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Applicability of inverse heat flux evaluation to thermographic measurements in SPIDER

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ABSTRACT

To study and optimize negative ion production, the SPIDER (Source for Production of Deuterium Extracted from RF plasma) prototype (beam energy 100 keV, current 48 A) is under construction in Padova, Italy. The instrumented calorimeter STRIKE (Short-Time Retractable Instrumented Kalorimeter Experiment) has been designed with the main purpose of characterizing the SPIDER negative ion beam in terms of beam uniformity and divergence during short pulse operations. STRIKE is made of 16 1D Carbon Fibre Composite (CFC) tiles, intercepting the whole beam and observed on the rear side by infrared (IR) cameras.

As the front observation is not convenient, it is necessary to solve an inverse non-linear problem to determine the energy flux profile impinging on the calorimeter, starting from the 2D temperature pattern measured on the rear side of the tiles. The aim of the paper is to give an overview about the transfer function technique which may be used to retrieve the flux profile, dealing with non-linearity and non-stationariness.

1. Introduction

As already stated in [1] the ITER project requires additional heating provided by two injectors of neutral beams resulting from the neutralization of accelerated negative ions. The negative ion source prototype SPIDER is under construction in Padova, with the aim of testing the beam characteristics and to verify the source proper operation [2]. The SPIDER beam (40 A, 100 kV, formed by 1280 beamlets) will be characterized by a full set of diagnostics [3], in particular by the instrumented calorimeter STRIKE [4] (Short Time Retractable Instrumented Kalorimeter Experiment) whose main components are anisotropic carbon fiber carbon matrix composite tiles (CFC). The calorimeter is designed for investigating beam divergence and halo and for measuring the uniformity of the ion current. The beam hits directly the front side of the calorimeter, see Fig. 1, but the measurements will be taken on the back side as the observation of the front would be disturbed by the optically emitting layer created by the beam interacting with the background gas, located between the beam source and STRIKE, and by the debris coming off the tile surface. In order to allow a better reconstruction of the impinging energy flux, the tile material must then transfer the thermal pattern from the front to the back side with as small distortion as possible; this requires the thermal conductivity along the beam direction to be much higher than the conductivity in the plane perpendicular to the beam, the tiles tested so far have a ratio of 20 [5]. Up to now the data analysis method consists in applying a multiple peak 2D fit to the beam thermal pattern on the rear side of the tile, while the features of the impinging flux are retrieved by an inverse heat transfer reconstruction. The solution proposed in the present paper, an inverse reconstruction with transfer functions, demonstrated to give faster solutions and more resolved beam.

2. Stationary case

The proposed method is based on the transfer function technique [6]: the CFC tiles are considered as systems providing an output (measured temperature pattern on the rear side) corresponding to the application of its transfer function to the input (energy flux impinging on the front side) To compute the transfer function a point-like input (e.g. representing a laser spot) is considered. This input is modeled as a 2D Gaussian curve with half width at half maximum (HWHM) equal to 1.5 mm, while its power is varied to scan a temperature range similar to the ΔT under consideration. The heat transfer simulation is performed in COMSOL. The mesh is

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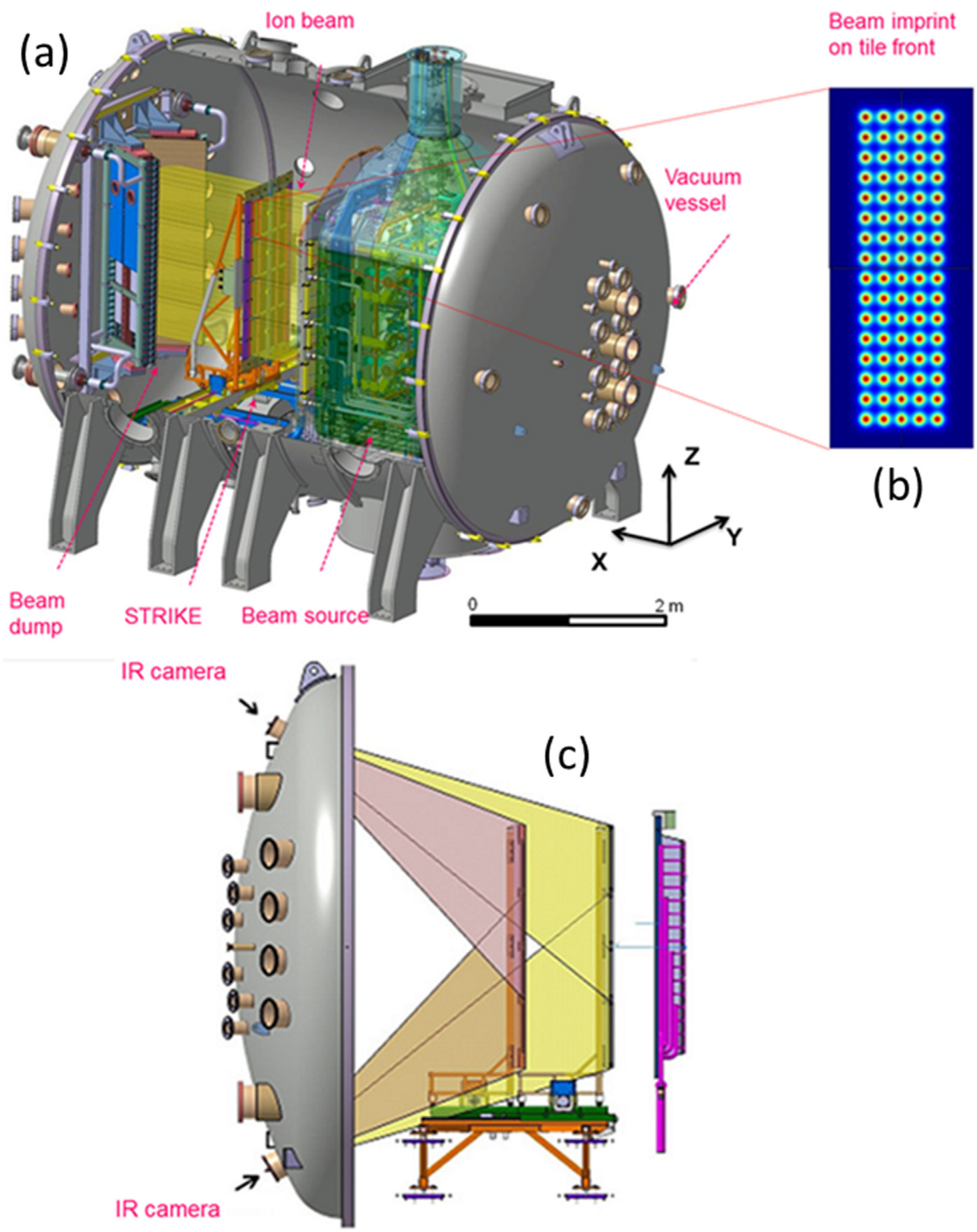

Fig. 1. SPIDER (a), imprint of beamlet group (b), view of STRIKE (c).

built by extrusion and its denser where the laser impinges (in the order of 0.1 mm, see Fig. 2 for details). Due to the symmetry of the laser spot 2D Gaussian curve, only a quarter of such spot may be simulated. The domain thickness is 20 mm, just like the real tile. As the transfer function should model the thermal properties of the tile, the domain size in the xy plane should be infinite. For the first set of simulations a $30 \times 30\,mm^2$ tile was considered (because of the symmetry corresponding to a $60 \times 60\,mm^2$ domain).

The temperature profile on the rear side was found to be well represented by the modified Hubbert function [7]; the simulated tile response also takes into account the initial temperature of the tile and the presence of non-linearity in the thermal parameter of the material as well as radiation boundary conditions at all surfaces. Fig. 3 shows an example of the temperature profile on the tile rear. The map of the variation of internal energy per unit mass $\Delta(cT)$, with c the specific heat of CFC, produced by the point-like input is fitted at every frame (100 ms) with a Hubbert peak. This allows defining a transfer function for every time instant. In order to speed up the fitting calculations, a reduced set of 15 beamlets has been considered and the resolution is 1 mm/1 pixel. That resolution is adequate for beamlets dimension and closer to experimental conditions (2 mm/pixel).

The $30 \times 30\,mm^2$ proved to be too small to behave as an infinite domain. As time goes by in fact, it was verified that the heat reaches the border of the simulation domain. Even if the temperature increase induced at the domain borders is negligible, this edge-effect affects the heat propagation. In particular it is found that the quality of Hubbert and Gauss fit applied to the data decreases. A larger domain is then expected to provide better results. For such a reason the size of the domain for the laser simulation was enlarged to $80 \times 80\,mm^2$ verifying as well that a larger domain had not a perceptible effect on the heat propagation. Fig. 4 evidences how

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