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Characteristics of ECRH-plasmas at the W7-X Stellarator

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The W7-X stellarator is equipped with a powerful ECRH-system, which reliably provided the plasma start-up and pure ECRH plasmas in most of the experiments of the last campaigns [1]. It consist of 10 gyrotrons at a frequency of 140 GHz with a maximum total power of up to 8 MW and a quasi-optical transmission line for the individual microwave beams. Purely ECRH heated plasmas are characterized by peaked electron temperature profiles and flat density profiles in case of edge gas fueling. The use of X2 and O2 polarization enabled to heat plasmas efficiently over a wide density range between 0.1 and 1.5 10^{20} m^{-3}. Remarkable is that plasma densities well above 10^{20} m^{-3} have been sustained with O2 ECRH heating only. The effect of the incomplete single pass absorption of the O2-mode was overcome by a multi-pass scheme with holographic reflector tiles. In these cases, the plasma start-up had to be initiated with the well absorbed X2-mode at densities below the cut-off. The polarization of the ECRH beams then was successively changed towards the O2 polarization before the X2-cutoff density was reached.

ECRH exclusively heats the electrons, which is similar to alpha particle heating in a fusion reactor. Due to the resonance condition for the EC-absorption, the power deposition is strongly localized in the plasma center in most of the discharges. Off-axis ECRH was also possible by changing the launch direction of the front steering antenna. The ions are heated indirectly by collisions with the electrons. The electron and ion temperature equilibrate at sufficiently high collisionality. This happened at the highest achievable densities for both gas and pellet fueled plasmas. In particular, after the pellet injection phase, where the density profile temporarily became peaked, the ion transport properties were improved and thus high plasma performance with high triple product values were achieved [2]. Here, the ion power flux approaches the neoclassical value enabling to test the neoclassical transport optimization of W7-X [3].

High-density O2-ECRH operation was also compatible with detached divertor conditions, a high edge radiation scenario with a strongly reduced convectional power flow at the divertor surface [4]. This reactor relevant scenario could be sustained for up to 26 s with ECRH only and was limited by the allowed energy load at the - so far - uncooled plasma facing in-vessel components.

At low densities and with X2 polarization the rotational transform (iota) profile could be significantly changed by ECCD. After the iota profile crossed a major rational number, strong MHD activity appeared, which generated repetitive core temperature collapses similar to the well-known “sawtooth” oscillations in tokamaks [5], [6].

ECRH plasmas were very stable and plasma operation of up to 100 s could be demonstrated, only limited by the maximum temperature of the uncooled divertor tiles. Stationary ECRH-plasmas also showed a very low impurity confinement without accumulation [7], which is in contradiction to neo-classical predictions, indicating transport dominated by plasma turbulence.

Furthermore, one gyrotron beam was used as a source for a CTS-diagnostic measuring ion temperatures.

For the next W7-X operation campaigns, where all plasma facing in-vessel components will be have active water cooling for steady state operation, an upgrade of the total ECRH power is planned. A new 140 GHz gyrotron with an output power of 1.5 MW is being developed at present. The number of gyrotrons will be increased stepwise up to 12. More than 10 MW of ECRH power is envisaged.

References

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