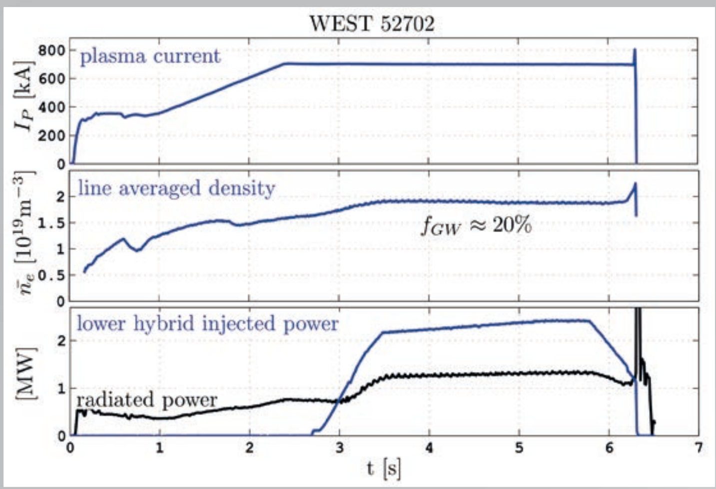
Institute for Magnetic Fusion Research

Newsletter N°20 - March 2018

First Megawatts of RF power in the plasma

The C2 campaign ended on February 16 with 2.5 MW of additional power injected into the plasma. This promising progression will be continued in May with the objective to reach the H-mode regime.



Having achieved stable X-point plasmas by the end of last year, Lower Hybrid Current Drive power was injected into the plasma so as to increase its temperature and extend its duration. After careful shaping of the plasma boundary in front of the launchers, the power could be progressively raised and reached 2.5 MW during several seconds at the very end of the experimental campaign. Highly ionized tungsten emission was observed by UV spectroscopy indicating high temperature in the core of the plasma. At this stage of the experiment low heat fluxes were measured on the plasma facing components of the divertor as a significant part of the injected power was radiated on the whole vessel due to the high intrinsic impurity content in the plasma.

WEST vessel is now open to welcome the ITER-like plasma facing units provided by the European Domestic Agency (see WNL19) and the second Ion Cyclotron Resonance Heating antenna. The 2nd WEST experiment planning meeting that will be held in Aix en Provence, March 20-21, will review the recent achievements and prepare the upcoming experimental campaigns.

A snake in WEST

During C2 campaign, the Articulated Inspection Arm (AIA) robot performed regular inspections inside the vessel. These deployments under ultra-high vacuum conditions provided a bunch of images of the inner components at different stages of experimentation.

Robotics will be needed in fusion machines to assist plasma operations and physics programs, by monitoring the exposed in-vessel components all along plasma campaigns. A robot able to operate inside the vessel under vacuum and temperature conditions allows mini-invasive inspections while preserving machine availability.

A first prototype was successfully tested in 2008 in Tore Supra. During WEST construction, a major upgrade was performed with the aim of converting the prototype to an efficient diagnostic. During this period, the robot was integrated and qualified in EAST, the Chinese Partner Tokamak, as reported in WNL8.

Today, the AIA robot is back at Cadarache and has been regularly used on WEST during C2 plasma campaign. The videos provided by the onboard camera unveil the evolution of the plasma facing components surface state due to plasma exposure and unexpected events (disruptions, runaway electron beams, etc.). It also allowed a more efficient preparation of the current maintenance phase by anticipating the machine in-vessel components status. In addition, the robot assisted mechanical assembly operations under nitrogen atmosphere inside vessel ports by providing a view from the torus as well as calibration of diagnostics under relevant vessel conditions.

For the next campaign, the AIA robot will be equipped with a new HD camera and the real time collision avoidance mode of the supervisor will be tuned to the WEST environment to be able to safely depart from inspection preset trajectories.

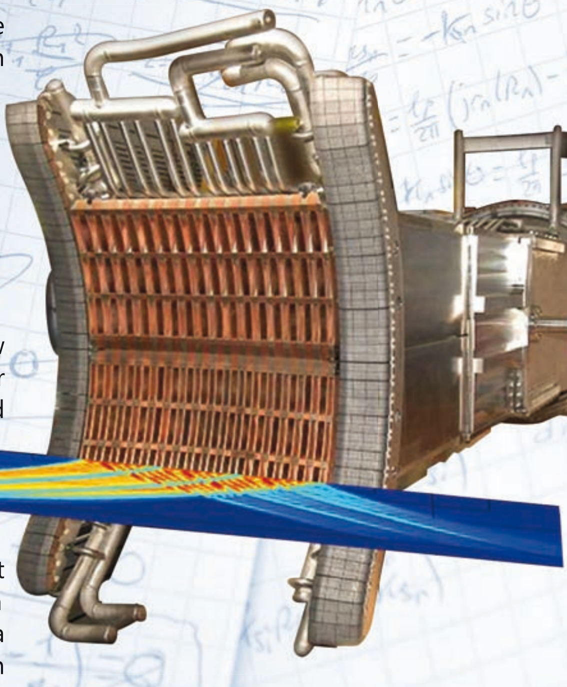
Why do we use LHCD ?

The Lower Hybrid Current Drive (LHCD) system enables to sustain the plasma current when the magnetic flux from the central solenoid has been used up and thus allow Steady-state operation in WEST

The main purpose of the system is to produce an electron current in the plasma that helps sustaining the toroidal electric current. High frequency waves are injected from the LHCD antennas predominantly in one toroidal direction (against the plasma current). These waves interact with electrons in the plasma to build up a tail of energetic electrons in one toroidal direction. This gives an electron current that helps maintaining the toroidal current in the plasma for as long as the LHCD power is turned on. It is by this method that Tore Supra achieved the 6 minutes long Gigajoule discharges in 2003.

The LHCD antennas are constructed of several small waveguides with built-in phase shifters that help to direct the power predominantly into one toroidal direction. The frequency of the waves that are used lies in the Giga Hertz range, i.e. similar to the frequency used in household microwave ovens. But the power used for heating the electrons in tokamak is far higher than what we need for boiling a cup of water. The power available for the LHCD system in WEST is 7 MW, which corresponds to approximately 10,000 household microwave ovens!

In order for the waves from the LHCD antennas to be transmitted (or "coupled") to the plasma, the electron density at the antenna mouth must exceed a critical density (roughly a factor 200 lower than the electron density in the plasma centre). If the density is below this critical density, most of the power is reflected back into the antennas and towards the klystrons. The electron density decreases exponentially in the layer between the plasma edge and the antennas and therefore it is important to control this distance carefully. When the electron density at the antenna mouth is adequate, high LHCD power can be injected into the plasma to provide the toroidal current needed to achieve steady-state operation.



LHCD antenna for WEST with a schematic illustration of the waves launched from one waveguide row. The wave intensity is asymmetric in the two directions, leading to a net acceleration of electrons in one direction.

The interferometer waveform back on the control room screen

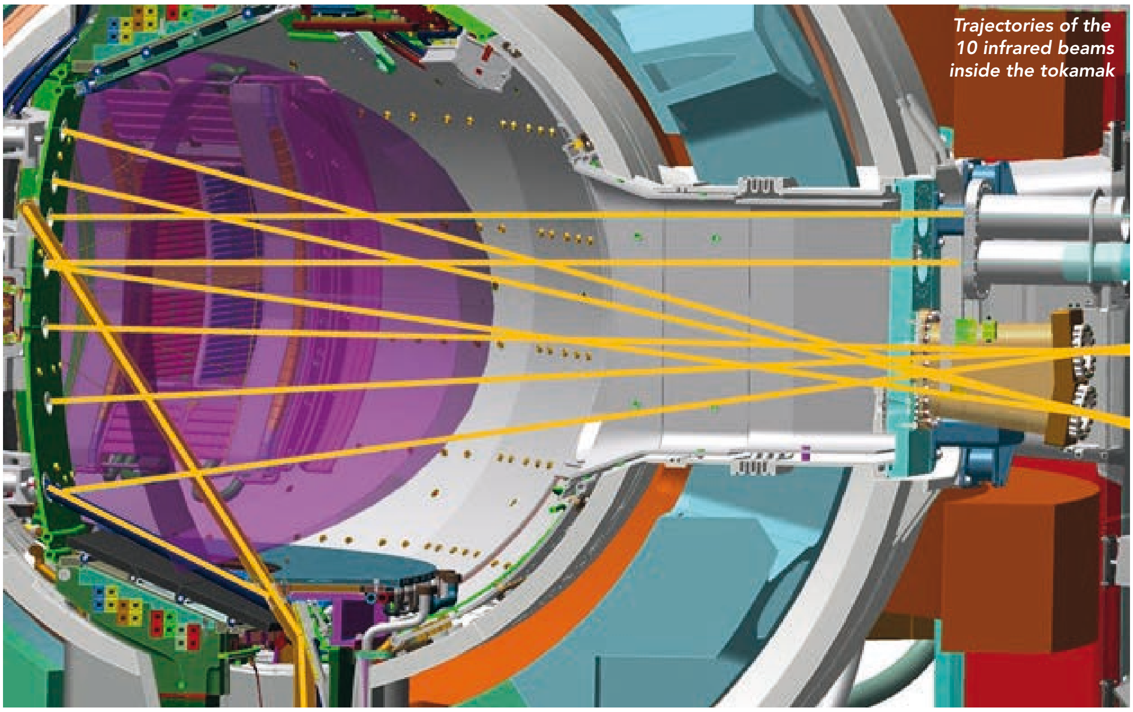
Subsequently with the improvement of plasmas, the Far Infrared Interferometer waveform has reappeared on the screen of the control room as a powerful tool to monitor and control the electron density.

To achieve this result, the ten channel of the combined interferometer-polarimeter diagnostic has been strongly modified to be adapted to the divertor configuration that partially occults the vertical ports.

The new infrared beams trajectories needed specific internal components such as corner cube mirrors welded on a customized cooled panel, windows and plane mirrors. The plane mirrors have been integrated under the baffle for the vertical beams to diagnose the divertor legs and the edge plasma region.

Outside the vessel, 90 out of the 450 existing optics were redesigned and repositioned and a new tower had to be inserted in the crowded tokamak environment to connect the infrared beams to the former detection system.

An up to date acquisition unit was set up to process the data sent by the new digital electronics. The algorithms, developed and flashed inside for both interferometry and polarimetry, benefit from the experience gained during the JET campaigns, where they were initially tested. A careful reconditioning of the laser and detectors cryogenic system allowed obtaining the interferometric signals simultaneously with the first plasma.



Trajectories of the 10 infrared beams inside the tokamak

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