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1. INTRODUCTION

Analyses and validation of data from neutron measurements present one of the key contributions of JET to research and development of diagnostic systems for fusion burning plasmas. In this respect the JET neutron profile monitor has a unique importance in deterimining spatial distribution of neutron emissivities [1]. The monitor consist of two cameras, one with ten collimated channels, and another with nine collimated channels providing fan-shaped horizontal and vertical views, respectively. The spatial plasma coverage provided by the neutron profile monitor is adequate for inverse reconstructions, albeit with a rather scarce spatial resolution. Minimum Fisher Regularisation (MFR) has been recently applied at JET for the 2D tomographic reconstruction of the neutron emissivity [2]. This contribution presents the latest extension of the algorithm that allows for emissivity profile reconstruction (abelisation) under the assumption of constant neutron emissivities along magnetic flux surfaces (i.e. full poloidal symmetry). This strong assumption, when realistic, allows for profile analyses even if neutron emissivities are low. The MFR abelisation principle is tested and validated on phantom functions, including simulations of emissivity evolution and random data noise. First analyses of experimental data are presented, with particular interest in their potential use for tritium transport studies.

2. ABELISATION VIA RAPID MINIMUM FISHER REGULARISATION

Plasma tomography can retrieve emissivities g_j from line integrals f_i :

$$f_i = \sum_j^N T_{ij}\, g_j + \zeta_j$$

where T_{ij} is geometric matrix, N number of pixels, ζ_i existing statistical and systematic errors. In abelisation, g_j is supposed to be axisymmetric, i.e. pixels are delimited by magnetic flux surfaces. In the MFR abelisation the matrix T_{ij} corresponds to the total length of the i-th viewing line in the j-th pixel. A smooth solution for g_j is found by minimising

$$\Lambda_{MF} = \frac{1}{2}\,\chi^2 + \alpha_R\, I_F, \quad \text{where } \chi^2 = \frac{1}{M} \sum_i^M \left(\frac{\varepsilon_i}{\sigma_i}\right)^2 ;\ \alpha_i = f_i - \sum_j^N T_{ij}\, g_j$$

is the “retrofit”; α_R is a regularisation (smoothing) parameter, σ_i the data errorbars, M number of viewing lines and I_F the Fisher Information of the emissivity distribution. Minimal I_F corresponds to emissivity distribution estimate with minimum variance. In practice this principle leads to higher smoothness in low emissivity regions. These postulates have been implemented into a Tikhonov regularisation algorithm, see [3]. A rapid version can simultaneously proceed data with their time characteristics [4] providing an efficient tool for studies of the emissivity evolution. Spatially and temporarily resolved neutron emissivities can be subsequently decomposed into spatial eigen-modes (topos) and corresponding time eigen-vectors (chronos) using Singular Value Decomposition (SVD): $g\,(r, t) = \sum_i^{\infty} v_i\,(r)\, s_i u_i\,(t)$, for details see [3].

3. TESTS OF THE MFR ABELISATION ON PHANTOM EMISSIVITIES

The rapid MFR Abelisation algorithm was tested and optimised in runs with simple phantom functions that model diffusion-like evolutions of neutron emissivities, see e.g. Fig.1a. In order to keep the tests realistic, the geometric matrix corresponded to experimentally determined flux coordinates (JET Pulse No: 61161, t = 10.5s) and > 3% random noise was superposed onto the phantom projections. Within the tests the MFR abelisation was optimised and validated however with a conclusion that central regions tend to be either oversmoothed or noisy, see Fig.1b. Low spatial resolution was identified as the main cause: Only two vertical and two horizontal chords carry information on emissivities from the $r/a < 0.2$ region. Due to this feature it currently seems difficult to fully automate the MFR abelisation. Errors of the inverse reconstruction can be determined via simpified Monte Carlo simulations: Results are presented in Fig.1c, where dots correspond to time averaged errors in 20 consecutive reconstructions of the phantom projections that differed only in the superposed 3% random noise. Other tests proved that the SVD analyses lead to highly dependent results even with noisy data.

4. EXPERIMENTAL RESULTS

In [5] it has been shown that at JET, tritium puff into a low density plasmas leads to D-T (14 MeV) neutron emissivities with good poloidal symmetry. The corresponding data are therefore suitable for abelisation, which is the case e.g. in JET Pulse No: 61161. Rapid MFR abelisation of this event, presented in Fig.2a, offered best results for α_R corresponding to 4% expected errors in central chords. Evolution of the reconstructed D-T neutron emissivity profile clearly visualise the Tritium influx, which is even more apparent in the consecutive SVD of the reconstruction, see Fig.2b. These results can be used as input for the ratio method [5] which can lead to quantitative estimates of transport parameters. Interestingly, retrofit of the reconstruction on the input data unveils a minor assymetry, with a slightly higher signal towards the high field side (!). Notice that the assymetries may originate in offsets of fast particles and/or in minor errors of the magnetic reconstruction [4]. The MFR abelisation was also applied on data from recent JET campaign that focussed on magnetic ripple studies: D-D (2.5 MeV) neutron emissivity in JET Pulse No: 69604 (low ripple) was compared to emissivity in a quasi-identical Pulse No: 69610 (high ripple) at t = 21.5s. Due to low neutron intensities in these pulses, neutron data for abelisation had to be integrated over one second. Nonetheless, in order to get a smooth reconstruction the factor α_R had to be high (s ~ 8% in central chords). The retrofit identified that this condition was caused by apparent data assymetry in the vertical channels towards low-field side. Still, the results of MFR abelisation clearly demonstrate - as expected - that the neutron emissivity profile is broader in plasmas with higher ripple.

To conclude, the MFR abelisation of neutron emissivities at JET proved to be feasible, albeit with limitations in the central plasma region. However, most of the data show some degree of poloidal assymetry, so that the MFR abelisation will be probably limited to a secondary role in the ongoing neutron data analyses. Importantly, the MFR abelisation can provide a precise indication on poloidal data asymmetries. The results of this study give strong incentive for further development of the 2D tomography.

ACKNOWLEDGEMENTS

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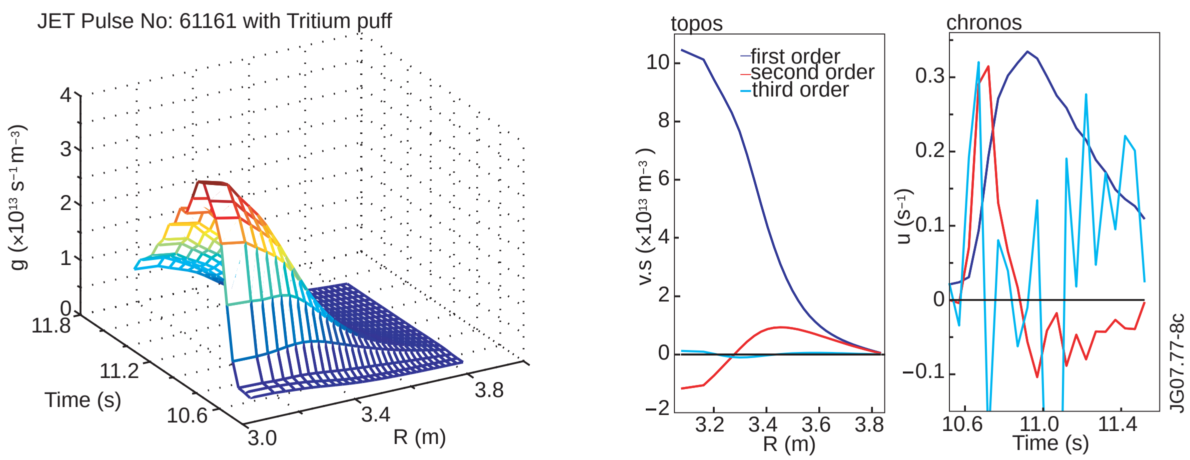

Figure 1: Tests of the MFR abelisation on projections of phantom data with 3% added random noise a) original phantom function b) example of the reconstructed function c) time averaged relative differences (reconstruction errors) for 20 different runs of the MFR abelisation.

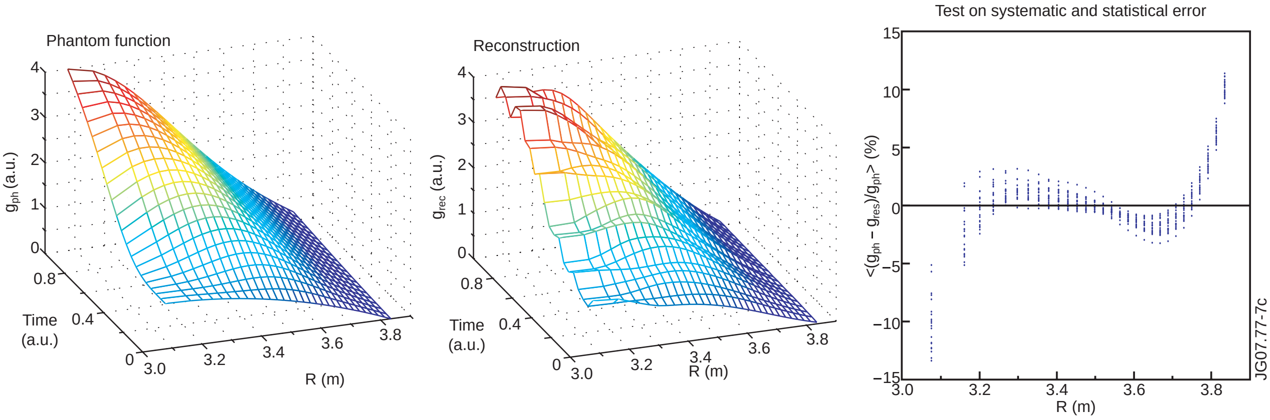

Figure 2: Experimental results – studies of Tritium puff: a) reconstructed evolution of emissivity profiles of 14MeV neutrons b) first three orders of the Singular Value Decomposition of the reconstructed emissivity evolution.