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Three-dimensional shaping of tokamak plasmas[1]

MICHAEL ZARNSTORFF, Princeton Plasma Physics Laboratory

Three-dimensional (3-D) shaping of advanced tokamak plasmas is explored to provide resilience against disruptions, eliminate the need for current drive, and stabilize several instabilities without external feedback. The 3-D shaping is constrained to be approximately quasi-axisymmetric, so the orbit and neoclassical properties of the original equilibrium are preserved. Sequences of numerically generated equilibria with β=4% are studied, parametrically varying the shape and aspect ratio to examine the properties achieved at different levels of shaping, and the impact on coil-set complexity. The base axisymmetric equilibrium has elongation of 1.8, high triangularity, and average aspect ratio $\sim$4. The 3-D shaping has N=3 periodicity in the toroidal direction. It is found that a small distortion, producing a vacuum rotational transform ι=0.05, stabilizes the vertical instability. With vacuum ι=0.1 and a self-consistent bootstrap current, the need for external current drive is eliminated, while keeping the Shafranov shift less than half the minor radius. Above vacuum ι=0.2, the equilibrium remains inside the vacuum vessel even if the plasma pressure and current disappear. Thus, this should be robust against disruptions, similar to experiments on W7-A. For vacuum ι=0.3, the external kink and resistive wall mode are passively stable. With fixed 3-D shape amplitude, variations of the average two-dimensional plasma shape changed the MHD stability thresholds as in axisymmetric tokamaks. Increased aspect ratio systematically reduces the toroidal excursion of a modular coil set that produces the 3-D shaped magnetic field, giving simpler, smoother coils. Other strategies to simplify the coil shapes will be discussed, including saddle coils combined with planar tokamak coils.

[1]In collaboration with A. Boozer and L.-P. Ku.