2D tomography of SXR data from toroidally separated cameras for studies of impurity injection and fast instabilities on JET

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1. Introduction

Spatially resolved soft X-ray (SXR) measurements will represent an important tool for monitoring impurity profiles in JET plasmas with an all-metal ITER-like first wall. Line-integrated profile measurements will be provided by pinhole cameras in three poloidal sections, see fig. 1: camera V at octant 2 and camera T at octant 7 (both with vertical view, 35 channels, 250 μm Be filters and new diodes installed in 2011), and the radiation protected camera S4 at octant 4 (horizontal view, 16 channels, 350 μm Be filter, ~15° tilt from the poloidal plane). The diagnostic is capable of high temporal resolution (up to 200 kHz); to implement it systematically, a new data acquisition system is being finalised. In this contribution, the potential of the diagnostic for reconstruction of 2D SXR emissivity is investigated.

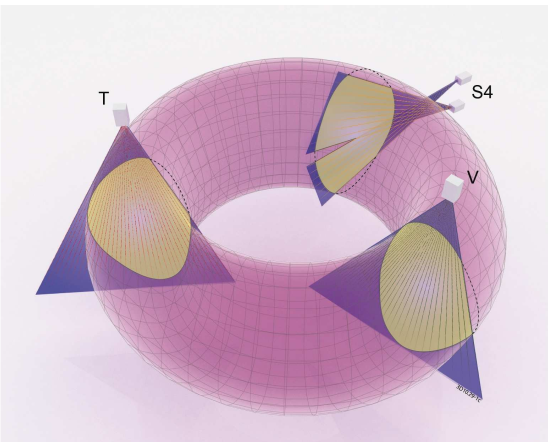

Figure 1. Scheme of the layout of the SXR diagnostics at JET with respect to plasma geometry.

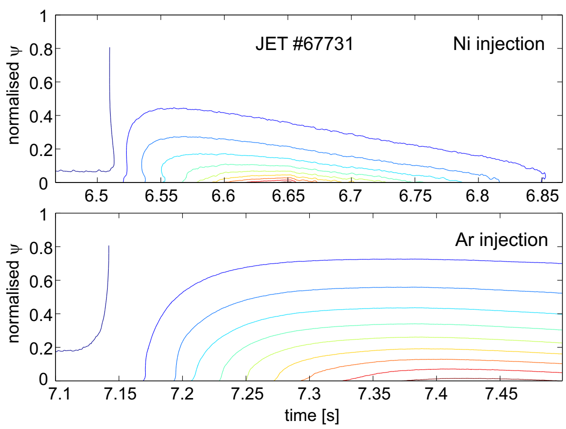

Figure 2. Evolution of the MFR reconstructed SXR profile perturbation after Ni and Ar injection

* See the Appendix of F. Romanelli et al., Proceedings of the 23rd IAEA FEC 2010, Daejeon, Korea

2. Principles of the SXR emissivity reconstruction

The Minimum Fisher Regularisation (MFR) tomography method [1] – exploited among other applications also in the JET neutron data analyses [2] – has been adapted for the JET SXR diagnostics setup. In MFR, a smooth solution for the 2D plasma emissivity g is found on a discrete rectangular mesh of pixels by minimising $\Lambda_{MF} = \frac{1}{2}\chi^2 + \alpha I_F$ where χ^2 is the goodness-of-fit parameter, α is a regularisation (smoothing) parameter and the Fisher information I_F is defined as $I_F = \int \frac{(\nabla g)^2}{g} dS$. Notice that the expected errors in data are the key input parameters to evaluate χ^2. As a significant novel physical constraint, anisotropic smoothness of the reconstruction with respect to the magnetic flux has been introduced in the following way: $(\nabla g)^2 \approx g\mathbf{H}g$ where $\mathbf{H} = \mathbf{B}_{\parallel}^T e^{\eta} \mathbf{B}_{\parallel} + \mathbf{B}_{\perp}^T e^{-\eta} \mathbf{B}_{\perp}$. Here, $\mathbf{B}_{\parallel}$ and $\mathbf{B}_{\perp}$ represent numerical differentiation matrices acting parallel and perpendicular to the magnetic flux, respectively. Notice that the anisotropy factor $\eta > 0$ enforces preferential smoothness along the magnetic flux surfaces, allowing for steeper gradients in the radial profile of the emissivity reconstruction. Non-negativity and zero border constraints have been also implemented, and in the rapid version, MFR can simultaneously process many timeframes of the SXR data [3]. The emissivity evolution can be eventually decomposed into spatial and temporal eigenvectors - topos v_i and chronos u_i - by Singular Value Decomposition (SVD): $g(r,t) = \sum_i^{\infty} s_i v_i(r) u_i(t)$, see [1]. The algorithm has been numerically optimised for the MatLab and the Python environments.

3. MFR tomography performance on slowly evolving SXR data

The first analyses have focused on studies of slow SXR perturbations where toroidal symmetry can be assumed, in particular on JET impurity injection data. It has been demonstrated that, in this case, the MFR provides reliable reconstructions of the emissivity evolution, reminiscent of neutron tomography analyses at JET [2]. In figure 2, evolutions of the emissivity perturbation profile after the Ar and Ni puff in JET pulse 67731 is presented. The perturbation profile has been derived from the 2D emissivity reconstruction by MFR on data from S4 and V detectors, with the first SVD topos (the steady profile) deducted and the result averaged poloidally along the magnetic flux surfaces. The advantage of this method, compared to direct 1D reconstruction (abelisation), is that correct positioning of the magnetic axis is of secondary importance in the 2D MFR. To illustrate this point and to investigate the potential of the MFR to actually determine correct positioning with respect to the anisotropy smoothness, various tests have been performed. A model 2D emissivity evolution of impurity injection has been used to generate test data, which were subsequently reconstructed by the MFR with added systematic errors in the magnetic flux positioning. For the average discrepancy between the reconstructed and model emissivities as a function of the flux positioning error see fig. 3. It is seen that the MFR is indeed robust with respect to the positioning of magnetic field, to the point that it not suitable for position optimisation. Next, stability and reliability of the reconstruction vis-a-vis statistical errors (noise) in the data has been studied by a simplified Monte-Carlo method [2]: the MFR has been run 2000x for both the test and the real data from impurity injection with additional random noise of amplitude from 0.1% to 10%. It is observed that, while the goodness-of-fit χ^2 is indeed kept constant by the MFR, in individual channels the misfit increases with the data noise as expected. More importantly, increasing noise in the data does not raise systematic errors (artifacts) in the reconstructed emissivity g; indeed it increases the standard deviation of g in individual pixels but its level is always lower than data noise due to the increasing regularisation factor. Next, for the first time, a possible automated optimisation of the anisotropy factor η has been examined using real data. Presently it seems that the overall smoothness defined as the norm of $(\nabla g)^2 \approx g\mathbf{H}g$ is a potential candidate for the optimisation, since it shows a shallow minimum in its dependence on η. The position of the minimum is the higher in η the higher is the expected error σ of the data, see the red dashed line in figure 4. This underlines the key importance of a correct estimate of σ as the MFR input parameter. Based on this expertise, the MFR method is foreseen now to contribute to quantitative impurity transport studies [4].

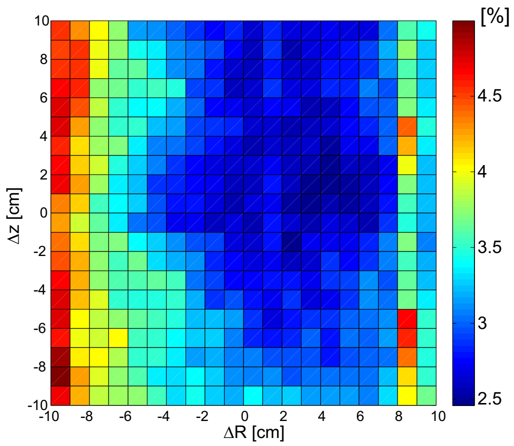

Figure 3. Error in the reconstruction of a model emissivity due to misposition of flux surfaces

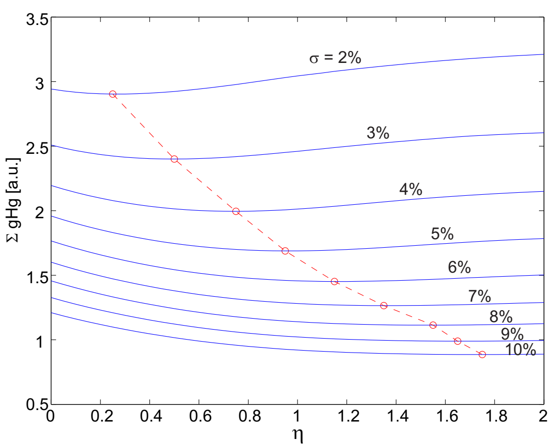

Figure 4. The emissivity smoothness as a function of the anisotropy factor and the expected data error

4. Feasibility of tomography using fast SXR data

With increasing temporal resolution in the SXR data, the different toroidal location of the pinhole cameras on JET presents a significant challenge. However, a phase shift in the data from different cameras may be introduced to adjust the data projections to a singular toroidal position. With this technique, reconstruction of m=1 MHD modes proved fully realistic, see figure 5. The figure shows 2^{nd} – 4^{th} order topos and chronos derived from 100 timeframes of the SXR emissivity reconstructed from 250 kHz SXR data in JET #65670, with an optimised phase shift in the camera V of 28 μs (ie 7 steps), determined from the correlation analysis of the data. In the fourth topos, even an m=2 mode can be recognised in spite of its low amplitude (<1% of the total emissivity maximum), however its phase analysis is beyond the spatial resolution of the available SXR system. Considerable efforts have been invested into attempts to distinguish higher MHD modes via the assumption of rigid body rotation, see e.g. [5], but no good results have been obtained so far. This is due to very weak perturbation of the SXR data by higher modes, as well as to the intrinsic characteristics of the MFR method that is better adapted for sparse data analyses as compared e.g. to [6].

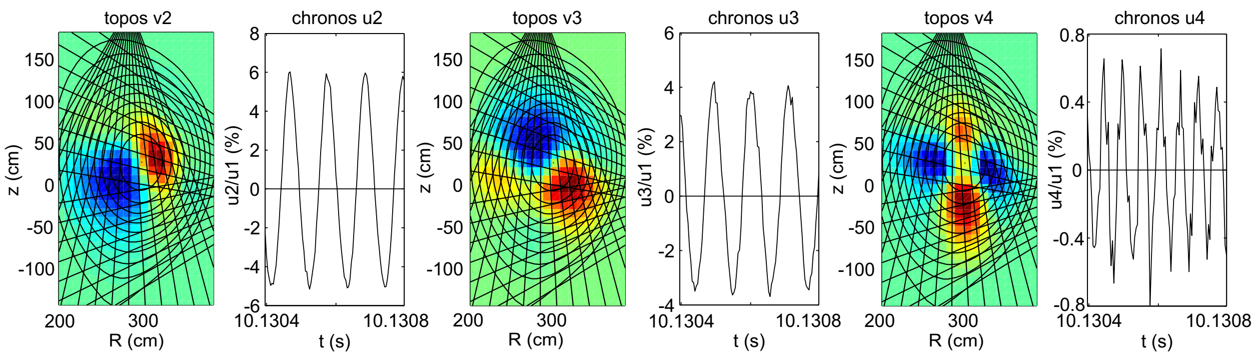

Figure 5. SVD decomposition of fast perturbation of the SXR emissivity evolution in JET pulse #65670, showing m=1 and m=2 modes

Acknowledgments

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