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Heat flux depositions on the WEST divertor and first wall components

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HIGHLIGHTS

- Heat fluxes up to 20 MW/m^2 are required on the divertor of Tore Supra WEST.
- Incident heat flux onto the main inner components are simulated with PFCFlux.
- Ripple of the magnetic field is accounted for.
- Results shows that expected heat fluxes are reachable on the divertor.
- Heat flux on the other components is within their limits.

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ABSTRACT

The primary goal of the WEST project is to be a test-bed for ITER W divertor components, in terms of manufacturing issues as well as fatigue and lifetime regarding thermal loads during operations. Therefore it is necessary to ensure that the thermal loads available in Tore Supra are of the same magnitude as those expected for ITER. It is also necessary to ensure that the other plasma facing components would not be a limitation to reach this target. On this basis, simulations of the incident heat flux on the main components have been done for different parameters. Those simulations are done with PFCFlux code and include the variation of the toroidal magnetic field called ripple effect. This paper reports the results of those simulations and concludes on the usability of the plasma facing components with the required heat loads.

1. Introduction

The main objective of the WEST (W Environment in Steady-state Tokamak) project, which is an upgrade of the Tore Supra limiter machine, is to fabricate and test an ITER-like actively cooled tungsten divertor made of 456 Plasma Facing Units (PFU), in order to mitigate the risks for ITER. Also in-vessel Plasma Facing Components (PFC) will be replaced by actively cooled components with a copper heat sink and a tungsten coating (upper divertor and baffle). The PFU should withstand heat fluxes close to the heat fluxes during ITER operations, which may reach up to 20 MW/m^2 [1]. It is therefore necessary to verify that not only Tore Supra will be able to achieve this level of power but also that for this level of power the other PFC are not overreaching their limits.

The key part of this paper shows simulations of the heat flux deposition pattern on different PFC, for two extreme steady-state plasma scenarios: a close X-point configuration, and a far X-point configuration. The heat flux density is computed with the PFCFlux [2] code for several power e-folding lengths in the Scrape-Off Layer (SOL) from 2.5 to 10 mm in the outer mid-plane. Some complexity is also added by taking into account the ripple of the magnetic field due to the discrete nature of the superconducting toroidal field coils. This effect is rather large on Tore Supra (few % in the outer equatorial plane) and plays an important role on the heat flux deposition pattern.

The paper concludes on the adequacy of the foreseen heat loads, the PFC concepts and the experimental program.

2. PFCFlux and the ripple effect

As described in [2], PFCFlux is a software dedicated to the calculation of the conducted power along the magnetic field lines, assuming purely parallel transport. With ray tracing techniques, it is able to simulate the shadowed and wetted areas of the internal components.

In Tore Supra, the ripple is not negligible because of the spacing between the 18 circular superconducting coils and because the plasma is close to the coils. This effect has to be taken into

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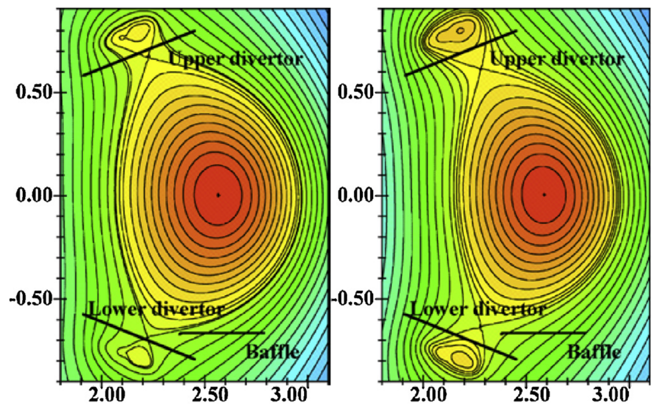

Fig. 1. Close X-point (left) and far X-point (right) magnetic configurations.

account. Considering precisely this perturbation would require a magneto-static computation at each run. This is not compatible with the simplicity and the effectiveness of PFCFlux. Moreover it would not be realistic compared to the achievable accuracy and therefore a model derived from analytical models was used [3,4]. It is based on exponential laws and describes the magnetic surfaces displacement between the coils.

$$\rho_M^R = \rho_M^{mer} + \Delta\rho_M^R(\cos(18\varphi_M^R) - 1)$$

$$\Delta\rho_M^R = -\left(\frac{R_M^R}{18}\right)^2 abe^{b\rho_M^{med}}$$

where R_M^R and φ_M^R are the radial and angular coordinates in global cylindrical coordinates, ρ_M^R is the radial coordinates in the plasma coordinates centered at $R = 2.20$ m, ρ_M^{mer} is taken in the meridian plane below a coil ($\varphi = 0°$). $\Delta\rho_M^R$ is the radial half-displacement of the magnetic surfaces between $\varphi = 0°$ and $\varphi = 10°$. The a and b coefficients come from numerical comparisons of this simple model with more complex models: $a = 5.7\text{E}{-4}$ and $b = 5.1\ \text{m}^{-1}$.

Generally the displacement of the magnetic surfaces due to ripple effect is low, typically a few mm in the area of the divertor. The strongest effect is a change in the incidence angle, typically a ratio up to 2.

3. Heat flux simulations

3.1. Main parameters

Two magnetic configurations are discussed in this paper. The first one is called close X-point (cXp), with first X-point localized around 1 cm above the lower divertor and second X-point a few mm below the upper divertor. In this configuration, the plasma current is 800 kA. The second configuration is called far X-point (fXp), with X-point localized around 7 cm above the divertor and second X-point 5 cm below the upper divertor. In this configuration, the plasma current is 500 kA.

The essential parameter is the value of λ_q, the decay length of the heat flux density in the SOL. As this parameter is not well known for now, several value are studied, in the range of 2.5–10 mm.

The inner/outer asymmetry of the conducted heat flux density is also taken into account. It is supposed to be 2, meaning that the total power deposited on the low field side is two times higher than the total deposited power on the high field side. Supposing this asymmetry is also conservative from the thermal point of view, as this will lead to higher maximal heat flux. No particular asymmetry is supposed between the upper and lower region of the SOL.

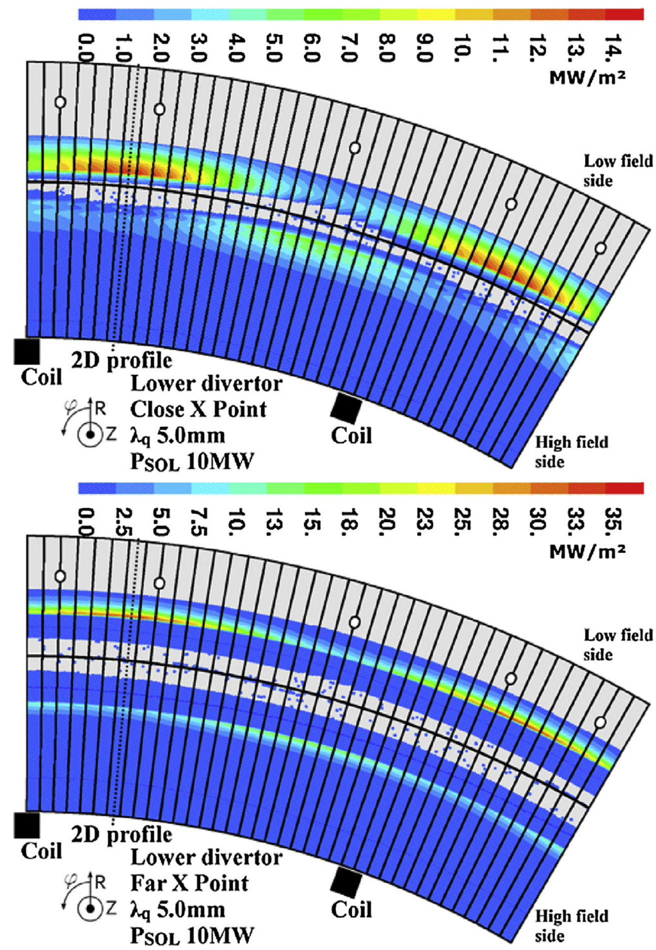

Fig. 2. Heat flux and shadowed area (gray) on the lower divertor target – cXp (top) and fXp (bottom).

Finally, the total power conducted by the plasma in the SOL is taken to be 10 MW. This is the most conservative value, as it requires a full heating power (around 15 MW). Of course, all the heat fluxes densities calculated are proportional to this value; therefore it is easy to extend the results presented here to a more realistic case.

3.2. Lower divertor target

The lower divertor target is located on the bottom of the chamber. Its role is to sustain the power conducted through the X-point to the strike points. Three different designs of the lower divertor target, composed of 12 sectors of 38 PFU are already foreseen. The first version to be installed will be made of non-actively cooled graphite components with a thin W coating (<30 μm). The second version will be made of actively cooled CuCrZr components also with a thin W coating [5]. Then it will be progressively replaced by the ITER-like W PFU, made of W monoblocks bonded to a copper alloy tube. It is important to note that all those three types of PFU will have an identical surface exposed to the plasma, meaning that the same scenario will produce the same heat flux on any of them. The difference will be in the capability of the PFU to endure a high-level heat load.

3.2.1. Heat flux patterns

Fig. 2 shows a 30° sector of 38 PFU. The heat flux pattern is represented in color, whereas the shadowed area is in light gray. The shadowed area in the middle of the sector corresponds to the