Topic: EXD

WEST first plasma operation with all tungsten plasma facing components

J. Bucalossi, C. Bourdelle, N. Fedorczak, T. Loarer, Ph. Moreau, E. Tsitrone, J.-F. Artaud, S. Brezinsek[1], H. Bufferand, X. Courtois, L. Delpech, C. Desgranges, P. Devynck, D. Douai, R. Dumont, F. Durodié[2], A. Ekedahl, J. Garcia, J. Gaspar, C. Gil, M. Goniche, J. Gunn, W. Helou, P. Hennequin[3], C.C. Klepper[4], P. Maget, Y. Marandet[5], D. Mazon, O. Meyer, G. Lombard, P. Mollard, J. Morales, E. Nardon, R. Nouailletas, Y. Peysson, C. Reux, F. Saint-Laurent, J.-L. Schwob[6], P. Tamain, G. Urbanczyk, L. Vermare[3], D. Vezinet and the WEST team*

CEA, IRFM, F-13108 Saint Paul-lez-Durance, France
[1]Forschungszentrum Jülich, IEK, Partner of the Trilateral Euregio Cluster (TEC), 52425 Jülich, Germany
[2]LPP-ERM/KMS - BE-1000 Brussels-Belgium
[3]Ecole Polytechnique, LPP, CNRS UMR 7648, 91128
[4]Oak Ridge National Laboratory, Oak Ridge, TN 37831-6169, USA
[5]PIIM, CNRS-Université de Provence, Marseille, France
[6]Racah Institute of Physics, The Hebrew University, IL-91904 Jerusalem, Israel

The transformation of Tore Supra into WEST [1], from limited to diverted magnetic configuration and from carbon to tungsten plasma facing components surface material was successfully completed at the end of 2016. The lower divertor is presently equipped with a set of actively cooled ITER-like units, complemented with inertially cooled tungsten plasma facing units The ongoing phase of operation is mainly dedicated to the development of plasma scenarios that will be extended over long duration in the second phase of operation with the full actively cooled lower divertor, which should start by the end of 2019. This paper reports on the achievements performed during the first phase of operation.

While plasma breakdown was readily achieved, plasma current ramp up was found to be more difficult to achieve. Indeed the in-vessel divertor copper coils with their thick stainless steel casing together with the copper passive structures which have been added to enable operation at elongation above 1.5 had major consequences on the evolution of the magnetic field map during the plasma initiation phase. In addition, the initial level of light impurities severely hindered the burn through phase. After a two steps modification of the in-vessel passive structures and extensive conditioning by deuterium glow discharge cleaning, a narrow operational window has been found by the end of 2017 at maximum loop voltage (~1.3V/m) and very low prefill pressure (~2mPa) and plasma current could be ramped up to nominal value in diverted configuration (800 kA). Transition to X-point configuration is typically performed after 0.5 s (at ~300 kA).

Magnetic configuration was successfully tuned up to get vertically and radially stable configurations all along the burn through phase with the help of a dynamic magnetic field solver which takes into account the full tokamak geometry including all passive structures, the iron core and the coils power supply circuit characteristics [2]. In particular, premagnetization coils currents and time traces of power supplies voltages were optimized using the inverse time evolution mode (with no plasma).

During the first period of operation, the prefill window was constrained to obtain proper ohmic plasma discharges. At lower prefill pressure, no breakdown occurred (consistent with Paschen law curve) while at higher prefill pressure, transition to electron slideaway discharges happened, indicating a too high level of impurities. Inboard and outboard limiters incurred significant damages (tungsten coatings melting) by runaway electron beams during these plasma startup attempts. A protection scheme was successfully set-up to avoid slideaway discharges based on the current ramp up rate value at the very beginning of the discharge. Slideaway discharges exhibit lower ramp up rate and were stopped rapidly (after 70 ms below 100 kA). At this stage, ohmic discharges were highly radiative (80-100% of input power radiated) and no clear improvement by successive plasmas was observed. Lower hybrid wave heating was applied up to

* http://west.cea.fr/WESTteam

2.5 MW [3] but still a limited fraction of power was conducted onto the plasma facing components resulting in limited conditioning effect. In addition, plasma density could not be raised to values compatible with higher LH power (>2 10^{19} m^{-3}) without radiative collapse. Therefore it was decided to boronize the tungsten plasma facing components to open the operational domain.

The first boronization was performed in July 2018 using 10%/80% diborane (B_2H_6)/helium mixture glow discharge. As expected, the deposited boron layer (~100 nm) dramatically changes the situation. Plasma startup window opened up allowing highly reliable startup with much larger prefill (up to 20 mPa achieved) and reduced loop voltage (although not fully investigated so far). Slideaway electron discharges disappeared and higher plasma density was reached. Heat load pattern on the divertor target was monitored by dedicated PFC diagnostics (infrared systems, Langmuir probes, thermocouples) allowing for first power deposition studies.

Scenario development towards H-mode plasmas was started. Up to 2.8 MW of LHCD and 0.5 MW of ICRH have been injected into the plasma so far [4, 5] with a fraction of radiative power around 60%. A typical L-mode discharge is presented in Figure 1. Doppler reflectometry measurements showed that the radial electric field profile deepens at the separatrix with the additional power, indicating that the H-mode threshold is getting near (values down to Er/B ~-5 km/s have been obtained). Note that the power through the separatrix is still below the Martin 2008 scaling law prediction (up to 1.5 MW).

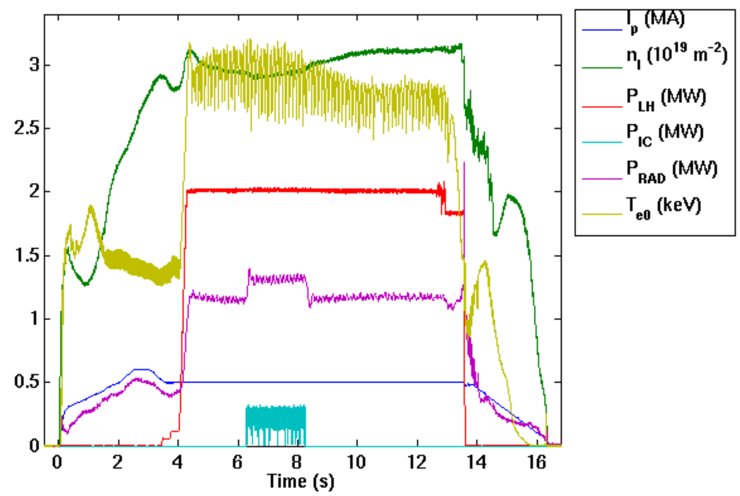

FIG. 1. Time traces of plasma current, line-averaged density, LHCD injected power, ICRH injected power, radiative power and central electron temperature for WEST #53234

Progresses have been slowed down by MHD activity in the current ramp-up attributed to the W influxes in the core plasma at the breakdown resulting in hollow temperature profiles. Depending on the initial current fast rise conditions, the discharge can evolve either successfully in a sawtoothing discharge after a large temperature crash (largely inverted q-profile Double Tearing Mode reconnection) or in a locked mode (2,1) preventing LHCD application. MHD modes could be clearly resolved with the tangential wide angle IR camera (in presence of runaway electrons) [6]. Breakdown and preforming will have to be optimized with present walls conditions to find reliable operation conditions. Experiments will resume at the end of October with the objective to establish a robust H-mode discharge in order to start the testing of the ITER-like plasma facing unit prototypes that are installed into the lower divertor target.

WEST first plasma operation points to the issues encountered when starting a fusion facility with high Z material first walls, and in particular with tungsten, which was found to reduce the operational domain and required conditioning with thin gettering films (boronization) to progress during this first operation phase.

References

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