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Unified parametric dependence, control, and reconstruction of 3D equilibria in the RFP[1]

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A helical, stellarator-like equilibrium emerges in the core of RFP plasmas when the normally broad tearing mode spectrum spontaneously condenses – the innermost resonant mode grows to large amplitude, while the other, secondary mode amplitudes are reduced. This quasi-single-helicity (QSH) transition is not fully understood, but it likely hinges on the nonlinear MHD that governs the tearing mode spectrum. Here we report (1) progress in understanding the transition in terms of the Lundquist number, S, a key dimensionless parameter in nonlinear MHD, (2) improved energy confinement in MST with QSH and inductive current profile control, and (3) progress in developing 3D equilibrium reconstructions for QSH plasmas. In MST, the likelihood and duration of QSH spectra increase strongly with the plasma current, Ip, similar to the trend in RFX-mod, but the Ip at which QSH emerges in MST is 3x smaller. However, given that MST can, for a given Ip, access lower density and higher Te, the two devices share a common range of S, which varies as Ip*$Te^{1.5}n^{-0.5}$, and the tearing spectra from the two devices exhibit a common dependence on S. The above results accrued in plasmas with largely Maxwellian electrons and ions. With the addition of neutral-beam-injected fast (25 keV) ions in MST, the likelihood of QSH in low-S plasmas decreases further. In high-S plasmas, the likelihood of QSH is largely unaffected by the fast ions. The dominant mode in MST can reach 8% of the equilibrium field. This, combined with the reduced secondary modes, leads to a locally enhanced Te in the core and a 50% improvement in energy confinement. The secondary modes are further reduced by slowly ramping down Ip, a form of current profile control. This leads to a larger Te >1 keV and a tripling of the energy confinement. These results were achieved with zero applied Bt (infinite toroidal beta). The 3D magnetic topology was measured directly for the first time in MST via Faraday rotation. This and other advanced diagnostics are being included in the V3FIT equilibrium reconstruction code through a multi-institution collaboration. The varying orientation of the 3D structure relative to the diagnostics will help in V3FIT optimization.

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