Fusion Engineering and Design 88 (2013) 1818–1822

Contents lists available at ScienceDirect

Fusion Engineering and Design

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

Improvement of non destructive infrared test bed SATIR for examination of actively cooled tungsten armour Plasma Facing Components

N. Vignal*, C. Desgranges, V. Cantone, M. Richou, X. Courtois, M. Missirlian, Ph. Magaud

CEA, IRFM, F-13108 Saint-Paul-Lez-Durance, France

HIGHLIGHTS

- Non destructive infrared techniques for control ITER like PFCs.
- Reflective surface such as W induce a measurement temperature error.
- Numerical data processing by evaluation of the local emissivity.
- SATIR test bed can control metallic surface with low and variable emissivity.

ARTICLE INFO

Article history:
Received 14 September 2012
Received in revised form 13 May 2013
Accepted 15 May 2013
Available online 5 July 2013

Keywords:
W-armoured Plasma Facing Component
Tungsten
SATIR test bed
IR thermography
Ultrasonic test

ABSTRACT

For steady state (magnetic) thermonuclear fusion devices which need large power exhaust capability and have to withstand heat fluxes in the range 10–20 MW m^{-2}, advanced Plasma Facing Components (PFCs) have been developed. The importance of PFCs for operating tokamaks requests to verify their manufacturing quality before mounting. SATIR is an IR test bed validated and recognized as a reliable and suitable tool to detect cooling defaults on PFCs with CFC armour material. Current tokamak developments implement metallic armour materials for first wall and divertor; their low emissivity causes several difficulties for infrared thermography control. We present SATIR infrared thermography test bed improvements for W monoblocks components without defect and with calibrated defects. These results are compared to ultrasonic inspection. This study demonstrates that SATIR method is fully usable for PFCs with low emissivity armour material.

1. Introduction

For steady state magnetic thermonuclear fusion devices which need large power exhaust capability, Plasma Facing Components have been developed. The ITER Divertor will be composed of water actively cooled targets based on monoblock technology (Fig. 1). The refractory armour material made of carbon fibre composite (CFC) or tungsten (W) is joined via a soft copper layer to a CuCrZr heat sink (Fig. 2). In order to guarantee the integrity of these components during the required lifetime, their thermal and mechanical behaviour must be assessed as a preliminary. Before the procurement of the ITER Divertor, the examination of the heat sink to armour joints with non destructive techniques is an essential topic to be addressed. Until now, ITER specifications for CFC components examination used infrared (IR) thermography, which is not foreseen yet for the W components. A former study using IR thermography for W components examination showed interesting results [1]. This study presents the last improvements on the IR thermography test bed SATIR (French acronym for the IR acquisition and data processing device) for the inspection of PFC with W armour material.

2. SATIR overview

The SATIR test bed is based on a thermal solicitation of the component through a fast temperature variation (105–10 °C in few ms) in the cooling channel (Fig. 3) [2]. During the transient phase, surface temperature is measured in order to evaluate component thermal exhaust capability. The methodology is based on the comparison of the surface temperature evolution of the inspected component with the evolution of a reference component, assumed defect free.

The armour surface temperature is measured with a digital IR camera (CEDIP JADE II $\lambda = 3–5\ \mu m$) located in front of the tested

* Corresponding author. Tel.: +33 442253156.
E-mail address: nicolas.vignal@cea.fr (N. Vignal).

0920-3796/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fusengdes.2013.05.053

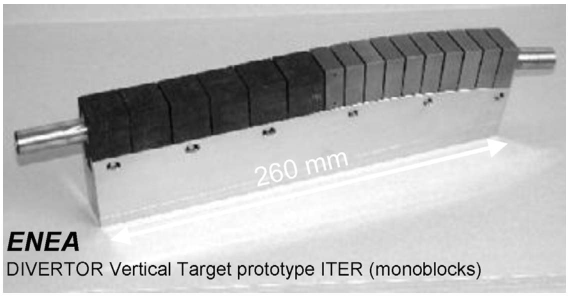

Fig. 1. ITER prototype monoblock CFC & W technology.

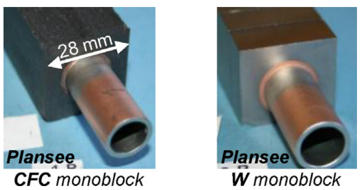

Fig. 2. CFC and W monoblocks.

PFC. For each Picture Element (PEL) of surfaces, the maximum temperature difference between the tested PEL and the reference one is calculated and is called DTRef. The maximum of this DTRef for an inspected surface is called DTrefmax.

SATIR is validated and recognized as a reliable and suitable tool to assess heat sink defaults on PFCs with CFC armour material used for different fusion devices (Tore-Supra, W7X, ITER) [3–5]. Thanks to high and almost constant emissivity (typically in the range 0.8–0.9) for the CFC material, IR measurements are accurate and give a reliable control.

3. Metallic armour for PFCs challenge

Metallic materials such as tungsten are foreseen in future fusion machines. For W armour material the difficulty of IR measurement, due to low and variable emissivity (typically in the range 0.1–0.4), can induce an erroneous temperature measurement. In Fig. 4 is illustrated surface temperature estimation for W material with a global emissivity of 0.15. Since a constant temperature of 105 °C circulates into the cooling channel, deviation of temperature from 105 °C is attributed to inaccurate local emissivity estimation. For CFC, an emissivity variation range from 0.8 up 0.9 corresponds to 5% of surface temperature. This error is within the noise level of SATIR test bed. For W armour material the low and variable emissivity from 0.1 to 0.4 may induce a temperature error up to 30%. Moreover, the low emissivity of W can cause parasitic reflected flux on the surface, and increase the error of the measured temperature. As consequence, the resulting errors on DTRef can lead to wrong conclusions on the quality of the tested W PFCs.

In this study, constraints of reflections and spatial resolution induced by tungsten were solved by the development of a new method which combines experimental conditions and numerical data processing by evaluation of the local emissivity.

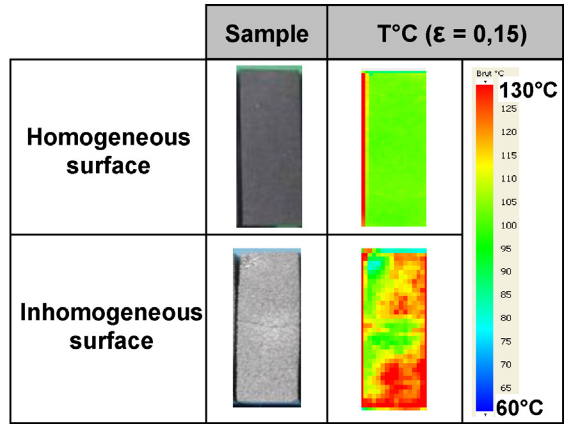

Fig. 4. Surface temperatures evaluated with global emissivity.

4. Improvement on temperature estimation

With this new method the emissivity of each Picture Element (PEL) is determined for each image of the IR film, therefore the actual temperature of each PEL of the tungsten surface is rebuilt via raw data camera measurement (L_{total}) and can be written as Eq. (1).

$$L_{total} = \tau_{Atm} \times \left[(\varepsilon \times L) + (1 - \varepsilon) \times L_{bg}\right] + [(1 - \tau_{Atm}) \times L_{Atm}] \qquad (1)$$

The background temperature environment L_{bg} is the source of undesirable reflections on reflective material. Reduced by the optimized camera position and insulation booth (Fig. 5), L_{bg} can also be considered as uniform and stable (less than 1 °C variation during one measure).

The atmosphere transmission τ_{Atm} and atmosphere emission L_{Atm} are considered as negligible because the air absorption is insignificant for the camera wavelength range and the viewing

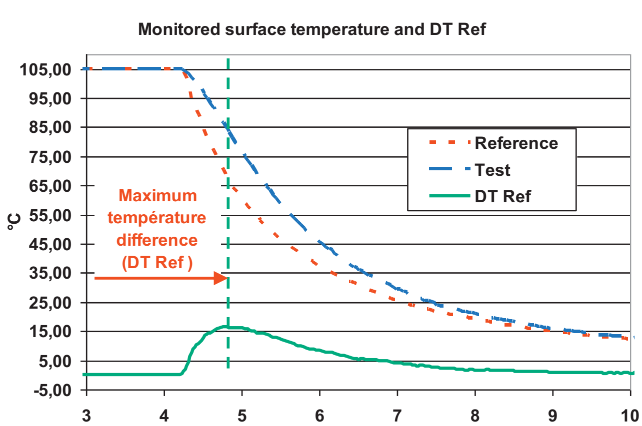

Fig. 3. Principle of SATIR test bed.

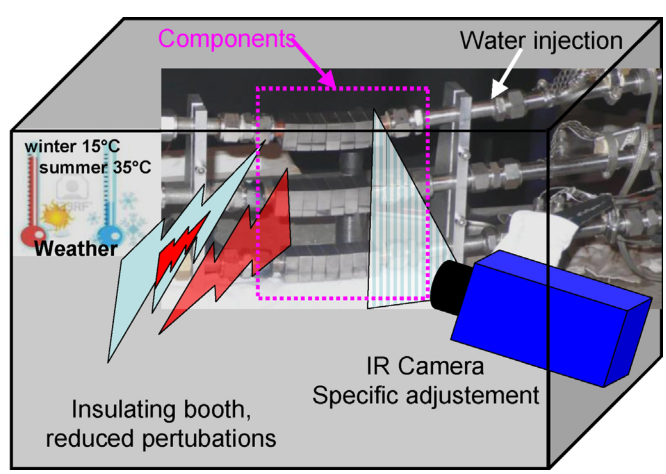

Fig. 5. SATIR test bed environment.