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 $\beta$ limit from optimizing the profiles and from optimizing the shape. For a circular cross-section with highly peaked pressure profiles, $\beta_N = \beta I/(I/aB)$ is limited to $\beta_N \sim 2\%$ (mT/MA). Small to moderate improvements in $\beta_N$ 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 $\beta$ and the root mean square $\beta$ denoted as $\beta^*$. With both optimal profiles and strong shaping, however, the gain in all the relevant fusion performance parameters is dramatic and $\beta$ and $\beta^*$ 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 $\beta_N$, thus minimizing steady-state current drive requirements. Sensitivity studies using other profiles show some variation in the actual $\beta$ limits but the general trends remain robustly invariant.