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Operating a full tungsten actively cooled tokamak: overview of WEST first phase of operation

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WEST is a MA class full tungsten superconducting tokamak, equipped with actively cooled plasma facing components [1]. WEST aims at demonstrating long pulse operation in a full tungsten environment, in support of ITER and DEMO. WEST heating systems include ICRH (up to 9 MW) and LHCD (up to 7 MW). During its first phase of operation, the lower divertor of WEST was progressively equipped with several ITER grade actively cooled bulk tungsten (W) Plasma Facing Units (PFU), while the remaining of the divertor was made of inertial tungsten coated elements. This paper reports on the main findings from WEST phase 1, in terms of operational domain, plasma performance achieved, and first tests of the ITER like PFU.

During the initial commissioning phase of WEST, operation was hindered by the production of runaways electrons (RE). This led to severe damage on PFC and even to the quench of one of the superconducting coils, due to the induced radiation following the impact of the runaway beam on the vessel walls [2]. A RE detection scheme was then successfully developed to trigger a plasma soft stop. Surprisingly, RE have been avoided in the start up phase of the discharge by reducing the prefill pressure. WEST initial operation was performed without boronization. This led to a limited operational domain, which was significantly extended, in particular in terms of density, after performing the first boronizations [3]. During the last campaign, boronization was regularly used.

In terms of plasma performance, the main achievements of WEST phase 1 include: up to 9.2 MW of combined LH and ICRH power coupled to the plasma, long discharges up to ~1 minute (Figure 1) and first transitions towards improved confinement (Figure 2).

On the actively cooled upper tungsten divertor, L mode long pulses have been routinely achieved in upper single null configuration with LHCD (P_{LH}=3.0MW), with a loop voltage down to 90 mV (Figure 1) [4]. This corresponds to a current drive efficiency of $0.6\text{-}0.7\times10^{19}$ $A.W^{-1}m^{-2}$ [5]. Higher efficiency ($\sim0.8\text{-}0.9\times10^{19}$ $A.W^{-1}m^{-2}$) can be achieved after a fresh boronization or at lower plasma current (0.4MA) when the LH power deposition profile, deduced from the hard X-ray diagnostic, is more peaked. In these L mode, electron heated, torque free plasmas, no W accumulation is reported despite peaked density profiles attributed to dominant TEM turbulence [6].

L-H transitions are observed after fresh boronization, when combining 4MW of LHCD with 1MW of ICRH [5], for a power crossing the separatrix of the order of the Martin 2008 scaling law [7]. It results in a significant increase of the particle confinement time (30% increase of plasma density with gas injection turned off). The ExB velocity well, measured by Doppler reflectometry, gets deeper, reaching -5km/s [8]. However, in most cases, the plasma radiation increases, leading to an oscillatory regime (Figure 2).

The fraction of radiated power in LHCD, ICRH or combined LHCD+ICRH pulses is around 50%. Tungsten has been identified as the major radiating species. W radiation can lead to central cooling hence deleterious (2,1) MHD modes, which were prevented using early N_2 seeding [9].

Concerning power exhaust studies, the divertor peak heat flux has reached up to ~5 $MW.m^{-2}$ [10]. Despite this moderate power, cracking and local melting have been observed for misaligned ITER like PFU [11]. In addition, optical hot spots, which have been predicted to occur in ITER, have been observed experimentally for the first time in a tokamak environment [12].

Finally, to investigate interactions between He plasmas and W PFC, more than a hundred of 20-30 s pulses were repetitively performed in LSN [13]. The conditions for W fuzz formation have been reached in the outer strike point area. Post mortem analysis of the W components is ongoing.

WEST phase 2 will start in autumn 2021, to address long pulse / high particle fluence operation on the newly manufactured ITER-grade actively cooled divertor, with the ultimate target of running discharges up to 10MW/1000 s.

References

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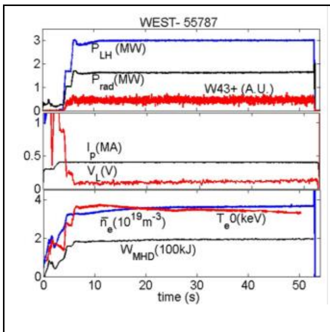

Figure 1 : long pulse discharge in WEST (Bt/Ip=3.7T/0.4MA, Upper Single Null configuration)

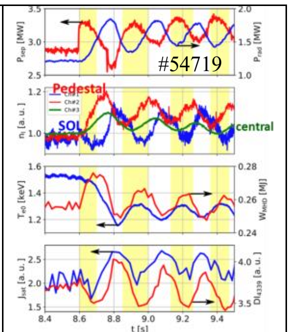

Figure 2 : oscillatory regime observed during transitions towards high confinement