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WEST Actively Cooled Load Resilient Ion Cyclotron Resonance Heating Results

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ELM-resilient antenna with the capability of operating in long-pulse operation is mandatory for Ion Cyclotron Resonance Heating (ICRH) system of ITER and next step fusion machines. The Associated Laboratory CEA-ASIPP had designed in collaboration with ERM, and manufactured three actively water-cooled and ELM-resilient multi-megawatt antennas for WEST [1]-[6] (Fig1). This paper reports on the successful design, manufacturing and operation of these antennas on WEST.

The intrinsic load tolerance property of the WEST ICRH antennas [5], already demonstrated during commissioning and first plasma experiments [7], has been confirmed in the 2019 experimental campaign and is in good agreement with RF modelling (Fig2). An automatic matching algorithm has been implemented and successfully used during operations [1]. Due to the antenna load-resilience, variations in plasma scenario parameters such as fluctuations of the fast wave cut-off layer or minor changes in resonance layer location do not affect the antenna operation significantly. Moreover, the operation of the antennas is quite straightforward, as once the antenna tuning capacitors have been set up for a given frequency, the antenna accepts small capacitance deviations from ideal match point.

Long pulse high power operation requires dedicated protections from the generator to the antenna [1]. For this purpose, several interlocks are used in the WEST ICRH system [2]. Sub-Harmonic Arc Detector (SHAD) and reflected power interlocks stop generators from feeding an antenna within 10 µs, then re-apply power after 30 ms. The RF power is real-time controlled in order not to exceed the antenna maximum electric field (2 kV/mm) or the maximum voltages and currents thresholds at the capacitors (30 kV or 915 A peak values respectively). The new optical arc detectors looking inside the antenna have been qualified and found to trigger mostly during the conditioning phases. These optical detectors are particularly essential to protect the low impedance sections of the antenna, where arcs may not trigger other safety systems. The pressure level inside the antenna is monitored from an auxiliary pumping system. RF power is cut if pressure is above a safety threshold of 3.5x10-3 Pa until pressure recovers. Abnormal events can also be detected from the antenna voltage measurements and additional interlocks have been added for safer operation. RF power is stopped within 10 µs in case of voltages lower than 10 kV (for power larger than 100 kW) or if voltages relative differences are higher than 50%. Thanks to all of these security systems and despite the higher power levels achieved, no damage has been observed on the three antenna front-faces after the WEST 2019 experimental campaign.

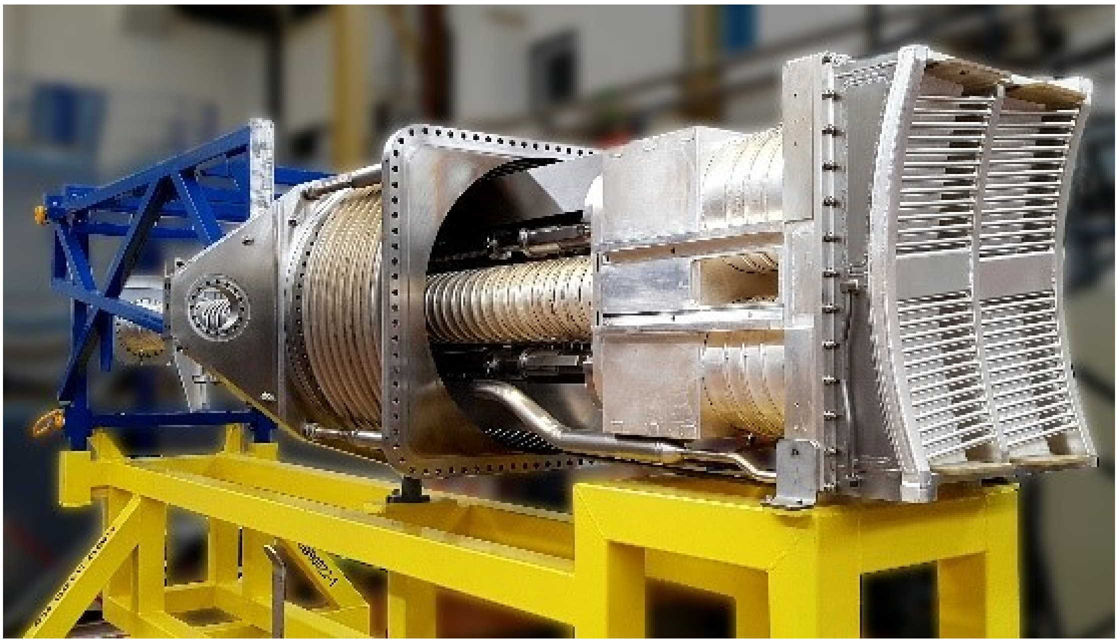

Figure 1: Picture of one WEST ICRH Antenna.

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The commissioning phase was relatively short, of about two days for each antenna to reach 1 to 1.5 MW. After this commissioning phase, all three antennas have been operated simultaneously on WEST plasmas, leading to 5.8 MW coupled ICRH power after around 50 plasma discharges (close to 2 MW per antenna). All antennas are equipped with dedicated gas puffing valves in order to improve the coupling conditions. However, due to the present WEST pumping system capabilities, no major coupling improvement has been observed for the limited level of gas flux injected by these valves so far. In combined operation with the Lower Hybrid Current Drive (LHCD) system, a total injected RF power of up to 9.2 MW has been achieved [8].

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