxed MHD* (MRxMHD) [4], was developed and bridges the gap between Taylor's relaxation theory and ideal MHD. Using the SPEC code [5], a numerical implementation of MRxMHD, we provide the first numerical proof of the existence of singular current densities and a novel theoretical guideline for the computation of three-dimensional ideal MHD equilibria with current sheets [6]. As an example, we provide new predictions for the ideal response to RMPs in tokamaks, together with an unprecedented verification between linearly and nonlinearly perturbed equilibria [7, 8]. Finally, we use SPEC in stellarator geometry to perform equilibrium calculations for W7-X in experimentally-relevant scenarios, thereby providing new quantitative insights for the effect of pressure and bootstrap current on the generation of magnetic islands and ergodic fields.

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