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I3.008 Wendelstein 7-X: Towards high-density long-pulse operation

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Stellarators have intrinsic advantages with respect to a fusion reactor operating in steady-state. They, however, need optimization to bridge the gap to tokamak plasma performance. The superconducting stellarator Wendelstein 7-X (W7-X) is optimized for neoclassical transport and improved plasma stability. The set of 50 non-planar and 20 planar magnetic field coils generate a magnetic field of 2.5T on axis with low shear and a range of rotational transform between 5/6 and 5/4. The third operation campaign of W7-X was finished in 2018. The primary focus of the campaign was the development of high-density plasma scenarios, which are compatible with divertor operation and have the potential for long-pulse steady-state plasma discharges, and the demonstration of the optimization criteria. This paper summarizes the key experimental findings of the campaign. Improved wall conditioning via boronization was applied to W7-X for the first time. The resulting strong reduction of plasma impurities, particularly oxygen, reduces core impurity radiation considerably and allowed plasma densities exceeding 1x10^20 m^-3 with ECRH heating powers up to 6MW in O2 mode polarization. At those high densities divertor detachment is observed with a neutral compression, which is sufficient for active neutral gas pumping envisaged for the next operation campaign. The predicted impurity accumulation in the plasma core is not observed and suggests that turbulent transport plays a significant role in the radial regulation of heat and particle transport. This scenario could be stabilized to a discharge length of 30s, corresponding to 150MJ of heating energy. At reduced heating power, an even longer discharge length of 100s with 200MJ injected heating energy was demonstrated. Improved confinement is observed when the plasma density is centrally peaked by pellet fuelling. High ion temperatures Ti=Te=3keV are achieved in this case. This phase is correlated with the suppression of turbulent fluxes. Gyrokinetic simulations suggest that this suppression is due to a stabilization of ion temperature gradient modes by the core density gradients, while trapped electron modes remain widely stable. This is a particular feature of the magnetic field optimization and stands in general contrast to the tokamak situation. Neutral beam injection heating with a maximum heating power of 3.5MW was operated at W7-X for the first time. It was demonstrated that the plasma can be sustained with neutral beam injection heating only and the highest plasma densities of 2x10^20 m^-3 were achieved in this scenario.

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