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The Wendelstein 7-X Stellarator: Plasma Generation, Heating and Current-Drive with the Worldwide Largest Electron Cyclotron Heating Facility

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The stellarator Wendelstein 7-X (W7-X) is equipped with a steady-state capable 10 MW ECH system, operating at 140 GHz, which corresponds to the 2nd cyclotron harmonic of electrons in the magnetic field of 2.5 T. Ten megawatt-class gyrotrons, two 5 MW quasi-optical transmission lines (94 % transmission efficiency) as well as 4 directly steerable and 2 novel remotely steerable launchers inside the plasma vessel are operational and already delivered more than 7 MW X2-mode heating to W7-X plasmas. Besides the reliable plasma start-up and routine ECH wall conditioning, stationary discharges up to 100 s have been achieved, which were only limited by the maximum test divertor energy load. Combined with pellet injection, the highest triple product $(0.68 \times 10^{20} keV m^{-3} s)$, observed up to now in stellarators, was achieved, exclusively by electron heating heating [T Sunn Pedersen et al 2019, Plasma Phys. Control. Fusion 61, 014035]. The corresponding plasma parameters were $T_{i0} = T_{e0} = 3.8$ keV, $n_{e0} = 0.9 \times 10^{20} m^{-3}$ and $\tau_E = 0.22$ s. For the first time, dense W7-X plasmas were sustained by 2nd harmonic O-mode (O2) heating, approaching the collisionality regime for which W7-X was optimized [T Stange, submitted to PRL]. O-mode heating needs high T_e and multi-pass absorption that was obtained by tungsten covered Mo mirror tiles with holographic gratings at the inner wall. After boronization of the plasma vessel, stationary O2-heated plasmas above the X2 cut-off with hydrogen gas fueling only; hydrogen plasmas with 6 MW ECRH for 30 s at only 1 MW divertor heat load (detached plasma), thermalization $(T_i = T_e = 1.5keV)$, density $1.6 \times 10^{20} m^{-3}$ and radiation control with $W_{dia} = 800$ kJ were achieved, which is a reference scenario for later long-pulse high density discharges. Power deposition scans did not show any indication of electron temperature profile resilience. In low-density, low-power plasmas compensation of the bootstrap current with electron-cyclotron current drive (ECCD) was demonstrated [RC Wolf et al 2019 Plasma Phys. Control. Fusion 61, 014037]. The long discharges were used to demonstrate current control and bootstrap current compensation by ECCD. Until 2018, the plasma vessel was equipped with an uncooled divertor, which allowed to extend the integrated heating energy from 4 MJ to 80 MJ. The full steady-state capability will be reached in 2021, after an actively cooled high heat-flux divertor has been installed which can tolerate steady-state heat fluxes of up to 10 MW/m^2. Plans for later upgrades include a further increase of the ECH power to 18 MW and the introduction of tungsten as a first-wall material.
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- W7-X Team: see author list of T Klinger et al., Nucl. Fusion 2019 doi.org/10.1088/1741-4326/ab03a7

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