Detachment stabilization by feedback-controlled gas injection in stellarator Wendelstein 7-X

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Wendelstein 7-X (W7-X) is an optimized stellarator with superconducting coils that started its first plasma operation in 2015 with five inboard limiters as main plasma facing components. The first experimental campaign with uncooled divertors, conducted in 2017, has shown thermal detachment of the plasma from the target plates at the highest line-of-sight integrated electron densities of \(~3-6\times10^{19}\) m\(^{-2}\) accessible in this campaign without wall conditioning by boronization. In the last campaign (in 2018) much higher line-of-sight integrated electron densities of up to \(1.6\times10^{20}\) m\(^{-2}\) were reached as a result of strongly reduced impurity fluxes from the walls already after the first of three applied boronizations. At these high densities the thermal detachment at the target plates was accompanied by high recycling of neutrals at the target plates and hence significantly higher neutral pressures in the divertor of up to \(8\times10^{-3}\) mbar which allowed to balance the fueled particles by gas pumping through the divertors. The optimum detachment working point was found at the radiation fraction of \(~80\%\), as also predicted by EMC3-EIRENE simulations. In this last campaign, a feedback control system was established for gas injection through the divertor, with the aim to actively maintain and control the detached plasma conditions. The line-of-sight integrated density, the total plasma radiation, and impurity line radiation in one of the divertors were used as input signals for the control algorithm. A minimum central electron temperature of 2 keV was also used as a feedback constraint, limiting gas flow rates, to avoid poor O2-mode ECRH coupling and radiation collapses of the plasmas. The feedback-controlled detachment stabilization worked very reliably and allowed for sustaining high power discharges in the detached state for up to 30 sec without noticeable thermal loads to the divertor plates. The implementation of the feedback-control system including the hardware and applied algorithms will be presented as well as the results of the detachment control.