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Pilot Results on Spectrally Selective Ultra-Soft X-Ray Tomography on TEXTOR

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Introduction. A novel instrumentation for wavelength and time resolved plasma emission tomography in the range 0.1 - 4 keV was earlier suggested and pre-developed for application at TEXTOR [1]. The technique indicated in the list of FOM diagnostics on TEXTOR as USXT (ultra-soft x-ray tomography) is intended for reconstruction of distributions of local emission coefficients (LEC) for impurity lines. Further determination (with additional data on electron density and temperature) of spatial distributions of impurity ions at particular ionization stages is considered as final experimental goal.
The principal instrumental task - formation of spectrally selective plasma images at several viewpoints around plasma - is solved by using miniature pinhole cameras supplemented with multilayer mirrors (MLM) [2] as dispersion elements. The x-ray image is converted to a visible image in a phosphor layer on the entrance surface of a fiber image conduit. The latter couples the MLM/pinhole camera with an image recording Electron Bombarded CCD camera. Due to compactness of the MLM/pinhole camera and remote location of the EBCCD camera, installation of the USXT system on several ports in one poloidal cross-section has become feasible. The present paper describes the performance and first demonstration results on LEC reconstruction after installation of a part of the USXT system at temporary ports. The complete diagnostics will be operational after the TEXTOR shutdown in 2001.

Instrumentation. The USXT instrumentation has been designed as a system of independent x-ray imaging modules. One of three modules currently installed on TEXTOR is shown in Fig.1. The new MLM/pinhole camera (a) is equipped with sets of changeable multilayer mirrors and pinholes. Selection and positioning of these elements, determining spectral and imaging parameters of the system, can be performed between plasma discharges with another new system unit - a driver (d) utilizing specific optical sensors [3]. The fiber image conduit (b) and the EBCCD camera (c) were described earlier [1].
The current positions of MLM/pinhole cameras and radiation collection angles are shown in Fig 2. This is a temporary installation, to test and demonstrate system performance using ports available before modification of the TEXTOR liner during the planned shutdown. The radiation collection angles shown in Fig. 2 are determined by the ports and the liner geometry and by construction elements of the liner. The bottom camera (3) was installed separately, in a cross-section, remote from that of cameras 1 and 2 by 45 degrees of the large torus circumference. Nevertheless, in spite of these temporary limitations, important functionality tests of the USXT system have been performed, resulted in probe reconstruction of LEC distributions for several impurity lines.

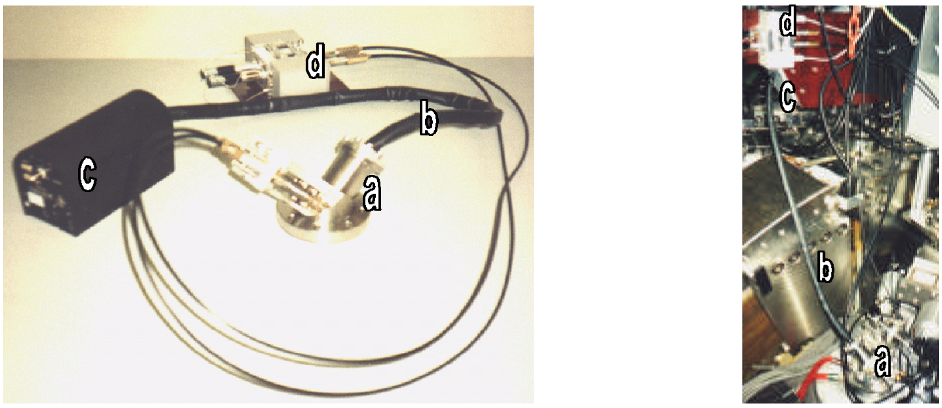

Fig. 1. USXT imaging module: a - MLM/pinhole camera, b - fiber image conduit, c - EBCCD camera, d - positioning driver of MLMs and pinholes

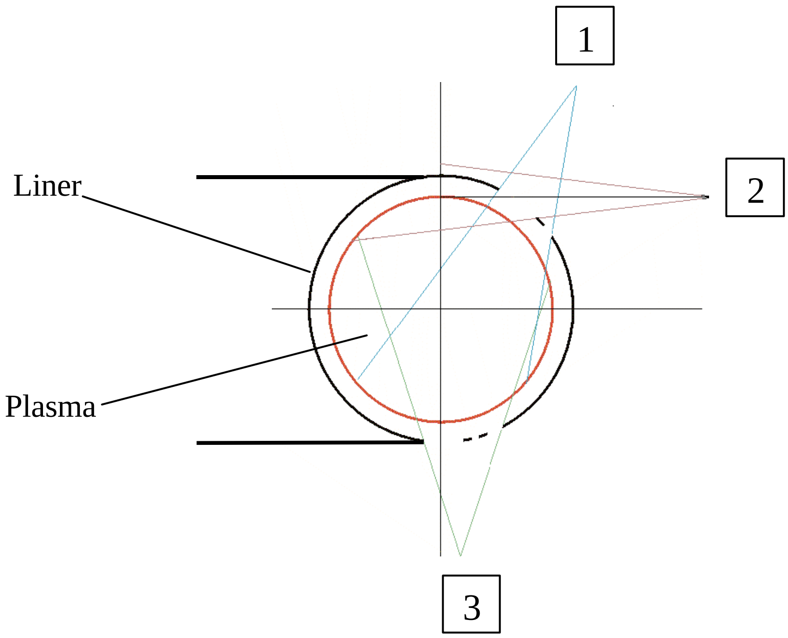

Fig. 2. Radiation collection geometry of temporary installation

Plasma imaging. The USXT imaging modules have been extensively tested and calibrated at laboratory facilities equipped with soft x-ray sources, monochromators and various optical accessories. The main measurements were associated with sensitivity of each module, its variation within the image field, absolute spectral and radiometric calibration. In particular, an investigation of sensitivity "map" of the image module entrance optics was done using a laser plasma x-ray radiation source.
Time resolved plasma images in emission lines of C V, C VI, O VIII, Ne IX, Ne X were recorded with 3 USXT modules in various discharges during several experimental sessions at TEXTOR. Fig. 3 shows typical image frames for lines of Ne IX (1.35 nm) and Ne X (1.21 nm). The images were processed taking into account the above-mentioned pre-installation calibration measurements of instrumental parameters, such as sensitivity "maps" of the imaging modules. Intensity distributions along the lines, measured for each frame of all cameras, served as data basis for time resolved reconstruction of LEC. In the pilot

experiments time resolution was reduced from 20 ms to 100-200 ms because of the use of a single framegrabber (Matrox Pulsar) with 3 cameras. The initially specified resolution of 20 ms during the whole discharge will be provided for the complete USXT system of 6 cameras using new data acquisition electronics.

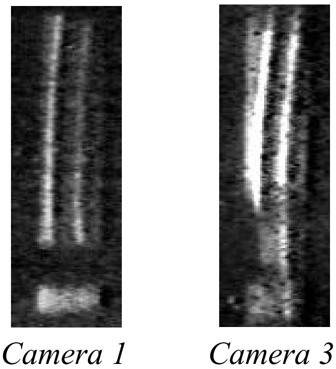

Fig. 3. Typical plasma images in Ne IX(1.35 nm, right line) and Ne X (1.21 nm, left line), recorded with cameras 1 and 3 (Fig. 2).
Images are obscured by construction elements of TEXTOR liner (schematically shown in Fig. 2)

Tomography reconstruction. The calculation technique has been further adapted to the real USXT geometry due to modification of the previously developed algorithm "Iterative Sinogram Restoration (ISR)" [4], which can be uniquely applied to a very irregular spatial distribution of view lines. For the current temporary layout of 3 cameras, which only partly cover the poloidal plasma cross-section (Fig. 2), additional assumptions, such as up-down symmetry, were introduced in ISR in some calculations. Fig. 4 illustrates the influence of the present angular limitations on reconstruction quality. A hollow-shaped circular model is acceptably well reconstructed with full view angles for each camera, whereas the lack of emission information from a part of the cross-section (a strong-field plasma side, as seen in Fig. 2) results in "melting down" of the distribution in that area. This simulation predicted similar deformations of distributions reconstructed from experimental data (Fig. 5).

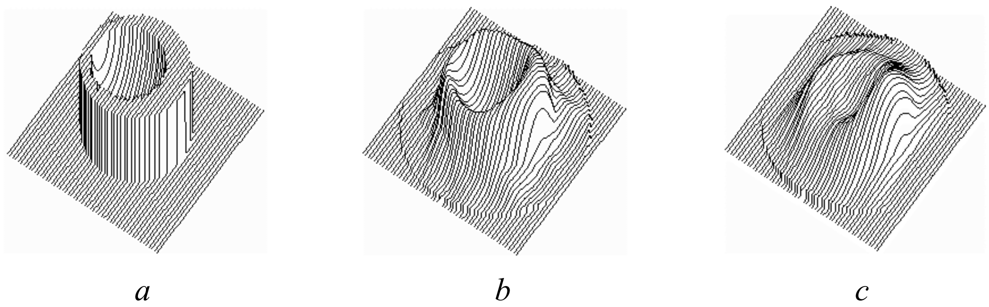

Fig. 4. Simulation results on reconstruction of exact model (a) for two cases of radiation collection by three cameras, positioned at present USXT mounting points: full view of plasma by each camera (b) and view within real angles shown in Fig. 2 (c).

Reconstruction results shown below in Fig. 5 were obtained using the above-mentioned modified ISR algorithm, with the same number of iterations (75) and effective chords (35 for each of cameras 1 and 3) for all sets of plasma images. Because of a poor data, determined by the limited view of plasma from the temporary locations of the cameras, additional assumption of up-down plasma symmetry was introduced in some calculations. However, this assumption has not change significantly the calculated distributions. For the above discussed reasons, the pilot LEC reconstructions are to be treated just as demonstration results providing an opportunity to estimate the future work after the complete UXST installation.

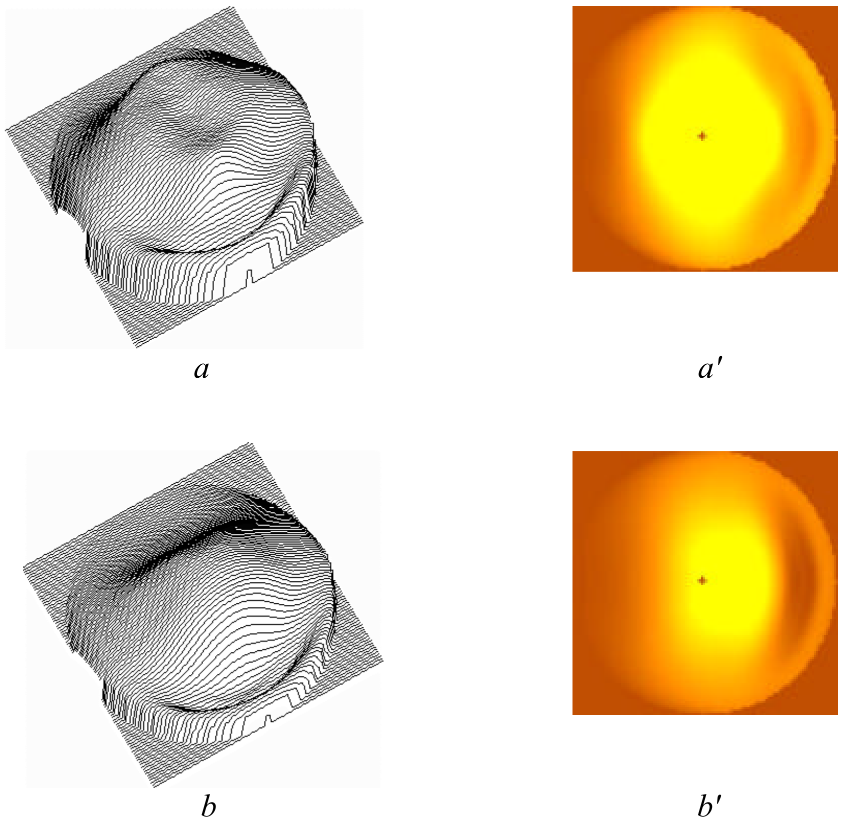

Fig. 5. Samples of reconstruction of LEC distributions for Ne IX (a, a') and Ne X (b, b') from imaging data obtained simultaneously, as shown in Fig. 3.
Essential deformation of reconstructed shapes at one side is observed, caused by absence of emission data in that area

Summary. The first part of USXT system including 3 (of 6) imaging modules has been installed on temporary TEXTOR ports. Time resolved plasma images in selected emission lines of intrinsic and seeded impurities have been recorded by all cameras. The ISR tomography algorithm was adapted to the real radiation collection geometry. In spite of limitations of the current installation, important functionality tests of the system have been performed, resulted in demonstration of reconstruction of LEC distributions for several impurity lines. These pilot results are considered as the basis for future full-scale implementation of the diagnostics after the planned modification of the TEXTOR liner.

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