Overview of the design and first experimental results of the ICRH system for the large optimized stellarator Wendelstein 7-X

J.Ongena[1], Ye.O.Kazakov[1], K.Crombé[1,2], D.Hartmann[3], D.Castaño-Bardawil[1], D.Lopez-Rodriguez[1,2], I.Stepanov[1], M.Verstraeten[1], M.Vervier[1], B.Schweer[1], A.Dinklage[3], T.Fornal[4], M.Gruca[4], K.P.Hollfeld[5], J.P.Kallmeyer[3], I.Ksiazek[6], A.Krämer-Flecken[7], M.Kubkowska[4], Ch.Linsmeier[7], F.Louche[1], O.Neubauer[7], D.Nicolai[7], G.Offermanns[5], G.Satheeswaran[7], L Syrocki[4], M.Van Schoor[1], R.C.Wolf[3], the TEC team[1,7] and W7-X team[8]

[1]*Laboratory for Plasma Physics, Royal Military Academy, TEC Partner, Brussels, Belgium*
[2]*Department of Applied Physics, Gent University, Belgium*
[3]*Max-Planck-Institut für Plasmaphysik, Wendelsteinstraße 1, D-17491 Greifswald, Germany*
[4] *Institute of Plasma Physics and Laser Microfusion, 23 Hery Str., 01-497 Warsaw, Poland*
[5]*Zentralinstitut für Engineering, Elektronik und Analytik – Engineering und Technologie, (ZEA-1),*
[6]*Institute of Physics, Opole University, ul. Oleska 48, 45-052 Opole, Poland*
[7]*Institut für Energie- und Klimaforschung / Plasmaphysik (IEK-4), Trilateral Euregio Cluster (TEC) Partner, Forschungszentrum Jülich, D-52435 Jülich, Germany*
[8]*See the author list of the paper by T.Sunn Pedersen et al., Nucl. Fusion 62 (2022) 04202*

e-mail (speaker): j.ongena@fz-juelich.de

The superconducting stellarator Wendelstein 7-X (W7-X) at the Max-Planck-Institute in Greifswald has been operational since 2015. One of the main goals of W7-X is to demonstrate efficient confinement of fast ions at high plasma densities. To achieve this, W7-X was specifically optimized to handle volume averaged beta values of up to 5%, which corresponds to plasma densities above 10^{20} m^{-3}. To simulate the behaviour of alpha particles in a future stellarator reactor, a population of fast ions with energies ranging from 80-100keV is required in the core of high-density plasmas in W7-X. A promising method to tackle this demanding task in W7-X is Ion Cyclotron Resonance Heating (ICRH), using minority heating of H in ^{4}He and D plasmas and the ^{4}He-(^{3}He)-H or D-(^{3}He)-H 3-ion scenario.

Figure 1. The ICRH antenna in the vacuum vessel of W7-X for three radial positions.

The ICRH antenna for W7-X consists of two poloidal straps, with each strap terminated by a pre-matching capacitor at one end, short-circuited at the other and the RF power is fed at an intermediate position along the straps [1]. The shape of the antenna is matched to the 3D shape of the Last Closed Magnetic Surface (LCMS) of the standard magnetic field configuration on W7-X, leading to a variable curvature in toroidal and poloidal direction over the plasma-facing surface of the antenna. In addition, the antenna can be moved radially over max. 35 cm (with a speed up to 6 mm/s), and a gas puffing system is incorporated to puff gas in the region between the scrape-off layer (SOL) and the LCMS to locally improve the coupling. The full system was commissioned on W7-X plasmas in February and March of 2023. In these experiments only one of the two straps of the antenna was powered, because of a faulty pre-matching capacitor (and vacuum feedthrough), leading to operation with $k_{\parallel} \sim 0$.
Two main milestones, operation at high power levels (above 500kW) and plasma breakdown using ICRH only at magnetic fields below the usual 2nd harmonic used by ECRH (2.5T), to allow realizing plasmas with higher beta-values at moderate heating power levels. In these experiments using the standard magnetic configuration in W7-X the LCMS was located at 17cm from the first wall and the antenna-LCMS distance was between 3 and 10cm. Up to 700kW RF power was delivered without hitting an upper limit for the voltage or currents in the system. Despite the unfavorable heating conditions ($k_{\parallel} \sim 0$), a clear increase of the plasma stored energy was seen at constant electron density, pointing to an increase in the ion temperature. The Faraday Screen is omitted in this antenna, based on extensive experience on TEXTOR [2]. No edge interaction could be observed and the impurity levels remained low when ICRH was switched on top of ECRH (see Fig.2). In plasma breakdown experiments at 1.7T plasmas were created for the full duration of the ICRH pulse with about 300kW RF power.
After removal of the antenna from the W7-X plasma vessel only a slight discoloration of the antenna straps and box was observed.

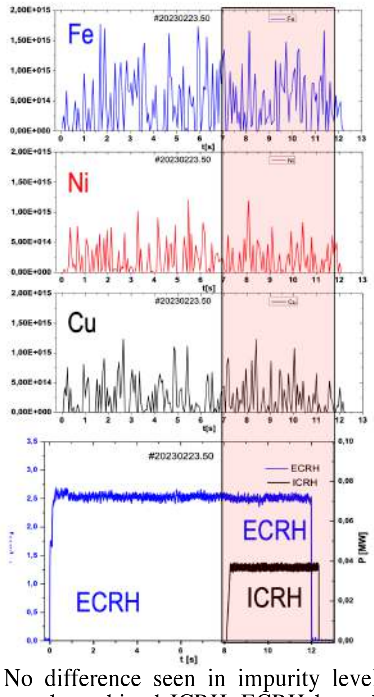

Figure 2. No difference seen in impurity levels between ECRH only and combined ICRH+ECRH heated phases in W7-X pulses.

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