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Observation of MHD phenomena with the visible light tomography system on RTP

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Introduction

MHD phenomena in the plasma of the Rijnhuizen Tokamak Project (RTP) are being studied with the 80-channel visible light tomography system. Three different spectral ranges have been used: the maximum range 300–1100 nm, the range 695 – 1100 nm, and the selection of the H_α-line (656 nm) by interference filters. Preliminary results are presented here. Parameters of RTP are: $R_0 = 0.72$ m, $a = 0.165$ m, $B_T < 2.4$ T, $I_p < 150$ kA, $T_e < 4$ keV, $n_e < 2 \times 10^{20}$ m^{-3}.

Description of the system and the tomography method used

The emitted visible light is collected in one poloidal cross-section from five viewing directions by optical imaging systems, each with 16 detectors.[1] On first approximation the measurements are line-integrated over the plasma. The coverage of the plasma can be described in projection space, which coordinates p and ϕ describe the lines along which the line-integration takes place: p is the distance from the line to the origin (e.g. the centre of the plasma) and ϕ the angle of the line with the horizontal. We choose ϕ between 0° and 180°, and p negative if it is below the origin. The viewing lines of the system in projection space are shown in Fig. 1. Because the imaging system is close to the plasma, corrections are needed to the assumption of line-integrals.[2,3]

The viewing chords have been chosen such that they cover mainly the edge of the plasma (where most visible light is emitted), and such that they are narrow and close together. In this way effects of small fluctuations in emissivity are not smoothed out by integration over the width of chords, and can be studied by means of correlation techniques. The positions of detectors and imaging systems are also largely determined by the limited access to the tokamak vessel. This results in a sparse coverage of projection space (Fig. 1).

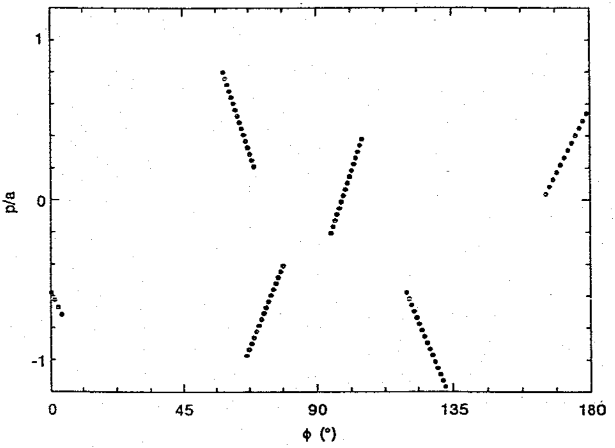

Fig. 1: The distribution of viewing chords of the system in projection space.

The quality of tomographic inversions of data sampled on such a sparse grid can be improved by reconstructing the entire projection space.[4] We have developed a method to interpolate the measured points in projection space to a regular grid.[2] The interpolation between the measurements f on a irregular grid to the values on a regular grid g, can be described by an interpolation operator A: $f = A\, g$. This system of equations can be solved by the iterative Algebraic Reconstruction Technique.[5] Because the problem is underdetermined, it is regularized by inserting a relaxation parameter into the iterations, and by using *a priori* information. *A priori* information used in our method is: smoothness (smoothing is applied in the iterations), boundary properties (zero emission outside the plasma and periodicity) and constraints. The constraints include the property of projection space that the integrals over p for all ϕ should be equal.[4] The choice of ranges of the p and ϕ coordinates of Fig. 1 facilitates the application of boundary properties and constraints. Furthermore corrections for the measurements not being exact line-integrals can be made in the iterations. Finally the resulting interpolated values on a regular grid in projection space are tomographically inverted; currently we employ a regularized version of the Filtered Back Projection method.[6]

Simulations have been done assuming certain model emission profiles. Figure 2 shows a simulation of a hollow profile with a one-island structure. The island is restored in the reconstruction, although the reconstruction is very smoothed. Noise (3%) was added to the calculated measurements of the model to test the method for stability. The reconstruction of projection space from the 80 measurements was done to a grid of 15 ϕ values, and 27 p values for each ϕ. The reconstruction errors that can be calculated for the restoration of projection space and for the tomographic inversion are consistent.

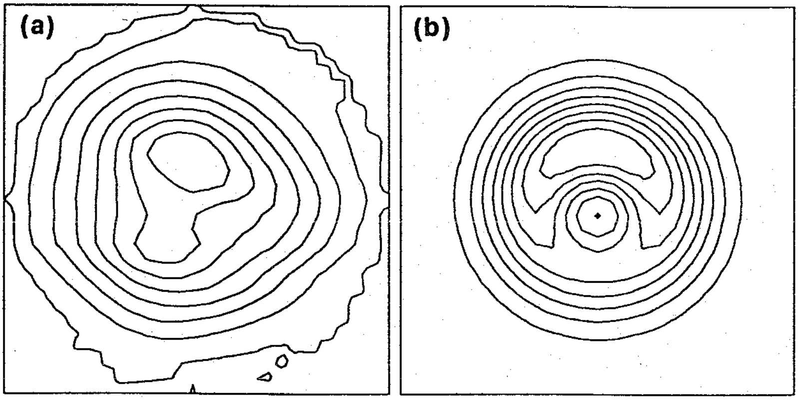

Fig. 2: Contour plots of a reconstruction (a) of a slightly hollow model emission profile with an island structure (b).

A Gerchberg-Papoulis-like iteration scheme is being added to our reconstruction method of projection space. In the standard Gerchberg-Papoulis scheme[7] an iteration is done between object space or an operation on projection space (backprojection), and its Fourier transform. In our scheme we implement a tomographic inversion and a back-calculation of what would be measured in all grid points with the inverted emission profile, i.e an iteration between projection space and object space. In this way the interpolation and smoothing is forced to result in a function that has all properties of a function that can be tomographically inverted.

Study of MHD phenomena

Effects caused by MHD-island structures near the edge of the plasma have been measured in the full spectral range of the system (300 – 1100 nm). For the discharge under consideration $q_a \approx 3$. Amplitudes of the oscillation of up to 60% of the time-averaged signal level have been observed for some of the channels, meaning that the oscillation in local emission is even larger (the signals are line-integrated, and thus smoothed, measurements). An asymmetric emissivity profile is observed, with a maximum near the edge at the upper outboard side. The asymmetry seems to depend only weakly on plasma conditions. If only H_α radiation is measured the asymmetry is less pronounced than for the other wavelength ranges that have been observed. The cause for the asymmetry is yet unexplained. It may be related to a slight offset in the vertical position control towards the top-limiter. To see more clearly the effect of the rotating MHD structures on the emission profile, tomographic inversions of the oscillating part of the signals have been made (Fig. 3). Tomographic inversions of such complicated structures with a system with a sparse coverage of projection space, will give artefacts in the reconstructions. The reconstructions shown in Fig. 3 are stable (a similar result after one rotation), and show a smooth transition from one timeslice to another (intermediate timeslices not shown in Fig.3). Therefore we believe that the main features of the reconstructions are reliable.

Other diagnostics like the ECE-radiometer, the interferometer and the pick-up coils observe a rotating $m = 2$, $n = 1$ island structure in electron density and temperature, and magnetic field. The reconstructions however do not show a rotating emission distribution, but rather that certain regions of the plasma oscillate in emission. Furthermore the structures appear are at radii which vary with the oscillation cycle. A confirmation that the structures do not rotate at fixed radii comes from correlation analysis. The correlation analysis has to take into account the line-integrated character of the measurements. If the visible emission would come from a rotating island structure like the one that is measured by other diagnostics, one can expect the channels viewing equal radius (equal p) to measure similar signals with a phase shift corresponding to the angle between the viewing chords. This method gives the expected result for model profiles with rotating islands, but not for the measurements. The unclear correlations between channels, and the oscillations seen in the tomographic inversions, could be explained to arise from, for example, an electron density profile rotating with the magnetic structure in a poloidally non-uniform background of neutral hydrogen density. For comparison the island structure as observed by other diagnostics is indicated in Fig. 3, were the electron density is lower in the O-points of the islands than in the X-points.[8] There seems not to be a clear correspondence with a positive or negative fluctuation in emission with the island structure, but there is a strong dependence on the position of the islands.

Conclusions

A new reconstruction method for sparsely sampled data in projection space has been demonstrated. It has been applied to the measurements in visible light emitted by a plasma during MHD activity. The results show that the structures that emit visible light do not correspond spatially with the island structures observed by other diagnostics, whilst there exists a clear correlation in time. A possible explanation is a poloidally asymmetric distribution of neutral hydrogen, or the lumping of emisson of various spectral lines, each of which might behave differently in space and time. Therefore more narrow spectral bandwidths will be used in the future.

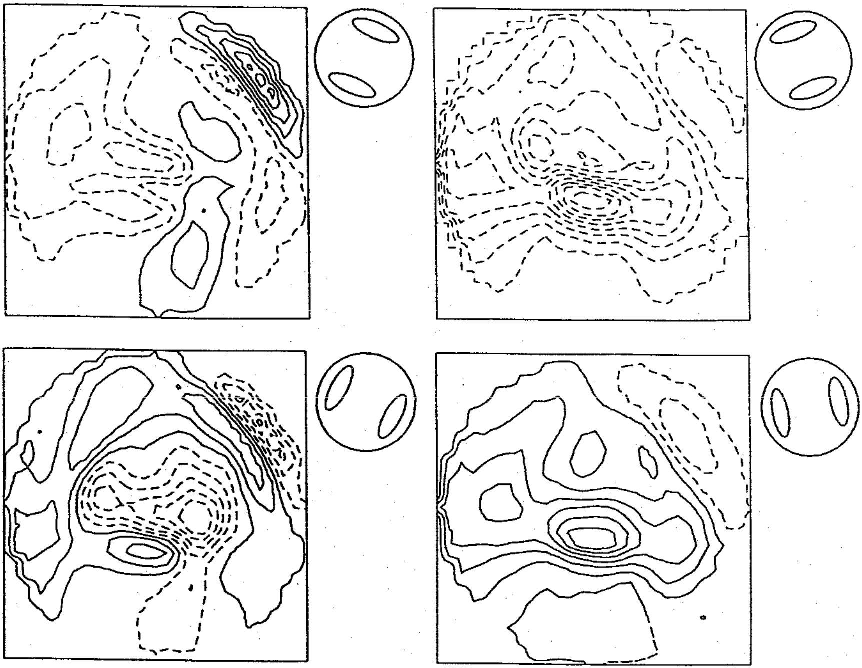

Fig. 3: Tomographic inversions of four equidistant timeslices of the fluctuating part of visible light measurements (without optical filters) during one oscillation period. The figures are contour plots in one poloidal plane (the left side is the inboard side) where the solid lines indicate positive values and dotted lines negative values. The ellipses in the circles indicate the positions of the O-points of the magnetic islands in the same poloidal cross-section. The radius at which the islands rotate is at approximately 2/3 of the radius reconstructed.

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