Overview and Initial Results of the ICRH Antenna for the Optimized Stellarator Wendelstein 7-X

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The superconducting stellarator Wendelstein 7-X (W7-X) at the Max-Planck-Institute in Greifswald began operation in 2015. To demonstrate efficient confinement of energetic alpha particles, which will be essential for a future Helias fusion reactor, W7-X requires a population of fast ions with energies ranging from 80 to 100 keV in the core of high-density plasmas. This can be achieved with Ion Cyclotron Resonance Heating (ICRH) using minority heating of H in ^{4}He and D plasmas, as well as the three-ion scenarios of ^{4}He-(^{3}He)-H and D-(^{3}He)-H.

The ICRH antenna for W7-X consists of two poloidal straps. Each strap is terminated by a pre-matching capacitor at one end and short-circuited at the other, with RF power fed at an intermediate position along the straps. The antenna's shape is tailored to match the 3D shape of the Last Closed Magnetic Surface (LCMS) in the standard magnetic field configuration of W7-X, resulting in variable curvature in both toroidal and poloidal directions over the plasma-facing surface [1]. The antenna can also be moved radially up to 35 cm, and a gas puffing system is incorporated to inject gas in the region between the scrape-off layer (SOL) and the LCMS to locally improve coupling. The full system was commissioned on W7-X plasmas in February and March of 2023. During these experiments, only one of the two straps was powered due to a faulty pre-matching capacitor and vacuum feedthrough, resulting in operation with $k_{||} \sim 0$.

Two significant milestones were achieved: operation at high power levels (up to 700 kW) and the generation of a target plamsa using ICRH alone at magnetic fields below the usual 2.5 T, where the 140 GHz ECRH system is not resonant. In these experiments, the standard magnetic configuration in W7-X was used, the LCMS was positioned 17 cm from the first wall, and the distance between the antenna and the LCMS ranged from 3 to 10 cm. Despite the unfavourable heating conditions, $k_{||} \sim 0$, there was a clear increase in the plasma stored energy at constant electron density, consistent with an increase in ion temperature.

The Faraday screen is omitted in this antenna design, based on extensive experience with TEXTOR [2]. No edge interaction was observed. Small levels of Cu and C impurities where observed with VUV and Soft X-ray diagnostics. In plasma start-up experiments at 1.7 T, plasmas were sustained for the full duration of the ICRH pulse with approximately 300 kW RF power.

[1] J.Ongena et al., Physics of Plasmas 21, 061514 (2014)
[2] R. Van Nieuwenhove et al., Nucl. Fusion 32 (1992) 1913