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Advances toward high-beta long-pulse operation in the WPTE tokamaks

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One of the crucial challenges on the path to a fusion power plant is the integration of long-pulse operation with high performance, while ensuring low disruptivity and an acceptable power flux to the wall. This contribution reports on how these issues have been addressed in several European devices within the remit of the EUROfusion Tokamak Exploitation Work Package (WPTE). Progress toward non-inductive operation has been recently made on TCV, where the plasma current has been reproducibly sustained over multiple current redistribution times without any flux contribution from the Central Solenoid (CS) in quasi-stationary conditions, reaching $\beta N \sim 2$ and ion and electron temperature of the same order of magnitude. A CS-free plasma current ramp up scenario has also been recently developed on TCV, extending previous efforts based primarily on the bootstrap current contribution [1]. Given the dominant role of the Electron Cyclotron Resonance Heating in these plasmas, these results could help define the operating basis of the JT-60SA steady-state scenarios. A different approach, based on the magnetic flux pumping, has been pursued on JET and MAST-U, both primarily heated by Neutral Beams and equipped with internal current density diagnostics. This mechanism, well established in hybrid plasmas on DIII-D [2] and ASDEX Upgrade [3], is appealing for high-beta long-pulse operation as it enhances the MHD stability and the non-inductive current fraction. A flux pumping scenario has been developed on JET for the first time and similar efforts are underway on MAST-U, where advances in the hybrid scenario development are being achieved through the optimization of the plasma current ramp up and its NBI heating. These experiments provide a valuable testbed to validate and improve the predictive capabilities of MHD models like JOREK [4] toward ITER and DEMO. Predictive modelling with the JINTRAC suite of codes on JET and MAST-U plasmas has also contributed to the validation of transport models in view of the high-beta operation on JT-60SA.The core-edge integration has been recently addressed on the full-tungsten WEST tokamak, where the X-Point Radiator (XPR) regime [5] has been controlled for more than 30 s, with the perspective of developing both a repetitive scenario addressing high fluence issues, and a non-inductive scenario for steady-state control purpose. In support of the latter, next campaign experiments plan to extend the pulse duration of this XPR scenario to several minutes by attaining zero loop voltage conditions.

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