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Progress in Theoretical RFP Studies: New Stimulated Helical Regimes and Similarities with Tokamak and Stellarator

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Recent theoretical studies of the reversed-field pinch (RFP) have demonstrated the possibility of stimulating new quasi-single helicity (QSH) regimes by allowing a small helical deformation of the magnetic boundary. In particular, 3D nonlinear MHD modeling predicted QSH states based on non-resonant helicities are predicted to be more resilient to magnetic stochasticity induced by secondary modes. These theoretical predictions have motivated a series of experiments in the RFX-mod device with applied magnetic perturbations (MPs).
We present here the current state of the art in research on nonlinear MHD modeling of helical RFP regimes, and we highlight similarities of the helical RFP with the tokamak and the stellarator. Helical RFP states with different helicities are compared in terms of their core confinement properties. We consider in particular stimulated helical configurations obtained by applying small m=1 helical MPs with toroidal periodicity corresponding to non-resonant (n=6) and resonant (n=7 and n=8) kink-tearing modes. The safety factor profile as a function of the helical magnetic flux decreases monotonically for the non-resonant case, whereas a region of flat or reversed magnetic shear appears in the core for resonant configurations. When secondary MHD modes are taken into account, a magnetic topology characterized by a conserved helical core enclosed by a stochastic region is typically observed. The width of the conserved core region turns out to be the largest for the non-resonant configuration, in qualitative agreement with RFX-mod experiments suggesting that QSH regimes with n=6 dominant mode are endowed with a larger hot core than spontaneous n=7 QSH states. By using a finite-time Lyapunov exponent method applied for the first time to magnetic confinement configurations, barriers to the diffusion of magnetic field lines are diagnosed in the weakly stochastic region surrounding the conserved helical core in numerical QSH states. Similarly to what observed in the tokamak configuration, the sawtoothing dynamics of RFP plasmas is mitigated with the application of helical MPs. The confinement properties of the RFP edge, characterized by m=0 island chains at the q=0 reversal surface playing a role similar to edge islands in tokamak and stellarator plasmas, are also discussed.

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