Contribution ID: **1381** Type: **Overview Poster**

[OV POSTER TWIN] Operating a full tungsten actively cooled tokamak: overview of WEST first phase of operation

Monday 10 May 2021 18:20 (25 minutes)

Operating a full tungsten actively cooled tokamak:
overview of WEST first phase of operation
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WEST is a MA class superconducting, actively cooled, full tungsten (W) tokamak. Equipped with two up-down symmetric divertors, it operates at 3.7T, up to 1MA, with a plasma volume of 15 m3 and an aspect ratio between 5 and 6. CW RF power is installed: up to 9 MW of ICRH power and 7 MW of LHCD.
In support of ITER operation and DEMO conceptual activities, WEST aims at power exhaust studies in long and steady-state pulses, in various divertor configurations (LSN, USN, DN), in a full W environment. The lower divertor, partially made of ITER-grade Plasma Facing Units (PFU) complemented with inertially cooled W-coated elements in phase 1 (2017-2019, see Fig. 1), will be replaced by a complete ITER-grade divertor in phase 2, starting autumn 2020. 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 grade PFU.

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Initial phase of operation was hindered by the production of runaway electron beams, when the ohmic current failed to rise quickly enough. Interestingly, start-up runaway electrons have been avoided by reducing the prefill pressure. Severe damages on PFC were observed [Diez] and one runaway beam impact induced radiation even quenched one superconducting coil [Reux].
Additionally to 200°C baking and glow discharge cleaning, boronizations have been performed in the second campaign leading to long lasting improved breakdown conditions and higher density operational domain.
Apart from the few post-boronization pulses, the fraction of radiated power in LHCD, ICRH or LHCD+ICRH pulses remains high, around 50%. Tungsten is, in most cases, the major radiating species [Goniche]. Remarkably, in presence of W antenna limiters, the fraction of radiated power using LHCD or ICRH is similar [Colas], as long as the ICRH coupling conditions are optimized [Hillairet].
In the ohmic phase, W radiation can lead to central cooling hence deleterious (2,1) MHD modes [Maget]. Nitrogen injection during this early phase, by increasing the edge resistivity, leads to more peaked electron temperature, hence reduced MHD [Manas], allowing for higher performance of the RF-heated phase. Up to 9.2 MW of combined ICRH and LHCD power has been achieved and up ~5MW/1s separately [Hillairet, Liang].
In L-mode, the stored energy, WMHD, increases according to the ITER96 L-mode scaling law up to 350kJ. L-H transitions are observed after fresh boronization, when combining 4MW of LHCD with 1MW of ICRH [Goniche], for a power crossing the separatrix of the order of the Martin 2008 scaling law [Martin J. Phys. Conf. Ser. 2008]. It results in a significant increase of the particle confinement time (30% increase of plasma density with gas injection turned off). The Doppler reflectometry ExB velocity well gets deeper, reaching -5km/s [Vermare]. But, in most cases, the plasma radiation increases leading to an oscillatory regime.
On the actively cooled upper W divertor, long pulses lasting up to 55 s have been routinely achieved (see Fig. 2), with a loop voltage down to 90 mV [Goniche]. In these L mode, electron heated, torque free plasmas, no W accumulation is reported despite peaked density profiles attributed to dominant TEM turbulence [Manas].
The heat flux level and pattern on the lower and upper divertors have been characterized thanks to embedded thermal measurements, IR and flush-mounted Langmuir Probes. The maximum heat flux currently reported

on the W-coated graphite components is slightly above 5 MW.m-2 [Gaspar]. This was obtained with a conducted power on the divertor of ~2MW in two different scenarios: 1/ with combined LH and ICRH power after boronization at low X-point height (dX = 40 mm), 2/ with LH power only and high X-point height (dX = 120 mm).

In SOLEDGE2D simulations, target temperature profiles measured by Langmuir probe, as well as the radiated power measured by bolometry, were well reproduced with 3% of Oxygen as effective medium Z charge [Ciraolo]. The simulated asymmetry of O between the inner and outer targets is in qualitative agreement with UV measurements. The force balance analysis shows that friction dominates over thermal gradient forces at the inner target, while, at the outer target, the repelling thermal gradient forces dominate.

On the ITER-grade PFU, cracking and local melting have been observed for misaligned PFU. In addition, optical hot spots, which have been predicted to occur in ITER at the projection of the toroidal gaps on the subsequent PFU, have been observed experimentally, even for PFU aligned within specifications [Diez].

Finally, a He campaign has been run to investigate interactions between He plasmas and W PFC, in particular the formation of W fuzz [Tsitrone, Pegourie, Douai]. More than a hundred of 20-30 s pulses were repetitively performed in LSN. The conditions for W fuzz formation have been reached in the outer strike point area on the inertial W divertor (Einc > 20 eV, fluence > 1e24 He.m-2, Tsurf > 700 ℃). Articulated Inspection Arm inspections before and after the He campaign have shown no macroscopic sign of surface modification. Post mortem analysis of the W components is ongoing to characterize the He induced nanostructures formed.

WEST phase 2 will start in autumn 2020, to address long pulse / high fluence operation on the newly manufactured ITER-grade actively cooled divertor, up to 10 MW/1000 s.

References:

[Diez], [Reux], [Goniche], [Colas], [Hillairet], [Maget], [Manas], [Liang], [Gaspar], [Ciraolo], [Tsitrone], [Pegourié], [Douai], this conference. [Martin 2008] J. Phys.: Conf. Ser. 123 012033

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Session Classification: OV-OV/P Overview Posters

Track Classification: Overview