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Transport barriers in helical equilibria: structural change in the reversed field pinch[1]

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Self-organization of RFX plasmas in single helical axis equilibrium, with m=1,n=7 helicity, is a structural change for the reversed field pinch (RFP) [Lorenzini et al., Nature Phys 2009 doi:10.1038/nphys1308]. This happens at high plasma current (I>1 MA) while axisymmetric boundary conditions are enforced: the helical state has almost conserved magnetic flux surfaces, interpreted as ghost surfaces [Hudson&Breslau PRL 2008], leading to strong core electron transport barriers. Electron temperature Te reaches 1.3keV @1.7MA. Ion temperature Ti is ∼(0.5-0.75)Te, consistent with collisional ion heating. The core barrier extends up to ∼0.65r/a. Magnetic surfaces quality improves with Lundquist number S, thanks to the simultaneous decrease of magnetic chaos and increase of the helical field strength. Helical equilibria are reconstructed by the 3d code VMEC. The (1,7) helicity acts to hold the core safety factor almost flat and below 1/7. The barrier foot coincides with a zero magnetic shear region, where density of rational surfaces is minimum, as in other configurations. Plasma-wall interaction is smoother. Main gas particle confinement time improves in pellet-fuelled plasmas, with record value ∼10ms. No core impurity accumulation is evident in Laser Blow Off experiments, which is consistent with numerical simulation results. High current sets a transition also for the edge, where robust Te gradients are observed with a pedestal of ∼1keV in ∼3cm, possibly due to improved magnetic topology and synergic with core barrier. As persistence and quality of these improved helical states increase with current, the likelihood of achieving steady helical multi-MA RFPs can be inferred. RFX experiments allow a study of the beneficial effects of non-axisymmetric shaping and may provide a platform for a more general validation of theoretical tools developed for stellarators. Moreover, these results are transformational in supporting the RFP as a low-external field, non-disruptive, ohmic approach to fusion, exploiting self-organization and technological simplicity.

[1]In collaboration with the RFX-mod team.