Modulation of the strike line position using control coils in Wendelstein 7-X

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In the middle of 2017 operating phase (OP1.2a) of Wendelstein 7-X (W7-X) has started. The stellarator was equipped with ten inertially cooled so-called Test Divertor Units (TDU) modules, two units per period with respect to the stellarator symmetry. Heat and particles are removed from the plasma boundary by so-called island divertor the concept of which was developed and tested for a stellarator first at Wendelstein 7-AS [1]. It uses large, resonant magnetic islands forming a region of open field lines at the edge separated from the core by last closed flux surface. Each divertor unit is made of fine corn graphite [2] and installed inside the vacuum vessel along the helical edge of the plasma contour. Their main purpose of the TDU divertor is to test the symmetry of divertor heat loads. Divertor units are build from several target plates, each consisting of series of target elements, to ensure resistance to the high heat flux of power and particles. Target elements are made from the monolithic pieces of graphite with a 3D surface reproducing a shape of future water cooled high-heat flux divertor (HHF which will be made of carbon-carbon fiber composite) planned for the next campaign OP2.

As W7-X aims to operate in a quasi steady state with discharge duration of up to 30 minutes, it is crucial to understand and learn how to control the power loads to the divertor, e.g. to avoid overheating of the components not designed to withstand such high loads. For this purpose each module, a total of five, is equipped with two control coils placed in the plasma vessel, behind the baffle and target plates, which by creating additional magnetic fields, can be used to vary the position and geometry of strike line and island size and position [3, 4] (Figure 1. In addition the control coils can be used for the correction of magnetic error field causing asymmetries in the heat load pattern and potential overloads on in-vessel components. This extra field can also correct symmetry of the field, sweep the strike line on the target in order to avoid local overheating or change the X-point position to control detachment (Figure 1).

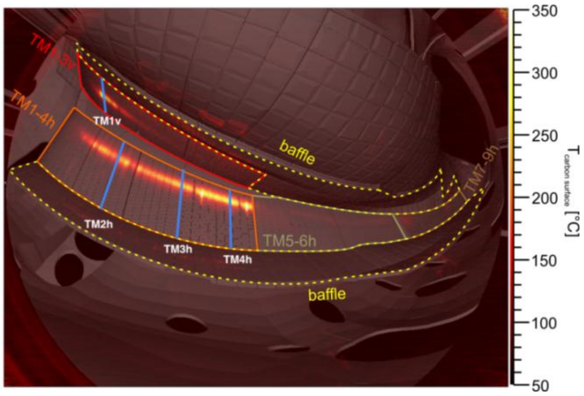

Figure 1 Infrared image of divertor surface temperatures during the discharge overlaid with a CAD model of plasma facing components. Two strike lines are visible as bright elongated structures, TMxh corresponds to target module number on the horizontal target and TMxv on the vertical target. Blue lines corresponds to the position where the strike line movement has been analyzed.

Control coils can be operated either with DC current of up to 2500 A or AC current of up to 625 A and with frequency of up to 20 Hz [5]. In DC mode each coil can be energized individually with the current amplitude and direction which allows to create correction fields, which are either symmetric or asymmetric in respect to magnetic field forming island divertor. In AC mode the ten power supplies are coupled in current amplitude and phase. For 1.2a the coil were connected such that an AC current resulted in an islands size sweeping (stellarator symmetric case). For the next campaign OP1.2b they are connected such that AC mode the islands will be shifted poloidally (stellarator asymmetric case).

In the symmetric case the same polarity of current in upper and lower control coils changes the island size. In the asymmetric case, the current polarity of the upper and lower coils is opposite. This results in slight poloidal movement of the islands. Figure 2 shows simulated behavior of the divertor strike line during symmetric (left) and asymmetric (right) variation of control coils currents. In the symmetric case blue dots corresponds to strike line when control coils are switched off. Energizing all coils with positive current of 2000 A (green dots, stellarator symmetric case) increases the island size and shifts both vertical and horizontal strike line towards pumping gap. With negative polarity current (-2000 A, red dots) strike line shifts on both target modules away from the pumping gap. A different behavior can be seen for asymmetric case (Figure 2, right). Here green dots correspond to strike line without any current in the control coils. Adding currents with amplitude of 2000 A, but with positive polarity in the upper module and negative in the lower one (red dots) results in a shift of strike line towards pumping gap on the horizontal target and away from the pumping gap on the vertical target. This is an effect of poloidal shift of the island. Reversing polarity (blue dots) results in the opposite movement of the island.

During the initial divertor campaign OP1.2a first experiments testing the influence of the control coils on the power loads distribution using DC and AC current were performed. All ten divertors are observed with an infrared system to monitor divertor power loads and during discharges.

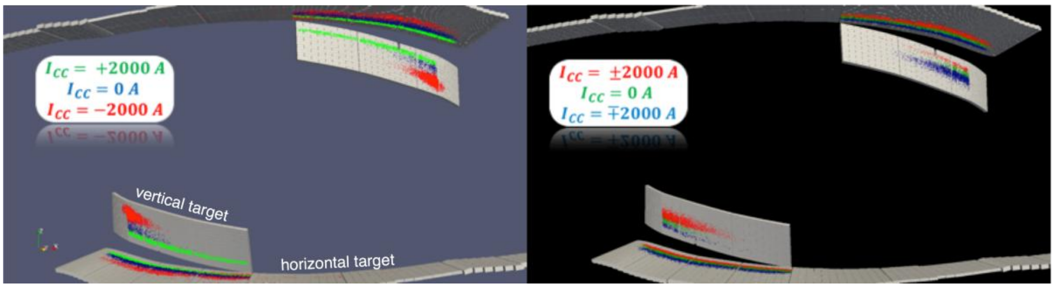

Figure 2 Movement of strike line during discharge, standard configuration. Symmetric case (left) and asymmetric case (right).

The heat flux density to the divertor is evaluated from the surface temperature evolution using THEODOR code [4]. During the experiment 20171018.019 control coils were operated with AC currents of amplitude of 600 A and frequency of 5 Hz Figure 2 shows strike line position depending on the control coils current where TMxh corresponds to target module number on the horizontal target and TMxv on the vertical target (Figure 1). AC discharge was realized with stellarator symmetric distribution of control coils currents, therefore vertical strike line (TM1v) moves towards the pumping gap with increasing current (by 7 cm) and away from the pumping gap when current is increasing towards – 600A. The maximum amplitude of the movement is 14 cm. The horizontal strike line moves in the opposite direction with the amplitude of the movement of up to 20 cm.

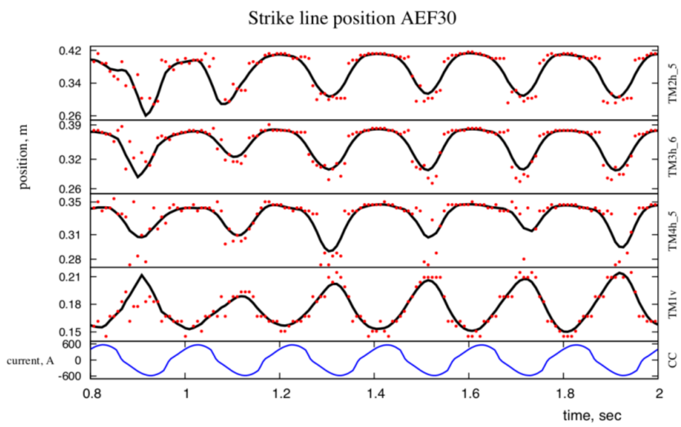

Figure 3 Strike line position for the AEF30 module (upper divertor), program number 20171018.019, TMxh_y for horizontal target module, TM1v for vertical one, CC – control coils, red dots correspond to experimental data and the black line is the fitted curve with noise reduction.

W7-X is equipped with 10 infrared systems to monitor power loads to 10 divertor units, which allows also to study asymmetry in the power loads. In the Figure 4 polar plots present amplitude of the strike line movement measured at three lower (modules 3 to 5) and four upper divertors (in modules 2 to 5). It shows that there is an asymmetry in the movement of the strike line. It has been measured that 1/1 and 2/2 error fields are present in standard configurations and their amplitude introduces asymmetry in the divertor power loads. In the previous campaign OP1.2a only 1/1 error field was corrected, however 2/2 was present throughout the whole campaign. Nevertheless movement of the strike line is rather symmetric when comparing target modules TM2h_5 (especially for upper divertors). For TM3h_5 and TM4h_5 some discrepancies between particular divertors appear, i.e. movement of the strike line on the AEF50 and AEF41 divertors is two times greater in comparison to the others. The maximum movements, which reaches over 20 cm, is observed for target module TM2h_5 and TM3h_5 in the divertor AEF41 and AEF50.

The control of the strike line is important for the steady state operation. In the initial divertor campaign the control coils proved to be a versatile tool for the manipulation of the island geometry, however the error fields and/or divertor misalignment introduce variation of the strike line movement when comparing different divertors. More experiments on error field corrections and strike control are planned for the present campaign OP1.2b(2018).

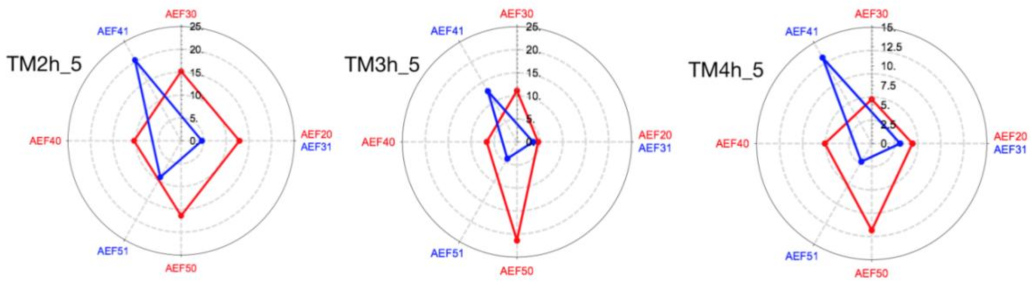

Figure 4 Polar plots of the movement of strike lines during discharge (#20171018.019, AEF30) for horizontal modules. Blue lines corresponds to lower divertors and red lines to upper

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[1] Feng Y.. et al. Nucl. Fusion **46**, 807 (2006)
[2] Wolf, R. C. et al. Nucl. Fusion **57**, 102020 (2017)
[3] McCormick, K. et al. J. Nucl. Mater. **313**, 1131-1140 (2003)
[4] Jauregi, E. et al. Fusion Eng. Des. **66-68**, 1125-1132 (2003)
[5] Sieglin, B et al. Review of Scientific Instruments **86**, 113502 (2015)