First results of LH coupling and current drive in WEST full metallic environment and commissioning of the new ELM resilient ICRF antenna

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Introduction: The WEST tokamak has achieved L-mode X-point plasmas with 12 s duration (I_P = 0.5 MA, $n_e \sim 3\times10^{19}$ m^{-3}, B_T = 3.7 T) during the last experimental campaign in summer 2018 [1]. WEST is the first and only full W-device relying on radiofrequency systems for heating and current drive. This paper presents the results of the Lower Hybrid Current Drive (LHCD) experiments in WEST, together with the commissioning and successful test on plasma of the first new load-resilient long-pulse Ion Cyclotron Range of Frequencies (ICRF) antenna, manufactured in collaboration with ASIPP, Hefei [2].

LHCD results: The high power CW LHCD system (9 MW at generator, two launchers, f = 3.7 GHz) has been extensively used in Tore Supra mainly for long pulse operation, and has since undergone modifications and maintenance for WEST. In the first WEST experimental campaign (Oct. 2017 – Feb. 2018), several plasma equilibria were tested aiming at optimising the coupling of the Lower Hybrid (LH) power. Once adequate plasma equilibria had been found [3], the LH power could rapidly be increased to 2.3 MW for 2 s [4]. In the summer campaign 2018, two boronisations were carried out, which allowed to operate at higher plasma density ($n_e \sim 3\times10^{19}$ m^{-3}), and thus to improving the LH coupling further. L-mode discharges lasting up to 12 s with coupled LH power of 1.9 MW for 9.5 s was achieved (Fig. 1), with low level of reflected power (reflection coefficient < 8% on both launchers). The LH current drive efficiency is found to be similar to that obtained in Tore Supra GJ discharges ($\eta \sim 0.7\times10^{19}$ m^{-2}A/W) [5]. The improved current drive efficiency as compared to the first WEST experimental campaign [4] could partly be due to lower Z_{eff} after the boronisations.

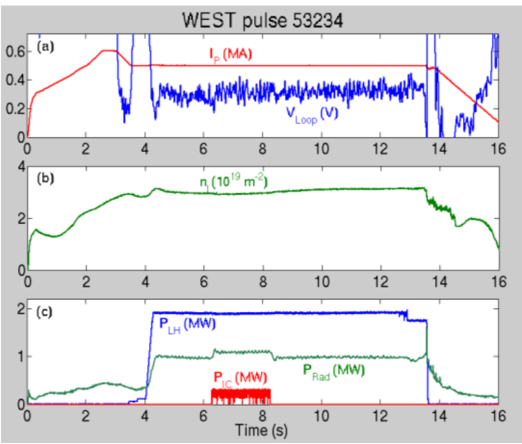

Fig. 1: Overview of WEST pulse #53234 with 1.9 MW coupled LH power for 9.5 s and 0.3 MW ICRF power for 2 s.

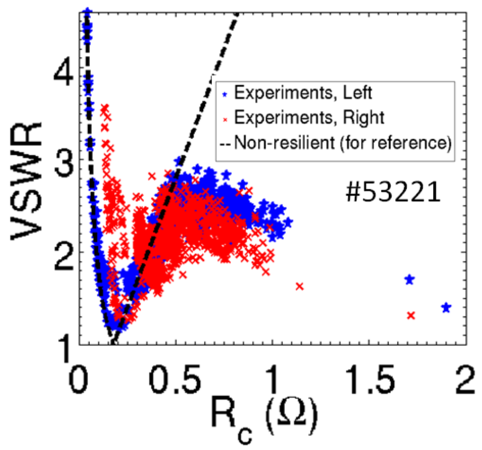

Fig. 2: Measured VSWR versus ICRF coupling resistance (R_c). The non-resilient case is shown for reference (black dashed line).

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It is worth noting that the radiated power fraction in the bulk plasma decreased as the LH power increased, from $P_{Rad,Bulk}/(P_{LHCD}+P_{Ohm})$ ~ 80% down to ~ 50%. This suggests that LHCD is not directly acting on W-sources, like the W-coated launcher side protections.

ICRF results: The ICRF system on WEST is designed to operate at a power level of 9 MW during 30 s or 3 MW during 1000 s, using three load-resilient antennas for ELMy H-mode operation. The first ICRF antenna has been installed on WEST and successfully commissioned on WEST plasmas in summer 2018. Before installation on the tokamak, the antenna underwent three categories of pre-qualifications tests [7]. These tests aim at validating the design and manufacturing of the antennas and accelerating their commissioning in the tokamak, hence avoiding operational delays to the WEST experimental program. Firstly, milliwatt-range RF experiments were carried out, validating the RF design and assessing the load-resilience, using a load consisting of a radially moveable glass aquarium filled with salty water [8]. Secondly, leak detection tests were carried out in the dedicated TITAN test bed. Thirdly, high RF voltage tests were carried out in TITAN, feeding each half antenna at ~ 15 kW range power in order to raise the RF voltage and current at the straps to their nominal peak values (27 kV and 915 A), corresponding the constructor limits and maximum electric field of 2 MV/m. One these three tests completed successfully, the ICRF antenna was installed on WEST and commissioned on plasma up to 0.3 MW for 2 s, and 0.6 MW of peak coupled power. These preliminary WEST experiments have indeed allowed confirming the load-resilience of the antenna. Fig. 2 shows that the VSWR remains below three during excursions in edge electron density and coupling resistance, as predicted by the low power tests and the RF modelling [8].

Summary: The recent WEST experimental campaigns in a full W-environment have shown promising results with the RF heating and current drive systems, both LHCD and ICRF. LH power of 1.9 MW has been injected during 9.5 s, with current drive efficiency similar to that obtained in Tore Supra long pulse discharges. The first WEST ICRF antenna has been tested in the TITAN testbed and commissioned on WEST plasmas in July-August 2018. The objective of a limit at 27 kV corresponding to the current limit of the matching capacitors at 915 A at 55.5 MHz under vacuum has been obtained during 2 s. In addition, 0.6 MW has been coupled on WEST L-mode plasma, and the load-resilient behavior of the antenna during plasma density variations has been demonstrated.

References

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