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Role of MHD dynamo in the formation of 3D equilibria in fusion plasmas

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This work investigates the formation of helical core equilibria in toroidal fusion plasmas, focusing on the role of dynamo, or magnetic flux pumping mechanisms in determining the equilibrium current profile. Dynamo effects determine the safety factor profile of the final 3D equilibrium, with important consequences on MHD stability and transport. We compare experimental results from multiple machines (RFX-mod, MST, AUG, DIII-D) and nonlinear MHD modelling. Two paradigmatic cases of helical state formation are considered and common physics is identified, by direct measurements of dynamo effects and MHD simulations: spontaneous formation in high-current reversed-field pinch (RFP) plasmas [1] and the hybrid scenario in high-beta tokamak plasmas [2]. Helical cores form in both cases, either spontaneously via saturation of MHD modes, or due to the marginally-stable ideal MHD response to external 3D fields. Direct measurements of the dynamo emf associated to 3D plasma distortions will be presented for a database of helical RFP plasmas from RFX-mod and MST, covering a wide range of plasma parameters. Similar measurements were also done in helical states forming in response to external 3D fields in Ohmic RFX-mod tokamak plasmas and in DIII-D high-beta hybrid plasmas. Experimental results qualitatively agree with nonlinear MHD modelling performed with the codes SpeCyl [3], PIXIE3D [4], and NIMROD [5]. They indicate that central current is redistributed by a dominantly electrostatic MHD dynamo. The underlying physics common to RFP and tokamak is thus revealed: a helical core displacement modulates parallel current density along flux tubes, which requires a helical electrostatic potential to build up, giving rise to a helical dynamo flow. Similar results were also recently obtained with the M3D-C1 code [6].

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