Synergism Between Cross-Section and Profile Shaping in Beta Optimization of Tokamak Equilibria with Negative Central Shear

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Abstract

Systematic stability studies of the Negative Central Shear configuration reveal a synergistic relationship between the gains in the ideal $n=1$ magnetohydrodynamic β limit from optimizing the profiles and from optimizing the shape. For a circular cross-section with highly peaked pressure profiles, $\beta_N = \beta/(I/aB)$ is limited to $\beta_N \sim 2\%$ (mT/MA). Small to moderate improvements in β_N result from either broadening the pressure or from strong cross-section shaping. At fixed safety factor the latter translates to a much larger increase in β and the root mean square β denoted as β^*. With both optimal profiles and strong shaping, however, the gain in all the relevant fusion performance parameters is dramatic and β and β^* can be increased by a factor 5. The calculations show that stabilization from a nearby conducting wall greatly contributes to this large improvement since coupling of the plasma to the wall is increased for the optimum profiles and cross-section. Moreover, the alignment of the bootstrap current density profile with the total current density profile is also optimized with broad pressure, strong cross-section shaping, and high β_N, thus minimizing steady-state current drive requirements. Sensitivity studies using other profiles show some variation in the actual β limits but the general trends remain robustly invariant.