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Exploitation of infrared thermography for WEST Plasma Facing Components protection during 2019 campaign

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The WEST tokamak (Tungsten (W) Environment in Steady state Tokamak) aims at testing ITER-like divertor plasma-facing units (PFU) in an integrated tokamak environment, and performing long pulse operation with high fluence. To operate long plasma discharges with power loads in the range of those expected in ITER (10-20 MW.m-2) on the Plasma Facing Components (PFC), infrared (IR) thermography are key diagnostics, enabling real-time monitoring of PFC surface temperature for safe operation, while providing essential data for various physics studies.
The infrared thermography system at WEST (ref. 1) consists of a set of three different diagnostics: 1) 7 endoscopes located in upper ports devoted to machine protection, providing a full coverage of the lower divertor and of the 5 antennas of the auxiliary heating systems; 2) a wide-angle view of the vacuum vessel observes tangentially one sixth of the vacuum vessel, and in particular upper port protections, upper divertor targets, bottom baffle, and inner guard limiter; 3) a very high-resolution view (100µm pixel size) of the lower divertor to study finely the thermal behavior of the ITER like PFUs installed in WEST.
During the WEST C4 campaign (July to Nov. 2019, about 1200 pulses with a duration > 2s), IR thermography diagnostics produced about 10 To of data, which are now easily accessible from the WEST database with the versatile software ThermaVIP, and thus available for further physics analyses. As a part of the Wall Monitoring System (WMS), the stream of IR data was also routinely used during C4 campaign with a real time processing for PFC temperature monitoring, through the plasma control system (PCS) that reduces the power of the heating device (antenna) responsible for a temperature increase (ref. 2). For about 14% of the pulses, the IR monitoring led to a thorough reduction of the heating devices injected power, and thereby helped to protect the PFCs and ensure a safe operation, while allowing plasma discharges continuation.
The correspondence between a region of interest (ROI) monitored by an infrared diagnostic and a heating device is given by the knowledge of the heating phenomena observed in WEST and acquired with Tore Supra since the 90s and along the firsts WEST experimental campaigns. For each couple ROI/heating device, two temperatures are defined: the first one (T1) is the maximal acceptable working temperature for the component (as stipulated in the WEST operation instructions) before triggering a plasma soft stop, the second one (T2<T1) is the threshold, which initiates the actuator power reduction of the heating device associated to the ROI. The power reduction is even more important as the measured temperature approaches T1, as presented on figure 1.

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Some overheatings above the T1 temperature were observed during C4 campaign, a couple of them being serious, despite the power feedback control. These overheatings are observable on components that are not directly affected by a heating power or that were not yet included in the real time protection process. For only one pulse, the power feedback control were followed by a minor overheating above T1, and an alarm was emitted toward the event distribution network. This case being unique demonstrates the feedback control efficiency for the PFC protection.
During C4 campaign, the IR interlock system was under validation step and the alarm was used only in a test mode, i.e. it was not connected to the plasma soft landing system. Nevertheless, its analysis on the overall campaign provides a satisfactory statistics: about 4% of the pulses should have been stopped during the plasma discharge if the interlock system would have been activated, with a false alarm rate of 1%. This result is promising for a forthcoming exploitation to reinforce the machine protection when feedback control is not efficient enough.
In addition to real-time monitoring, IR data post-pulse analyses are usually performed to validate thermal events and improve understanding of them. In order to help human interpretation of complexes IR thermal scenes, due to emissivity uncertainties, which vary with surface properties and variable viewing angles, or due to multiple reflections on metallic surfaces, an "interpretation by modeling" method were developed. It is based on Ray-tracing simulations, and it takes into account the optical properties of materials, and the di-

agnostics features. This development ended up at a synthetic diagnostic, which helped the interpretation of infrared images during C4 campaign, as illustrated by figure 2.

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