Global analysis of the 2-D Soft-X ray tomography reconstructions

at Tore Supra by means of form factors

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Introduction

An unfolding algorithm for reconstructing 2-D soft X-ray (SXR) emissivity profiles has been validated, firstly on analytical generated emission profiles and then on Tore Supra plasma discharges [1]. The inversion method is based on a Minimum Fisher Regularization technique, on a squared pixel matrix, and it does not rely on any assumption about the magnetic topology [2]. In order to get the best of diagnostic potentiality, a very accurate calibration of the Tore Supra SXR poloidal tomography cameras has been previously performed, where all the 82 lines of sights were absolutely calibrated in the SXR diodes X-ray domain (5– 30 keV), including electronics and geometrical corrections [3]. A new analysis tool has been then developed for an automatic recognition of the shapes of the SXR emissivity, as a preliminary step for future automatic techniques to be used in real time applications. The results for a shot with sawtooth activity are discussed in the following, together with a plasma discharge during the ramp-up, phase with ECRH, and ramp-down.
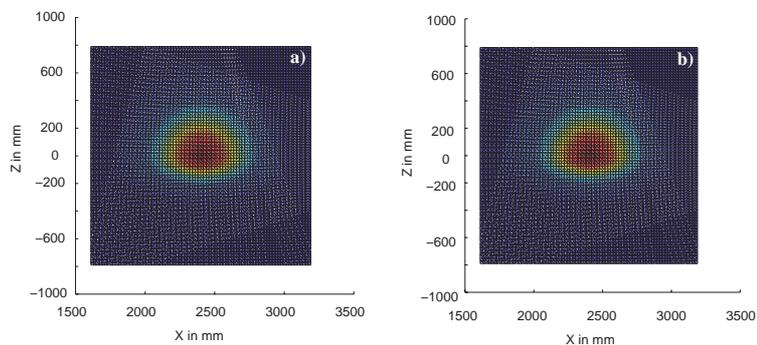
Form factors of the SXR emission and test results

In order to evaluate the quality of these reconstructions, Gaussian distributions of SXR emissivity with different shapes and asymmetries were used for test purposes.

One of these cases is shown in fig. 1: the simulated plasma emission in fig. 1a and its reconstruction in fig. 1b, (obtained applying the unfolding algorithm to the calculated data), are in excellent agreement.

Figure 1a) SXR emission distribution simulated and **1b**) reconstructed by means code inversion from the calculated tomography

We then defined some parameter, zero and first order momenta, for characterizing, in an automatic and quantitative

way, the reconstructed 2D emissivity profiles $G(x,y)$. We firstly found the coordinates (x_M, y_M) of the maximum of the G function in a polidal section. The full width at half maximum (FWHM) of the emissivity can be therefore calculated in the four semi-planes $(x<x_M , x>x_M , y<y_M , y>y_M)$, referred to the maximum:

$$a_e = \frac{\iint\limits_{D(x>x_M)} x \cdot G(x,y)\,dx\,dy}{\iint\limits_{D(x>x_M)} G(x,y)\,dx\,dy} - x_M \qquad \text{and} \qquad a_i = x_M - \frac{\iint\limits_{D(x<x_M)} x \cdot G(x,y)\,dx\,dy}{\iint\limits_{D(x<x_M)} G(x,y)\,dx\,dy}$$

$$b_h = \frac{\iint\limits_{D(y>y_M)} y \cdot G(x,y)\,dx\,dy}{\iint\limits_{D(y>y_M)} G(x,y)\,dx\,dy} - y_M \qquad \text{and} \qquad b_l = y_M - \frac{\iint\limits_{D(y<y_M)} y \cdot G(x,y)\,dx\,dy}{\iint\limits_{D(y<y_M)} G(x,y)\,dx\,dy}$$

where a_e and a_i are respectively the external and internal first order momentum, while b_h and b_l the high and low ones, and $D(x,y)$ is the integration domain.

Subsequently, to better characterize the plasma shapes, we defined suitable "plasma shaping factor" by combining the previously calculated momenta a_e, a_i, b_h and b_l and labeling them with names resembling plasma parameters: dipoles along R and Z (d_R, d_Z), barycenter or magnetic axis (x_b, y_b), plasma elongation (ε), triangularity in R and Z (t_R, t_Z), peaking factor in R and Z (p_R, p_Z), by means of the following expressions: $d_R = a_e - a_i$, $d_Z = b_h - b_l$,

$$(x_b, y_b) = (x_M + \frac{d_R}{2}, y_M + \frac{d_Z}{2}), \qquad \varepsilon = \frac{b_h + b_l}{a_e + a_i}, \qquad t_R = \frac{a_e}{a_i}, \qquad t_Z = \frac{b_h}{b_l}, \qquad p_R = \frac{2r_0}{a_e + a_i} \qquad \text{and}$$
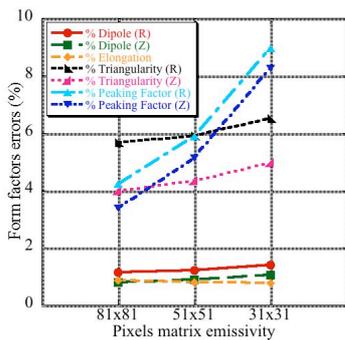
$$p_Z = \frac{2r_0}{b_h + b_l}.$$

Figure 2 form factor errors as function of the pixel grid for the Gaussian symmetric SXR profiles
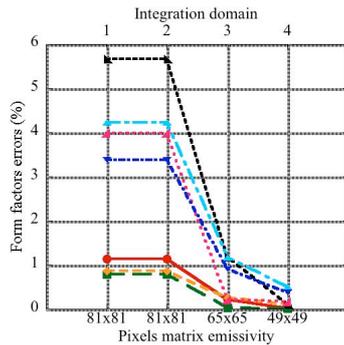
Figure 3 form factor errors as function of the integration domain on 81x81 pixel grid
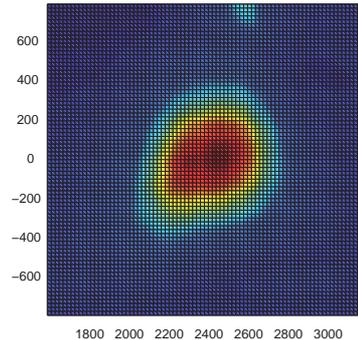
Figure 4 reconstructed emissivity (shot 40490) at a time just after the sawtooth crash (grid 81x81)

We checked the correctness of the calculations of the form factors, by means of different analytical emission distributions: circular and centered Gaussians, asymmetric Gaussians and elliptical Gaussians. It allowed also the study of the relative errors of these form factors, as function of the pixel grid size (fig. 2). The errors were then calculated for different integration domains (fig. 3), based always on the emissivity reconstructed on the 81x81 pixel grid. Accurate reconstructions start from a 51x51 pixel grid, while the best calculations for the form factors (errors less than 1%) are for reconstructions 81x81 and with form factors calculated on a domain 49x49.

Experimental results

The SXR reconstruction algorithm has been applied to some Tore Supra plasma discharges with a time resolution of 4 ms. Despite the circular geometry of Tore Supra, 2-D emissivity surfaces show sometime a lack of poloidal symmetry, like the case after the sawtooth crash (shot 40490 in fig. 4).
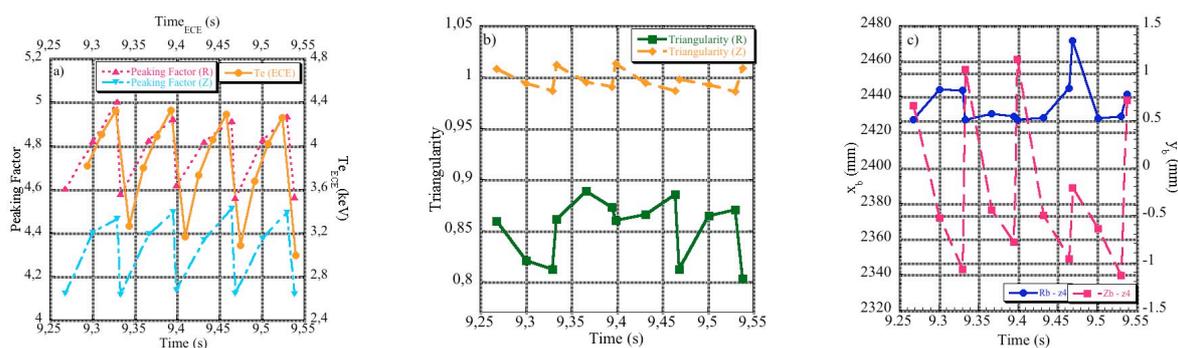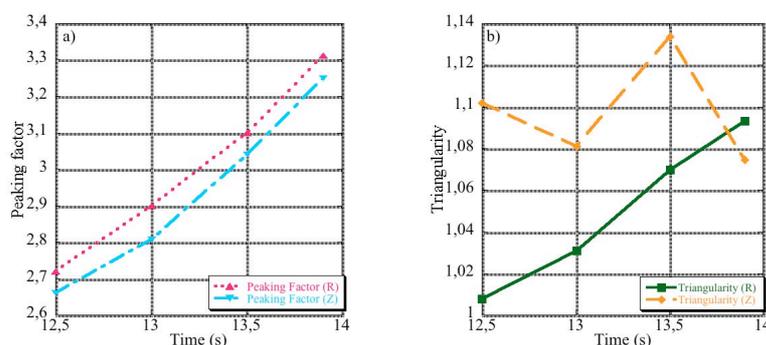

Figure 5a) peaking factors, **5b**) triangularities and **5c**) barycenter, during sawteeth for shot #40490

The SXR emissivity in the phase before the crash is always perfectly circular. The most relevant plasma shaping factors, for the shot 40490, are plotted in fig. 5.
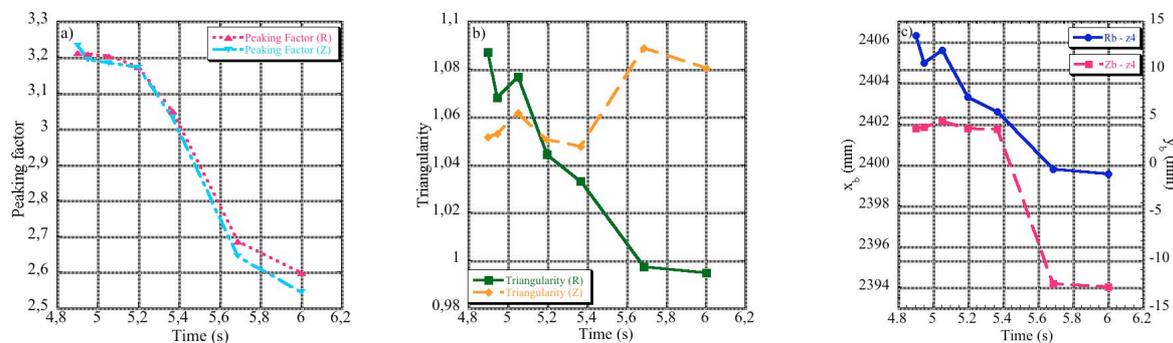
Figure 6a) peaking factors, **6b**) triangularity and **6c**) barycenter evolution during ramp up phase with ECRH for shot #40977

It can be observed that the peaking factors follow the sawteeth behaviour (fig. 5a) as well as the triangularity in Z (fig. 5b), while less regularly that in R (fig. 5b). It is worth noting that oscillations of the plasma barycentre as small as 2 millimetres in Z can be detected (fig. 5c). Progressive changes in the plasma shaping have been observed also during current ramp up phase (shot 40997), with ECRH (Electron Cyclotron Resonant Heating). Peaking factors, triangularity and barycentre are plotted respectively in fig. 6a, 6b and 6c for this case. An opposite trend was revealed during the ramp down for the same shot. The ramp down phase shows similar values but with an opposite evolution (fig. 7a, 7b, 7c), confirming the significance of these form factors and a clear correlation with the current profile.

Figure 7a) peaking factors and **7b** triangularity evolution during ramp down for shot 40977

Finally we observed (not shown here) that the evolution of the peaking factors and the barycenter are pretty well maintained, even degrading the SXR emissivity reconstruction to a grid 31x31. Conversely the parameters related to asymmetry (i.e. triangularity) or shaping (i.e. elongation) require necessarily a better accuracy in the emissivity reconstruction (grid 81x81).

Conclusions and perspectives

The tests with different emissivity distributions revealed that the form factors follow very well the plasma shape evolutions, confirming that all these tools of analysis were well optimized to reduce undesired reconstruction effects, without loosing important information. The correlation between plasma shaping factors and plasma parameters is under investigation. These form factors could be used also as constraints for the reconstruction of the magnetic surfaces in the core. Since SXR tomography can be acquired with high time resolution we will investigate the possibility to approximate the calculations of these shaping factors using directly the integral values of SXR brightness.

References

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