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PHYSICS ISSUES OF COMPACT QUASI-POLOIDAL STELLARATORS

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Quasi-poloidal (QP) stellarator symmetry has recently allowed the design of very low aspect ratio ($R_0/\langle a\rangle = 2.5\text{-}3$) two field period (racetrack-shaped) hybrid devices that generate their rotational transform from a combination of internal plasma currents and external shaping. The equilibria of compact QP plasmas involve strong poloidal/toroidal couplings due to the need to minimize the 1/R terms in the magnetic field spectrum, which constitute "undesirable ripple" in this context. Significant improvements have been made in 3-D equilibrium solvers allowing not only routine calculation of strongly coupled QP equilibria, but comprehensive optimization of these systems for good confinement, bootstrap current consistency, stability and coil-engineering properties. It has also been possible to form configurations having very little change in the flux surface shape with increasing plasma β and reduced resonant magnetic island width. Neoclassical transport in QP stellarators has been minimized so as to be negligible in comparison to the expected anomalous levels. Recent improvements in the neoclassical transport theory of 3-D systems have allowed calculation of the full transport matrix (diffusion of particles and heat, viscosity, and bootstrap current) for multiple helicity |B|, arbitrary electric fields and collisionalities, and including momentum–conserving corrections. QP systems possess an anisotropy in their viscous damping coefficients (poloidal viscosity < toroidal viscosity) that is opposite to that of tokamaks. This feature is expected to help maintain sheared radial electric fields driven by cross-field transport and may facilitate access to enhanced confinement regimes. The stability analysis of QP devices indicates first ballooning stability boundaries exist at $\langle\beta\rangle = 2\text{–}2.5\%$ and kink/vertical stability boundaries at $\langle\beta\rangle = 4\text{–}5\%$. Many QP systems also have second stable regimes; for example, a class of devices with low vacuum transform has been studied that are second stable up to $\langle\beta\rangle \approx 15\%$. A favorable synergism exists between the finite β effects on the equilibrium and confinement of such systems, allowing not only relatively constant bootstrap current levels with increasing β, but also improved QP-symmetry and energetic particle confinement. MHD Alfvén gap modes have been analyzed in these systems, indicating a denser spectrum than tokamaks with helical couplings that are unique to 3-D devices. By varying the coil currents in proposed QP systems, substantial flexibility has been demonstrated theoretically with respect to neoclassical confinement, MHD stability, and magnetic island widths. This flexibility coupled with the unique magnetic structure of these systems will contribute to our basic understanding of plasma transport, MHD phenomena and confinement. The physics issues of these devices will be discussed along with new challenges in the theory and modeling of such compact 3-D systems.

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