Helical Self-Organization in 3D MHD Modeling of Fusion Plasmas

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Self-organization is a ubiquitous aspect of magnetized plasmas and may lead to the formation of large scale helical structures. Long-lived helical fields are observed in astrophysical plasmas such as relativistic jets or solar prominences related to emerging helical flux ropes. Helical self-organization occurs in laboratory plasmas as well, such as dynamo experiments, plasma guns and toroidal devices for the magnetic confinement of fusion plasmas. In current carrying fusion plasmas, helical self-organization is associated with the kinking tendency of such plasmas, which can lead to the emergence of long lasting helical states in tokamak and reversed-field pinch (RFP) experiments.

In this talk we will mainly focus on the RFP configuration, briefly reviewing past modeling history and experimental evidence. Similarities with tokamak helical states will also be discussed. Helical states are observed in all major RFP experiments at increasing plasma current and are associated with favourable confinement properties, such as magnetic chaos healing and the occurrence of internal transport barriers. Such states are periodically interrupted by magnetic reconnection events associated with enhanced dynamo activity and the formation of current sheets. The dynamical bifurcation to helical states was predicted for current carrying plasmas by the nonlinear visco-resistive 3D MHD model with standard ideal boundary conditions since the '90ties. When the visco-resistive dissipation is increased, the transition from sawtoothing regimes involving reconnection events to helical stationary regimes is indeed observed in both tokamak and RFP configurations [1,2]. The talk will focus on more recent developments concerning the impact of helical boundary conditions. Such magnetic perturbations are shown to provide an effective handle to mitigate the sawtoothing activity and to substantially enlarge the parameter space of helical solutions towards small dissipation conditions. Various degrees of quiescence can be achieved depending on the amplitude of the applied perturbation in both configurations. In the RFP case, helical boundary conditions are essential to reproduce experimental features of RFP states [3] and to select the pitch of the final helical regime [4]. Numerical predictions are provided by two cross-benchmarked 3D MHD codes [2] and are confirmed by recent experimental results from the RFX-mod device, which can be operated in both RFP and tokamak configurations. Finally, extensions of the numerical tools for the inclusion of self-consistent heat transport and the implementation of stellarator configurations will be discussed.

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