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Introduction

A system for tomography in the wavelength range 300 – 1100 nm has been designed for the Rijnhuizen Tokamak Project (RTP). The plasma is viewed from five directions in one poloidal plane with a total of 80 *pin*-diode detectors. To obtain a sufficiently large number of photons on the detectors and to have a good spatial resolution, an optical imaging system relatively close to the emitting plasma is used to collect the light (Fig. 1). For four of the viewing directions the imaging system consists of two spherical mirrors inside the vacuum vessel; the fifth viewing direction (E) has a lens system outside the vessel. View dumps have been installed on the walls of the vessel opposite to the various detectors to reduce the unwanted background light caused by reflections on the walls. The presence of view dumps is very important as measurements that will be discussed indicate. In front of the mirrors masking apertures have been installed to reduce the effect of reflections on the walls of the ports and to stop light that is not imaged by the mirrors. The electrical system has a large bandwidth (200 kHz) so that fluctuations can be monitored on a microsecond time scale. Different wavelength regions can be selected by optical filtering, e.g. to study H_α- and Z_{eff}-profiles. The system for visible light tomography has been described in more detail in Ref. 1.

Results of the tomographic inversion method that is being implemented for the system are shown, and measurements with the system in a table-top set-up using known light sources are discussed.

Tomography algorithms

Because of the complexity of the imaging, implementation of the system into commonly used tomography codes is not straightforward. Ray-tracing is used to calculate the contribution of the local emissivities g in the plasma to the power f measured by the various detectors [1]. This can be

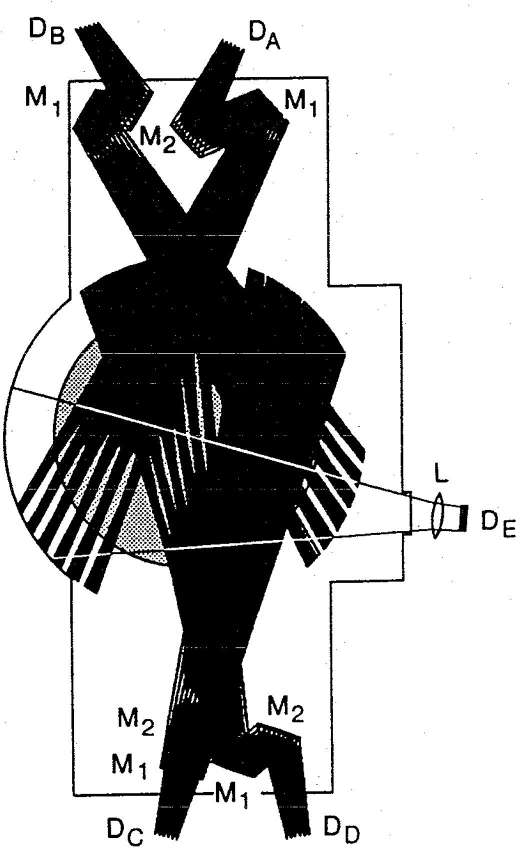

Fig. 1: *The regions seen by the detector elements in the poloidal plane of the plasma (shaded) with respect to the vacuum vessel. The detectors for the different viewing directions are numbered D_A through D_E and for four viewing directions the rays that reach every third detector element are shown. M_1 and M_2 are mirrors. For the fifth viewing direction with a lens (L) only the total region viewed is shown.*

expressed in the weight matrix W:

$$f_j = \sum_{i=1}^{N} W_{ji} g_i \quad , \tag{1}$$

where i is the indicator of the N cells in which the poloidal cross-section is divided, and j indicates one of the M detectors. Inversion of Eq. (1) by tomographic techniques gives an approximate emission profile.

Because of the limited number of views of the plasma, the weight matrix is not used directly to obtain a reconstruction from the measurements. Instead, as a first approach, the number of viewing directions and the number of detectors is "increased" by interpolation and smoothing of the measurements. The new interpolated viewing directions can best be chosen to be part of a detection system with parallel beams. This method has been described in Ref. 2. For the smoothing process an iterative procedure was used that includes averaging in a 3×3 window and independent spline smoothing with regularization in two directions. Boundary conditions, such as zero signal for chords looking outside the plasma region and periodicity of the solution were included. The iteration was interrupted when the norm of the residual started to increase.

After the interpolation to parallel beams the signals are used in a regularized scheme of the Filtrated Back Projection (FBP) algorithm [3]. Results for a simulated emissivity profile where information about the actual measuring system has been taken into account are shown in Fig. 2. The result for the visible light tomography system shows oversmoothing, while better results can be obtained by a similar system that is more evenly distributed. To improve the result additional *a priori* information should be included. We plan to add constraints such as energy conservation and other properties of integral projections. It should be stressed that this system was not designed to have an optimal coverage of the plasma, but especially to enable one to study fluctuations at the edge of the plasma as well as to make reconstructions of hollow profiles.

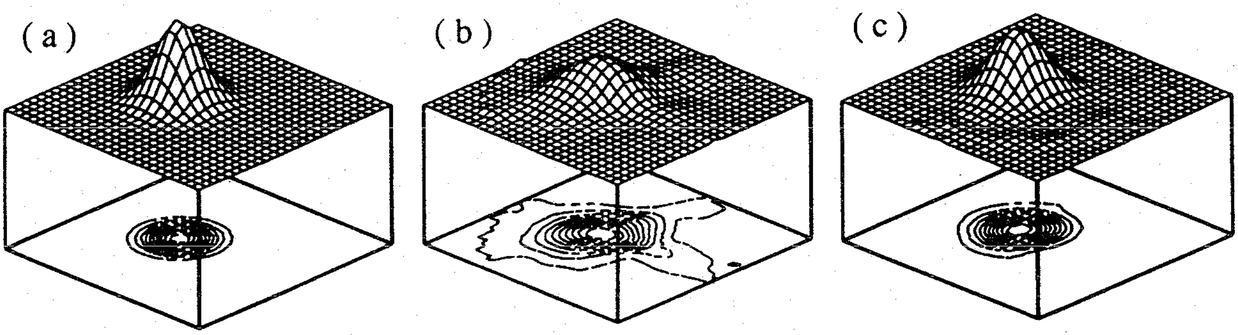

Fig. 2: *Results of tomography of a simulated off-axis circular Gaussian emission profile. Three-dimensional and contour plots of the emission profile (a), the reconstruction for the actual visible light tomography system (b) and the reconstruction for a system with the same number of viewing directions and detectors, but more evenly distributed, (c) are shown. The tomographic reconstructions (b) and (c) were obtained after calculation of the signals that would have been measured by these systems with 3% noise added, followed by interpolation to a parallel beam system with 11 viewing directions and 27 detectors each.*

Table-top measurements

Measurements with the system installed on a dummy tokamak section have been used to evaluate the performance of the hardware and software. Light sources were used to simulate structures in the plasma region and the signals from all 80 detectors were measured simultaneously. The light sources were elongated in the toroidal direction because the detectors see a slab that is approximately 1.5 cm thick, and two views (B and C, see Fig. 1) are slightly tilted with respect to the poloidal plane. With the set-up we could study the effect of reflections on the walls with and without view dumps, and differences between the measured weight matrix and the calculated one. Also larger light emitting structures were applied to obtain measurements that could be used to investigate the performance of the reconstruction algorithms, but a complicating effect is that for this purpose only optically thick sources could be found (while in the optical wavelength range the plasma is optically thin).

To study the contribution of reflections on the walls to the signals, separate measurements of the background of reflected light and "direct" light are needed. This can be done by measuring the light from a small source: some detectors will see the source directly, while others will only measure the background light. An estimate of the total background light produced by a constant emission profile can be obtained by multiplying the measured background light averaged over all detectors by the number of times that the light source would fit into the plasma. An estimate of the direct light can be obtained by multiplying the signal of the detectors seeing the source by the number of times the source fits into the viewing region. Measurements have been taken with the source in different positions, which yield comparable results. With view dumps the background radiation was just measurable and an upper limit for the contribution of background light to the total signal of 10% is found (possibly partly containing a contribution from noise). Without view dumps (the tokamak walls were simulated by sheets of aluminium) a background level about two to three times as high was observed for the viewing directions with mirrors, while for direction E (with the lens system) it is even more. The absence of the view dumps would therefore have large effects on the interpretation of measurements.

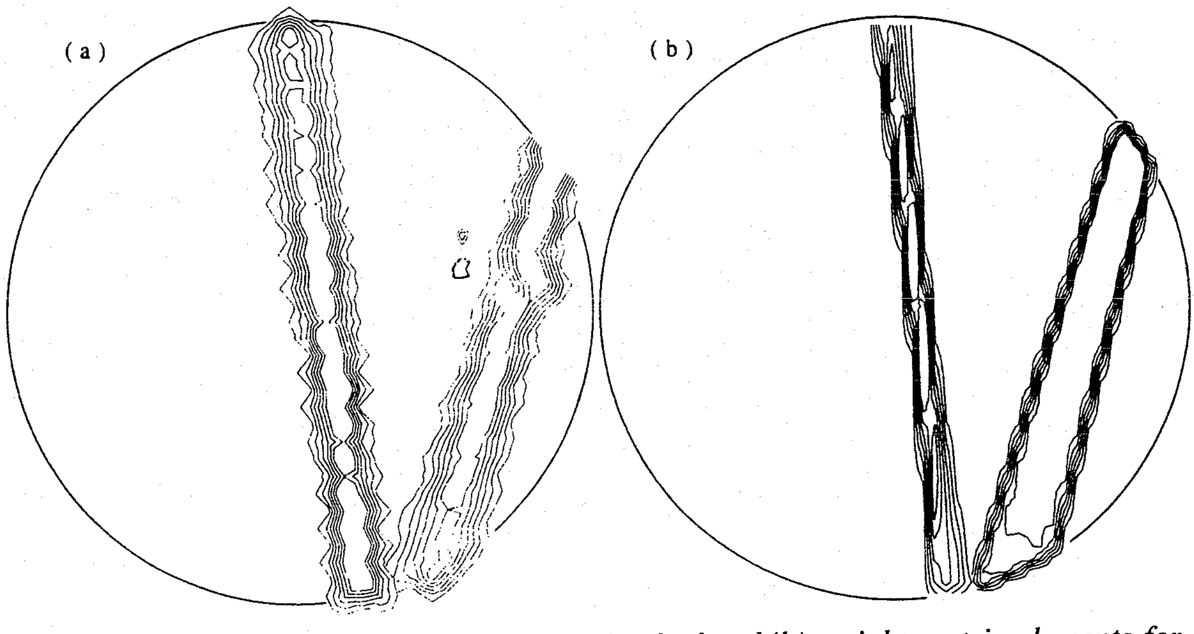

Fig. 3: *Contour plots of the measured (a) and calculated (b) weight-matrix elements for two detectors. The circle represents the plasma boundary (radius 170 mm). The "wobbly" shape and the appearance of local maxima and minima in both (a) and (b) are digitizing effects of the grid [square cells of 14 mm for (a), and 7 mm for (b)] and have no physical significance.*

The weight matrix was measured by using a cylindrical light source with a diameter of 18 mm: the source was moved in a grid in the poloidal plane and for every position the contribution to all detectors was measured. With a source of finite size a slightly smoothed matrix is obtained [Fig. 3(a)] which is quite similar to the calculated one [Fig. 3(b)]. The measured and calculated weight matrices have been used to calculate the signals that would be measured by the detectors for three different emission profiles (Fig. 4). The overall shapes of the curves are quite similar, but some effects still have to be explained. For the measured weight matrix, noise and systematic errors in the measurements, and the possibly not accurately enough known calibration factors, could cause "unsmoothness" in the curves. Errors in the measurements could include inaccuracies in the positioning of the light source, and the fact that the source is a cylindrical surface emitter of finite size while for the calculated weight matrix the average over a volume element is taken. Furthermore: (1) for the calculated case the design positions of the mirrors were taken which differ from the actual positions, (2) the ray-tracing was done for two dimensions while especially for the viewing directions that are tilted out of the poloidal plane (B and C) a three-dimensional calculation is needed, and (3) reflections where no view dump was possible (especially A) and light not imaged by the mirrors reaching the detectors (only in B) are not taken into account in the calculation of the weight matrix.

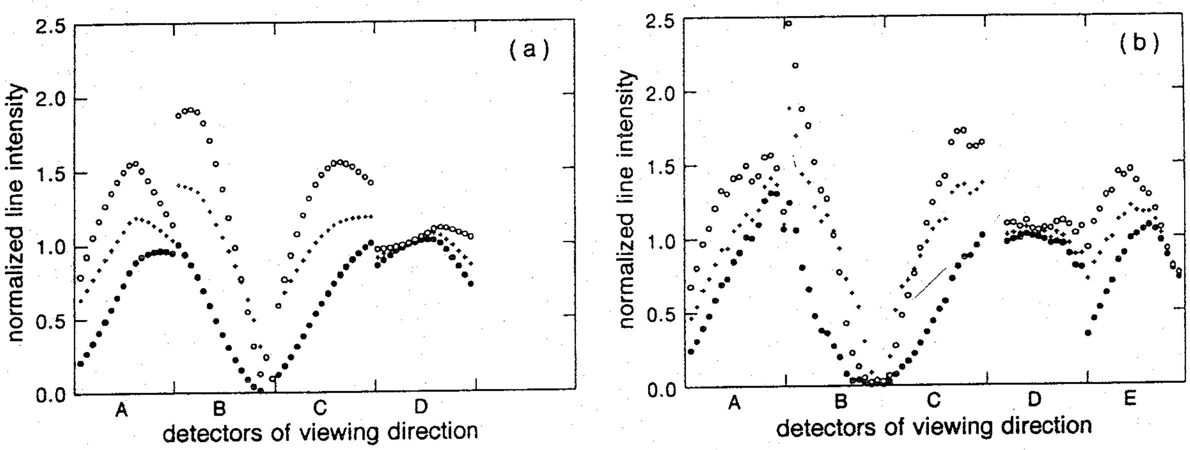

Fig. 4: *Signals (line integrated intensities) that would be measured by the detectors of the different viewing directions (indicated by the letters defined in Fig. 1) for the calculated (a) and measured (b) weight matrix, for three different radial emission profiles: + = constant, • = parabolic and ∘ = hollow. The values of the two graphs have been normalized to the average signal values for the constant profile. Viewing direction E is missing in (a) because the current ray-tracing code can only calculate the weight matrix for the mirror systems, not for the lens system.*

Acknowledgements

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