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Long pulse operation in fully metallic tokamak WEST: control and scenario development

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WEST is a tungsten tokamak designed for long pulse operation with actively cooled components. The main missions of WEST include high fluence plasma divertor exposure and the demonstration of long pulse H-mode in a full tungsten environment. Achieving long duration and high performance plasma discharges while ensuring the protection of the machine requires features such as specific controllers to keep the plasma in steady-state for several minutes and real-time machine protection algorithms to keep the plasma within operating limits.

One of the key parameters for long duration plasma is the flux consumption, which directly determines the pulse duration. To achieve this, simultaneous control of the loop voltage and the plasma current is required. The control scheme uses the voltage applied to the central solenoid and the power of the lower hybrid current drive system as actuators. These controllers have been developed and tested on the WEST flight simulator before being implemented in the Plasma Control System (PCS). A final tuning of the control parameters has been performed on only a few pulses.

Discharges of several minutes lead to triggering low dynamics phenomena such as Plasma Facing Component (PFC) temperature rise, which need to be monitored to avoid damage to the machine. Based on the infrared system measurements, the PCS decreases the heating power when surface temperatures of critical in-vessel components exceed pre-defined thresholds. If a second threshold is reached, a hard stop of the plasma is triggered.

In addition to these efficient controllers, a robust scenario has been developed. The LH power and plasma density ramp-up are set by using a scaling law to avoid ripple losses and tungsten radiation (leading to a plasma collapse). Then a slow ramp-down of the loop voltage on several tens of seconds is performed to avoid MHD and to reach a final value of 3-4 mV. Despite these strategies, unexpected events like Unidentified Flying Objects (UFOs) or long time-scale outgassing (>300 s) of in-vessel component located further away from the plasma heat load have required several repetitions to reach the current WEST plasma duration record of 6 minutes and 4 seconds with 1.15 GJ of injected/extracted energy.

The generation of UFOs during operation of a full metallic tokamak and the outgassing of remote in-vessel components are some of the main lessons learned during the recent WEST campaigns. To solve the UFO issue, the use of nitrogen injection to trigger X-point radiation seems promising. In this case, feedback control is required to maintain partial detachment without leading to a collapse of the plasma.

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