

New soft X-ray measurements and associated tomography reconstruction on Tore Supra

D.Mazon, C. Bouchand, P. Defrasne, D. Garnier, G. Huysmans, E.Joffrin, M. Jouve, F. Leroux, P.Maget, D. Pacella^{*)}, P. Pastor, A.L. Pecquet, N.Ravenel, P. Spuig.

*Association Euratom-CEA, CEA/DSM/DRFC, Centre de Cadarache,
13108 St Paul lez Durance, France*

^{*)} Associazione Euratom-ENEA sulla Fusione, C.R. Frascati, 00044 Frascati, Italy

1) Introduction

Plasma diagnostics based on broad-band emission of soft X rays (SXR) by the plasma are used on most fusion research devices and applied in general to study MagnetoHydroDynamic (MHD) phenomena, heat pulse propagation and impurity transport [1-3]. The Soft X-ray diagnostics which is implemented on Tore Supra has been recently totally refurbished in order to improve the quality of the measurement and associated treatments. Particular efforts have been made for designing the electronics part where the simultaneous requirements of low noise, high gain, high time resolution placed strong demands on the new system design. Solutions adopted concerning signal treatment including, preamplifiers, filtering and finally data storage which for long pulse machines like Tore Supra can become a critical issue, will be given in section 2. Finally description of the new tomographic inversion technique of the SXR measurements developed for Tore Supra based on the minimum Fisher regularisation on a grid of rectangular pixels will be described in section 3. This inversion technique is designed to be used in real time and examples of local emissivity reconstruction in the case of pulses presenting MHD activity will be presented.

2) The Tore Supra SXR diagnostics

The Soft X-ray diagnostics which is implemented on Tore Supra uses 45 viewing lines in a horizontally oriented fan and 37 in a vertical fan (see Fig. 1), providing a poloidal and toroidal resolution of about 3 cm and 10cm respectively. It records the integrated Soft X-ray emission between 1 to 15 keV using Silicon diodes polarized with a tension of 120V. The hardware and electronics of this diagnostics has been recently totally refurbished in order to improve the quality of the measured data. The measurement chain is depicted in Fig.2. A first current-tension amplification is performed in the close vicinity of the detectors (placed in vacuum) by an electronic card (Ampix). The signal is then transmitted in a

differential form (in order to reduce the noise) to the electronic cubicle where another electronic card (Receptix) put in form the signal. The originality comes from the fact that each of these cards can be programmed by software for managing offsets corrections, gains (1, 2, 5, 10) and cutting frequencies (from 62.5Hz up to 500 Hz for the slow acquisition rate and from 1kHz up to 250kHz for the fast one). Offset corrections are required: indeed the dark current of the diode is strongly influenced by the environmental temperature and it can fluctuate significantly. The offset value is therefore read and stored just before the plasma shot for each channel. Adjustable gain is also required for the electronics to follow the wide dynamic range of the diodes, almost four orders of magnitude. The information is then transmitted to analog to digital conversion boards (ETEP) located in the acquisition crate. Another important particularity of this new electronics comes from the fact that it now uses VME technology for Real-Time (RT) data collection which allows slow (from 1 to 8ms) and fast (from 1 μ s to 1ms) RT acquisitions, the last ones being acquired on predefined time windows. Pneumatic jacks driven at distance allow to insert sheets beryllium (25 μ m and 50 μ m) in front of each camera for low level energy selection. An example of signal acquired with this new diagnostics in a case of a pulse presenting sawteeth activity with Nickel injection at t=7s and fuelling at 10s can be seen in Fig. 3. Special attention has been paid to signal offset correction. Indeed such remaining offset may have some strong effects on tomographic reconstructions. A test bed reproducing the electronic chain of the diagnostics (see Fig. 4) has been created to study and improve the offset correction. A sinusoidal signal at 40Hz (amplitude of about 20 mV) with variable programmed offset (blue curve of Fig. 5) ranging from 0.6 to 1.5 V was used to stimulate the detector, the pink curve being the response of the current voltage amplifier. Experimental results showed accurate corrections despite the high value of the offset (up to 1.35V) compared to the signal acquired in the tokamak.

3) Tomographic inversion technique and experimental results

One way to address the tomography problem is to subdivide the area of the poloidal cross section where we want to reconstruct the emissivity into rectangular pixels (Fig. 6) and to assume constant emissivity within one pixel. Then the SXR line integrated measurement f can be written in the matrix form: $f = T * g$ where g is the searched 2D local emissivity and T the geometrical matrix whose elements T_{ij} equals the length of chord number i in pixel number j . To obtain an unique and sensible solution one can look for a minimum of a

functional $\Phi = \frac{\chi^2}{2} + \alpha.R$ with R a regularisation function, $\chi^2 = (T \times g - f)^t (T \times g - f)$

with t denoting the matrix transpose and α a positive parameter. The minimum Fisher regularisation uses $R = g^t \times H_n \times g$ with $H_n = \nabla_x^t \cdot W_n \cdot \nabla_x + \nabla_y^t \cdot W_n \cdot \nabla_y$ and ∇_x, ∇_y are finite difference matrix representation of the corresponding differential operators with respect to x and y respectively and W_n a diagonal weight matrix $W_{ij} = \delta_{ij}/g_i$. In order to minimize the Fisher information of the distribution g , we do not insert $1/g_i$ as a weight, thus avoiding non linearity. Instead we start with $W_n=1$, the unit matrix which is equivalent to first order linear regularization. We then solve the normal equations $(T^t \times T + \alpha H).g = T^t \times f$ and use the solution $g(1)$ thus obtained to determine a new weight matrix and so on. The process ends when $g_{n+1} \approx g_n$. An example of tomographic inversion using a 55*55 pixels grid using this techniques can be seen in Fig.7 in a case presenting a Gaussian shaped emissivity profile. For MHD studies, an inversion method using a prescribed equilibrium is more appropriate. The inversion matrix then contains the signal produced by Fourier modes on a given flux grid. An example showing the case of $m=1$ mode can be seen in Fig.8. Work is in progress to develop a RT version of this tomography techniques that will be used for MHD feedback control and is also foreseen for constraining the topology of some RT equilibrium code [4], providing for example constraints for the magnetic axis or some boundary flux surfaces.

References:

- [1] C. De Michelis, M. Mattioli, Nuc. Fus. Vol21 N°6 (1981).
- [2] G. Fuchs et al. , Plasma Phys. Control Fusion 36 (1994) pp 307-316.
- [3] J. Mlynar et al. , Plasma Phys. Control Fusion 45 (2003) pp 169-180.
- [4] K.Bosak et al.proceedings of the 30th EPS conference(2003).

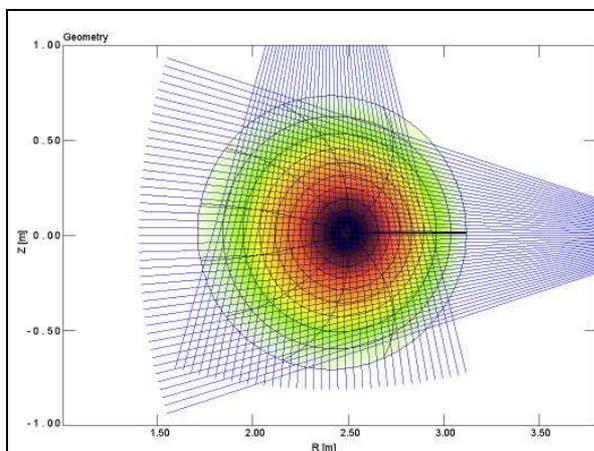


Fig. 1 Tore Supra SXR line of sights

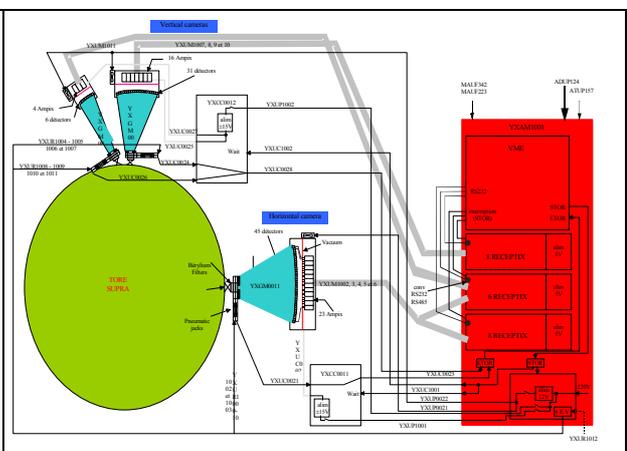


Fig. 2 SXR measurement chain

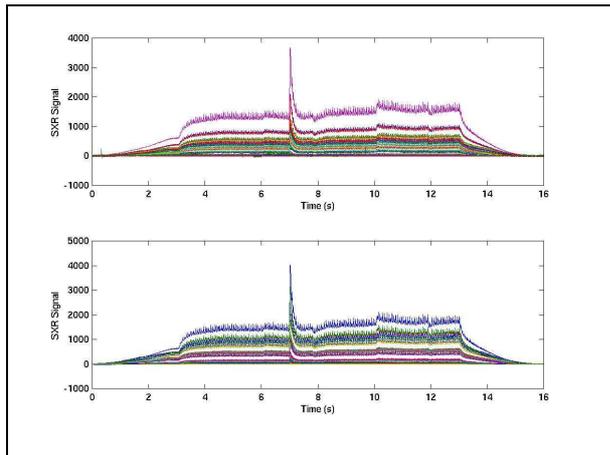


Fig. 3 SXR signal pulse #39600. Nickel injection at $t=8s$.

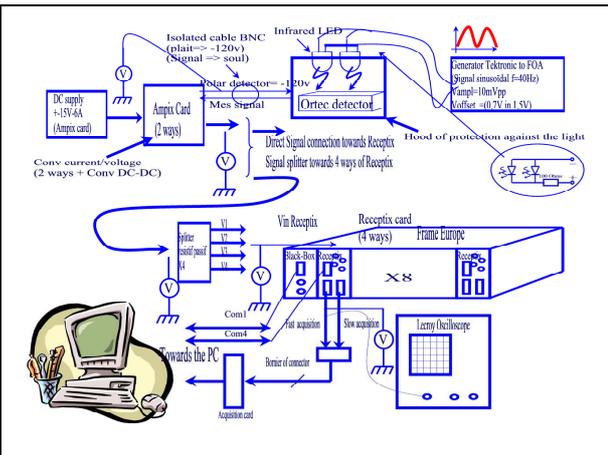


Fig.4 Test bed reproducing the electronic chain of the SXR diagnostics

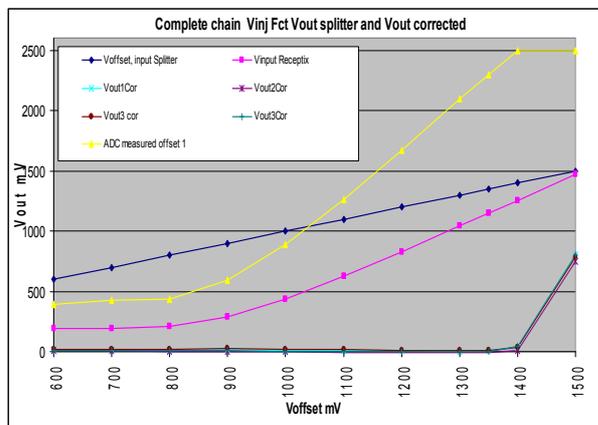


Fig. 5 Experimental evidence of the offset correction limit.

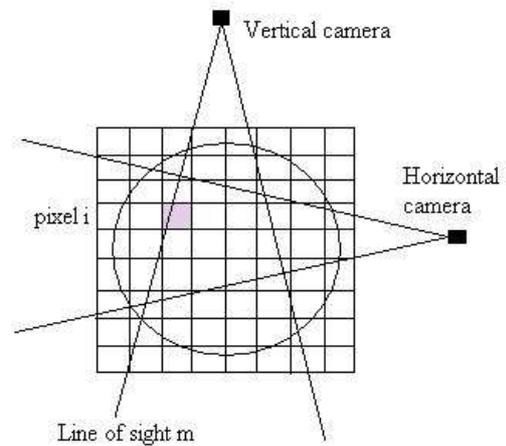


Fig. 6 Tomographic principle

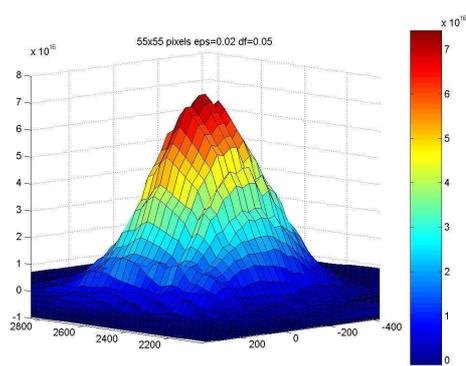


Fig. 7 Example of tomographic reconstruction using a 55*55 grid pulse #37040.

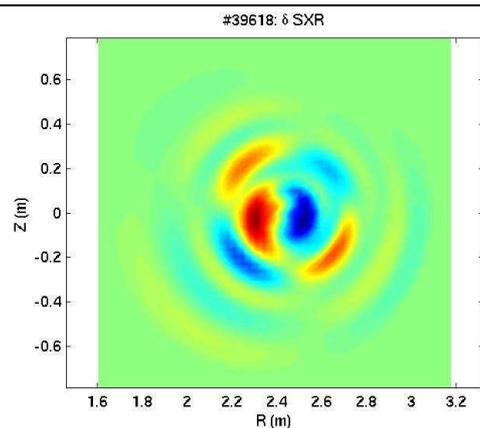


Fig. 8 $m=1$ mode as seen by SXR tomography pulse #39618