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High-performance ECRH at W7-X: Experience and Perspectives

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W7-X is the first large fusion device where stationary reactor relevant densities have been achieved with electron heating only as it will be also the case for alpha particle heated fusion reactors. Employing the multi-pass ECRH scenario in the second harmonic O-mode (O2-ECRH), stationary (12 s) densities of up to 1.5 1020 m-3 had been achieved with hydrogen gas fueling. This scenario also made the stationary divertor detachment possible [1]. With a strongly reduced power load at the divertor tiles, detachment is a candidate for particle and power exhaust in fusion reactors. Even though electrons have been heated primarily, the collisional electron-ion coupling at that high density brought the ion temperature up as well. In particular in combination with pellet injection transiently ion temperatures Ti above 3 keV and close to the neoclassical limit of the W7-X magnetic configurations could be achieved. Thus enabling to test the W7-X neoclassical optimization [2]. Also the beneficial effect on impurity control by electron heating could be demonstrated.

The 140 GHz EC-wave with ordinary (O2) polarization give access to densities beyond the cut-off limit of the commonly used extra-ordinary (X2) polarized waves, but for the expense of incomplete single pass absorption for the W7-X plasma parameter. This disadvantage could be compensated by a special the multi-pass scenario, where the partially (60-70%) absorbed ECRH-beams have been reflected by specially shaped tiles and passed three times through the plasma core with an overall absorption of up to 90%. A detailed analyses of the absorption and losses for all 10 ECRH beams in the experiments enabled further optimization of the reflector tiles, thus in the next campaign an overall absorption of 95% is envisaged. This on the first glance small improvement will reduce the none-absorbed ECRH stray radiation by 50%, which is a remarkable step forward for prospective future steady state operation, since the microwave stray radiation gives an additional load to all W7-X components even if they are outside a line of sight to the plasma [3]. The O2-opereration scenario has been also routinely used for plasma operation below the X2 cutoff at densities above 0.8 1020 m-3 prohibiting the otherwise high risk of uncontrolled beam deflection in the X2-mode ECRH case. In order to keep the absorption high, the density feed-back controls for a central Te above 2 keV. In this scenario stable and stationary detachment for 24 s could demonstrated, which was only limited by the energy limit given by the uncooled plasma facing W7-X components in OP1.2. A further benefit of the O2-ECRH scenario was the compatibility with high neutral pressure at the plasma edge. Even though after the boronization of the W7-X wall no glow discharge cleaning has been performed any more the density control was never lost and the high density operation was very robust. But on the other side in the presence of the high neutral fluxes, plasma radiation and charge exchange losses pushed down the edge temperatures as shown in Fig 1.

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The possible large density range enable a combined operation with pellet injection without the risk of approaching the cut-off condition for the here pellet-induced peaked density profiles. After the pellet injection phase, the transport properties are being improved for the ion and thus high plasma performance with high tripple product values have been achieved [4]. Here the ion power flux approaches the neoclassical value enabling to test the neoclassical transport optimization of W7-X.

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The neoclassical impurity transport in stellarators predicts an inward pinch and thus a impurity accumulation. Electron temperature gradient driven turbulence is counteracting here and thus in ECRH-plasmas with gas fueling no accumulation has been found [5]. In particular the laser blow off experiments estimated impurity confinement time of the order of 70-80 ms which is far below the neoclassical confinement times of 2-10s [6]. Even more in cases, where impurity accumulation has been found, like in the exclusively NBI-heated high density plasmas, additional O2-ECRH significantly flattened the otherwise peaked Impurity profiles and pushed the impurities toward the plasma edge.

The high density operation with the multi-pass O2-ECRH scenario showed an excellent plasma performance. However the maximal achieved temperature were limited by the amount of available heating power (6MW for

20s) and the respective transport parameters of the plasma scenarios. In particular the gas fed ECRH-plasmas suffered from low plasma edge temperatures, which prohibit the efficient use of magnetic confinement region. For the next operation campaign an upgrade of the available ECRH power to 10 MW and more effective multi-pass reflector tiles are planned. In particular a new more powerful (1.5 MW) gyrotron is being developed now [7] and number of gyrotrons and beamlines will be increased from 10 to 12. In addition the maximal power capability of the in-air quasi-optical transmission line is being enhanced with a strong air drying system. Plasma performance enhancement is also expected by an improved edge neutral density control with cryo pumps in the divertor pumping gap and gas valves in the divertor region. In addition a steady state pellet injector will enable continuous core fueling at low neutral edge density.

References:
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