Fusion Engineering and Design 88 (2013) 1793–1797

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

The WEST project: PFC shaping solutions investigated for the ITER-like W divertor

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HIGHLIGHTS

- We studied the design of the ITER-like W components occurred for the WEST divertor.
- Shaping solutions were investigated to mitigate the harmful effect of leading edges.
- We performed an optimization mainly based on the surface temperature rise.
- The *fish-scale* shaping solution appeared as the most relevant solution.

ARTICLE INFO

Article history:
Received 14 September 2012
Accepted 15 March 2013
Available online 8 May 2013

Keywords:
ITER
Tore Supra
WEST
Tungsten
Divertor
Plasma facing components
Shaping

ABSTRACT

Among major issues for PFCs design, the impact of leading edges (exposed surface) which would be directly intersected by particles following magnetic field lines at glancing incident angles in the high heat flux areas is much discussed. This paper presents the key outcome of a thermal analysis performed on different shaping solutions for the ITER-like W monoblocks occurred for the components of the WEST (W Environment for Steady state Tokamak) divertor which could shadow any direct leading edge and to counteract a potential misalignment due to assembly tolerance. The results, in terms of surface temperature rise and wall heat flux into the cooling channel, are discussed for magnetic field lines incident at glancing angles expected in the higher heat flux regions of divertor (i.e. close to the strike point regions) and for perpendicular incident heat flux up to 20 MW/m^2.

1. Introduction

The WEST (W – for tungsten – Environment in Steady-state Tokamak) project [1,2] aims at transforming Tore Supra from a limiter based tokamak with carbon PFCs into an X-point divertor tokamak with full-tungsten armour in order to adapt it to a unique relevant facility as test bed for ITER. Combined to its long pulse active cooling capability, the WEST project will primarily offer the key capability of testing for the first time the ITER technology in real plasma environment. In particular, the main divertor (i.e. the lower divertor, Fig. 1) of the WEST project will be based on actively cooled tungsten monoblock components and will follow as closely as possible the design and the assembling technology, foreseen for the ITER divertor units (inner vertical target – IVT). The WEST divertor could hence address ITER critical issues in the demanding environment of a tokamak.

One major issues for PFCs design is the existence of leading edges, where high cumulative incident heat flux occurs, inducing component embrittlement or local melting [3] with the inherent risk of poisoning of the plasma and/or inducing a critical heat flux event in the water cooling. Leading edges are due to the perpendicular orientation of electron and ions flux direction with respect to the surface component. For the WEST divertor, leading edge could be due for instance to important gap between components (toroidal gap in the 0.5–1.0 mm range) and between monoblocks (poloidal gap close to 0.5 mm), but also to a potential misalignment due to assembly tolerance. To mitigate the harmful effect of leading edge, angle between surface component and flux direction should be optimized, for example using judicious shaping and tile shadowing.

In this paper, different shaping solutions were investigated and discussed for a field line incidence assessed close to maximum heat flux density and for perpendicular incident heat fluxes up to 20 MW/m^2. The main goal is to assess the most relevant shaping solution based on the surface temperature rise and wall heat flux into the cooling channel of actively cooled W components of the WEST divertor under steady-state heat load. Thereafter, the

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http://dx.doi.org/10.1016/j.fusengdes.2013.03.048

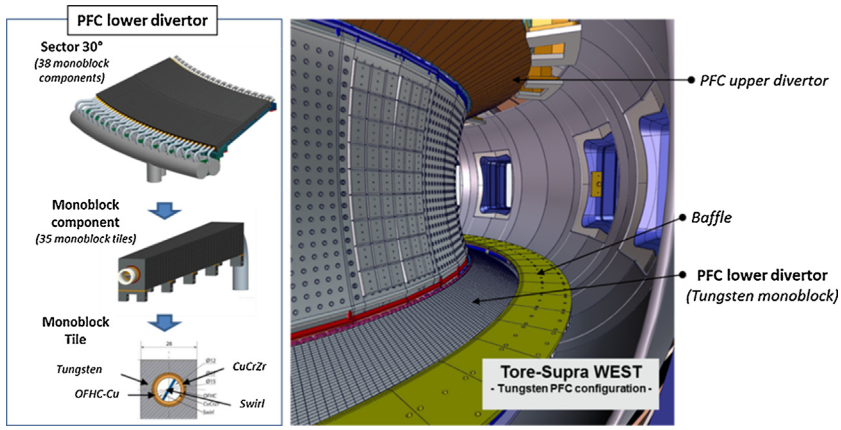

Fig. 1. 3D view of the actively cooled W divertor implementation in Tore Supra.

thermal behaviour of the WEST divertor, including the most relevant shaping solution, is reported for expected heat flux patterns based on standard plasma scenarios.

2. Investigation for different tiles shaping solutions

2.1. Assumptions

Based on the levels of peak heat flux expected during high performance operation of WEST tokamak [2] (typically, above 10 MW/m^2 as projected perpendicular heat load ($\Phi_\perp$) and above 200 MW/m^2 as incident parallel heat load ($\Phi_\parallel$)), some local melting is to be considered on the leading edges offered by PFC surfaces. As a consequence, in order to shadow any direct leading edge and to counteract a potential misalignment due to assembly tolerance, different tiles shaping solutions (round edge, dome and fish-scale shaping) for monoblock plasma facing surface have been investigated (Fig. 2). Consequently, 2D finite element simulations (ANSYS V13 software) were performed for W monoblock geometry envisaged for the components of the WEST divertor to assess the surface temperature and wall heat flux into the cooling channel under steady-state heat load. In order to have a conservative approach, the field line incidence angle (α) of 3°, expected in the higher heat flux regions of divertor (i.e. close to the strike point regions), was chosen for this study (Fig. 3). For each shaping solution, the thermal behaviour under a potential misalignment (δ) as well as the influence of some relevant geometric parameters (radius, scale of chamfer, etc.) was assessed for projected perpendicular heat flux of 10, 15 and 20 MW/m^2 in order to identify the most relevant shaping solution.

2.2. Results and discussion

Based on the W melting temperature (~3400 °C) and the wall critical heat flux into the cooling channel (including a margin of 1.4), as critical thresholds, the main results in terms of admissible limit of misalignment (δ_a) are summarized in Table 1 for each shaping solution (including optimized geometric parameters) and discussed hereunder.

By comparison with the no shaping solution, the *round edge shaping* solution (i.e. machining of each monoblock by an additional small radius in the toroidal direction, see Fig. 2a), the *dome shaping* solution (i.e. machining of each monoblock by an additional curvature radius of the front surface, see Fig. 2b) and the *fish-scale shaping* solution (i.e. chamfering of each monoblock only in the toroidal direction, see Fig. 2c), improve the thermal response of the monoblock component in removing locally any direct leading edges (i.e. in reducing the angle between the heat flux lines and the hit surface), for both *round edge* and *dome shaping* solutions, or in removing completely any direct leading edges and in shadowing partially each monoblock by the previous one, for *fish-scale shaping* solution.

In addition, based on the manufacturer tolerances and the experience about the engineering misalignments, the maximum theoretical misalignment, due to cumulative tolerances between adjacent components, is expected to reach a maximum of 0.3 mm (over a maximum toroidal gap of 0.5 mm). Being given this threshold value in terms of assembly misalignment:

- *Round edge and dome shaping* solutions of the monoblock allows globally a higher misalignment compared to the no shaping

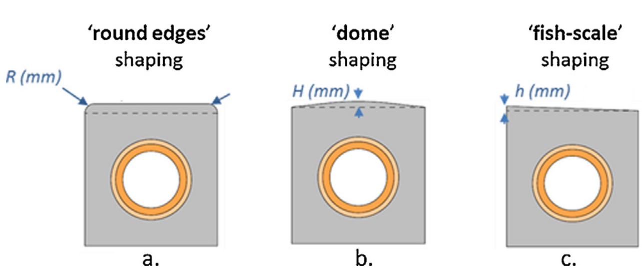

Fig. 2. Sketch of shaping solutions investigated.

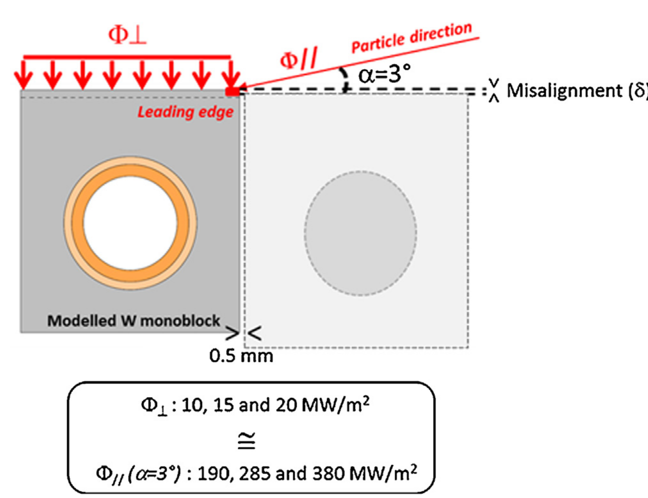

Fig. 3. Sketch of 2D modelling and incident heat fluxes studied for ITER-like W monoblock.