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Advancements in Commissioning the ICRH System for Wendelstein 7-X

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The Ion Cyclotron Resonance Heating (ICRH) system for the stellarator Wendelstein 7-X (W7-X) at the Max-Planck Institute for Plasma Physics, Greifswald, Germany, was developed through a collaboration between the Laboratory for Plasma Physics from the Royal Military Academy in Belgium, the Research Centre Juelich, and the Max-Planck-Institut fuer Plasmaphysik Greifswald in Germany, under the Trilateral Euregio Cluster (TEC). Designed to deliver up to 1.5 MW Radio Frequency (RF) power for 10-second pulses, the antenna consists of two poloidal straps, with a pre-matching capacitor on one end and a short-circuit on the other [1, 2]. The antenna shape is adapted to the Last Closed Magnetic Surface (LCMS) and can be radially adjusted by 35 cm to optimise coupling, aided by a gas puffing system. The antenna was installed in W7-X in 2021, integrated into the CoDac system in 2022, and first operated during the experimental campaign OP2.1 in 2023. A refurbishment autumn in 2023 enabled full two-strap operation in the following campaign OP2.2 (2024). Initial experiments in February - March 2023 used a single strap due to a faulty pre-matching capacitor. The plasma consisted of ^{4}He with a minority of H, the central magnetic field in W7-X was 2.5T. Over 500kW of RF power was delivered in the first hours of operation without hitting an upper limit for the RF voltages or currents in the system. Despite the unfavourable heating conditions ($k_{\|}$ close to 0), an increase of the plasma stored energy was seen at constant electron density, pointing to an increase in the plasma temperatures. Furthermore, plasma breakdown at 1.7T with 300kW RF power was successfully demonstrated. Despite the absence of a Faraday screen, impurity levels remained low, and no significant wall interaction was observed. The second experimental phase, OP2.2 in October - November 2024, involved commissioning the two-strap antenna, achieving up to 450kW in 6-second pulses under dipole and monopole phasing (Figure 1). Extensive RF conditioning was necessary, maintaining the antenna at about 80°C between operational days. Despite successful power injection, high plasma radiation levels limited the increase in stored energy, with radiation concentrated in the island region in front of the antenna. Hydrogen minority heating in ^{4}He plasmas and ^{3}He minority heating in H plasmas faced challenges due to elevated hydrogen concentrations (>10%). Further experiments in 2025 (OP2.3) focused on reducing hydrogen concentrations below 10% in ^{4}He plasmas, supported by Ion Cyclotron Wall Conditioning (ICWC). A new diagnostic tool facilitates precise ^{3}He concentration measurements for three-ion heating experiments. First results with a better control of the minority concentrations leading to ion heating and the generation of fast ^{3}He ions, are presented in the talk. Plasma start-up was tested using both dipole and monopole phasing on plasmas at 1.7 T with varying concentrations of ^{4}He and H. Plasma densities of several times 10^{18} m^{-3} were achieved with up to 400 kW of power applied to the antenna straps (Figure 2). These densities are sufficient for Neutral Beam Injection (NBI) in the plasma.

The advancements mark significant progress toward efficient ICRH operation in W7-X.

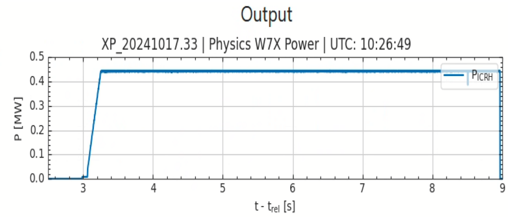

Figure 1: Example of a high power (450kW) long pulse experiment with the two-strap antenna.

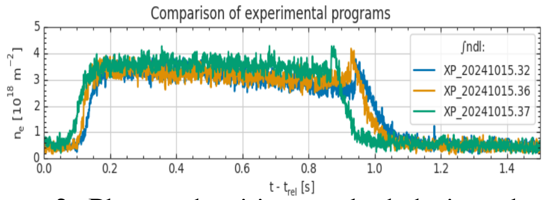

Figure 2: Plasma densities reached during plasma startup experiments with the two-strap antenna at 1.7T, RF antenna powers between 200 and 400kW.

References
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