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The quasi-optical steady state 10 MW ECRH system of Wendelstein 7-X - commissioning, plasma operation and future plans

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During the first operational phase (OP1.1) of Wendelstein 7-X (W7-X) electron cyclotron resonance heating (ECRH) was the exclusive heating method, and it will also remain dominant in the next operational campaign (OP1.2). The microwaves are provided by ten gyrotrons (140GHz, 1MW), which were developed within the PMW-project at KIT. The ECRH-system is also the only heating system able to operate steady state at W7-X. The quasi-optical transmission line to the plasma vessel is the first of its kind. It consists of ten single beam sections (SBS) matching the non-perfect Gaussian beam output of the gyrotrons to the subsequent 40m long multi-beam section (MBS), which has an efficiency of at least 97%, and is intrinsically broadband. The whole MBS consists of two lines, each with 7 large-area multi-beam mirrors transmitting five of the ten gyrotron beams in parallel. Finally, the MBS separates the beams and directs them to their respective vacuum window in a single beam line. The windows interface to the four equatorial launchers installed on W7-X with three beam lines each. The plasma facing mirror of each beam line is steerable in the poloidal and toroidal direction. This way, the radial heat deposition in the plasma and the plasma current drive can be varied, respectively.
The flexibility to adjust the mirrors of the quasi-optical transmission line enables alignment of the beam line with the high-power microwave beam itself. Furthermore, only two beams were necessary for the final adjustment of the imaging MBS, demonstrating its nearly perfect imaging properties. Finally, the overall transmission efficiency up to the launcher window was determined to be 94% including diffraction, beam truncation, misalignment and absorption of the mirrors and the atmosphere.
The whole ECRH-system was successfully used in OP1.1 for plasma start-up, wall conditioning, heating and current drive - all disciplines with high reliability. However, only six gyrotrons with a total power of maximum 4.3MW were used, because the divertor was not yet installed in this commissioning phase of W7-X. Therefore, the energy throughput during a discharge was limited to 4MJ. Nevertheless, electron temperatures up to Te ≈ 10keV were easily achieved using ECRH with typically peaked profiles in case of central X2 deposition. The electron density was operated up to n$_e$ ≈ 0.3•10^{20} m^{-3}, leading to an ion temperature of 2keV. The ions are heated by electron ion collisions. Therefore, the Ti profile is determined by the - typically flat –electron density profile of the electrons. Even though the densities in OP1.1 were far away from the X-mode cutoff at n$_{x-cutoff}$ = 1.2•10^{20} m^{-3}, a multi-path O2-heating scenario could already be demonstrated. It is thus feasible to achieve almost full equilibration of electrons and ions during n$_e$ > n$_{x-cutoff}$ scenarios in OP1.2. All ten gyrotrons will be in operation by then, with a total power of up to 9MW and a typical pulse length of 10s –100s. Furthermore, two so-called remote-steering launchers (RSL) were installed to investigate advanced current drive scenarios, and to test this reactor relevant launcher concept at high-power.

Eligible for student paper award?

No

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