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Acceptance criteria for the ITER divertor vertical target

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Abstract

In the frame of the toroidal pump limiter fabrication for Tore Supra, CEA developed a large experience of infrared test for acceptance of high heat flux components armoured with carbon fibre composite flat tiles. The test is based on a thermal transient induced by an alternative hot/cold water flow in the heat sink structure. The tile surface temperature transients are compared with those of a reference element, the maximum difference for each tile leading to a value called $\Delta T_{\mathrm{ref\_max}}$. This method is proposed for the commissioning of plasma facing components for the ITER divertor vertical target. This paper describes the determination of the best acceptance criteria for the "monoblock" geometry of the carbon part. First, it has been shown that the location and the extension of the defects could reliably be determined by monitoring both top and lateral surfaces during the test. Second, it was possible to fix an acceptance method based on $\Delta T_{\mathrm{ref\_max}}$. Samples with calibrated defects are now under fabrication to validate the results.

Keywords: ITER divertor; Plasma facing components; Acceptance criteria; Infrared thermography

1. Introduction

The divertor system is aimed at exhausting the alpha particles and helium produced by the fusion reaction as well as other impurities resulting from plasma–wall interaction [1]. It is made of 54 modules or "cassettes", located at the bottom of the vacuum vessel. Each cassette supports a set of three actively cooled carbon fibre composite (CFC) or tungsten (W) armoured plasma facing components (PFCs): an inner and an outer vertical target that must tolerate high heat loads (10–20 MW m^{-2}), and a dome (Fig. 1). The reference design is "monoblock" (or "tube in tile") geometry for the CFC part and "flat tile" geometry for the W armour. A high-quality bonding between the armour and the heat sink is essential to ensure the lifetime of the components. With Tore Supra, CEA developed a significant know-how in the field of non-destructive

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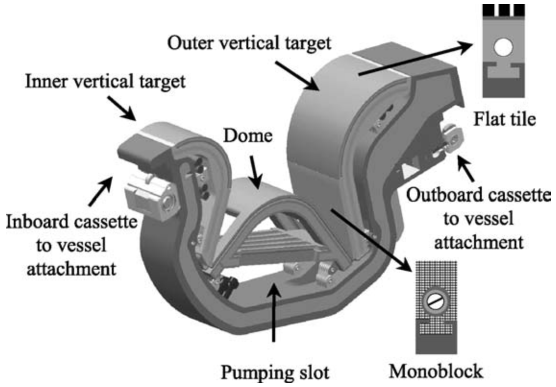

Fig. 1. Schematic view of the ITER divertor.

control of high heat flux components, initially with the Tore Supra pump limiter, next with the ITER vertical target mock-ups. From this knowledge and recent results, acceptance criteria have been determined for the CFC monoblock geometry.

2. Experience gained with the Tore Supra toroidal pump limiter

CEA has developed a large experience of acceptance criteria for actively cooled high heat flux elements armoured with CFC flat tiles using infrared thermography [2–5]. More than 1000 components of the Tore Supra (TS) toroidal pump limiter (TPL), i.e., more than 21,000 tiles, were controlled at their delivery on the “SATIR” infrared test bench at CEA (1999–2002) [6–8]. The testing protocol consists in inducing a thermal transient within the heat sink structure by an alternative hot/cold water flow. The surface temperature of the tiles is monitored by an infrared camera. The transients are compared with those of a reference element, afterwards the maximum difference of temperature – called $\Delta T_{\mathrm{ref\_max}}$ – is evaluated for each tile [9]. For Tore Supra TPL tiles, the applied acceptance criterion was $\Delta T_{\mathrm{ref\_max}} = 3\,^{\circ}\mathrm{C}$, i.e., the maximum acceptable difference of temperature between the controlled tile and the reference element during a cooling down transient. This theoretical value corresponded to a 25 mm^2 square defect over a tile of 500 mm^2 (5%). Actually, it was often more severe since the geometric tolerances and the noise from the camera led to an uncertainty of $\pm 1\,^{\circ}\mathrm{C}$. Many defects were revealed, mainly due to a change in the CFC grade, however, most of the defective elements were successfully repaired [7,8]. By the end of the fabrication, it was decided to accept the tiles showing a $\Delta T_{\mathrm{ref\_max}}$ value lower than the criterion increased of 50% (4.5 °C), provided that a visual control did not emphasis a visible edge crack. By precaution, these elements were installed in the shadowed (i.e. less loaded) zones of the limiter. This allowed the limiter to be completed. Being in service since 2002, the TPL has an excellent behaviour [10]. High-quality plasma physics experiments could be performed [8,11,12].

The transient infrared thermography method is well established for flat tiles. The work is now focused on the control of CFC monoblocks for the ITER divertor.

3. Experience gained with the ITER vertical target mock-ups

In the frame of the ITER divertor design, various mock-ups or prototypes have been manufactured and controlled using ultrasounds or transient infrared thermography. They were also extensively tested under high heat flux loading (FE200 facility at Framatome, Le Creusot [13]).

The identified mock-ups are PRODIV (a 500 mm long CFC monoblock component), VTMS (Vertical Target Medium Scale), VTMSdef (Vertical Target Medium Scale with calibrated defects), which are prototypes for the divertor, Baffle samples, Critical heat flux CFC monoblocks, Round Robin tests samples, VTFS (vertical target full scale), Baffle prototypes [14].

The identification of the manufacturing defects within CFC monoblocks is essential, in order to be able to take the decision of the acceptance. Considering the monoblock geometry, a methodology based on the experience of these mock-ups has been developed to determine reliably the location (CuCrZr/Cu or Cu/CFC joint), position (θ) and extension ($\Delta\theta$) of the possible defects (Fig. 2).

To start with, ultrasonic inspection of the components gives precise information about the defects located at the CuCrZr/Cu joint. Defects above 2 mm can be distinguished. The second step consists in transient infrared thermography (SATIR) examination of the top surface and the lateral surfaces of the monoblocks. While the inspection of the top surface