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Preliminary Investigation of the use of Visible Images to Validate the Magnetic Reconstruction of the Boundary on JET

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ABSTRACT

The reconstruction of the magnetic fields, which produce the confinement of the plasma, is an essential ingredient of Tokamaks, since they affect both the operation of the devices and the interpretation of the physics results. This work reports a preliminary investigation to determinate whether the position of last magnetic flux surface can be evaluated from the images collected by JET visible cameras. To this end, the frames of some JET visible cameras have been analysed with the phase congruency method to extract the position of the emission at the boundary on the high field side. The results of the comparison between the optical reconstruction of the plasma boundary obtained from the cameras and the separatrix position derived from the equilibrium code EFIT has been performed. Depending on the measurements used as inputs to EFIT, the difference between the two estimates of the separatrix position is below 10cm.

1. INTRODUCTION

The configuration of the magnetic fields inside the plasma is an essential ingredient of tokamaks, since these fields influence both the operation of the devices and the interpretation of the physics results. In modern day machines, the magnetic topology is normally derived from equilibrium codes, which solve the Grad-Shafranov equation with constraints imposed by the available measurements, both external and internal to the plasma. On JET the main code used for this purpose is EFIT[1] and at present a critical review of the reconstructions is under way to try to improve their quality. In this framework, it has been investigated whether the position of the separatrix can be validated using the images of JET wide angle visible cameras, normally used for operation. Indeed, as already shown on other machines, particularly MAST, the visible emission of the plasmas can present a halo around the region of the separatrix, which can be used to check the accuracy of the magnetic reconstructions[2]. On JET this approach can be quite useful to validate the reconstruction of the separatrix on the high field side where only a limited number of magnetic pickup coils are available at the moment.

In this perspective, the frames of some JET visible cameras have been analysed with the phase Congruency (PhC) method to extract the position of the emission at the boundary. The PhC method is based on the assumption that highly informative features in the image coincide with those points where the Fourier components, at different frequencies, have congruent phases[3]. The PhC calculation for 2-D images is obtained by applying the 1-D calculation over specific orientations, using log-Gabor filters. They are constructed using a Gaussian kernel function modulated by a sinusoidal plane wave. This filter will therefore respond to frequency, but only in a localized part of the signal and over a specific direction. The self-similarity of these filters (all filters can be generated from one mother wavelet by dilation and rotation) leads to a straightforward implementation over several scales and orientations.

Phase congruency is a reliable feature detection tool under varying illumination, contrast and magnification conditions[4]. Various alternative EFIT reconstructions, using different constraints at the edge and various diagnostics as inputs, have then been investigated (see section 3). The position

of the separatrix derived from the analysis of the visible cameras videos has then been compared with the estimate provided by EFIT (see section 4).

2. THE FRAMES OF KL1 VISIBLE CAMERA AND EFIT RECONSTRUCTIONS

Figure 1 shows a typical frame of the visible camera KL1 (KL1-o4wb), routinely used to monitor JET operation, in which the plasma boundary on the high field side is clearly visible. It is located on the horizontal plane of the fourth octant. It is worth emphasizing that the frame shown in Figure 1 is quite representative of the images collected by the KL1 camera. Since only a thin shell at the plasma edge around the last closed magnetic surface is expected to emit a significant amount of visible light, it is possible to use this emission to try to locate the position of the separatrix.

Contrary to MAST, where the camera position and the plasma emission permit a reconstruction of the complete separatrix [1], on JET the KL1 camera allows visualising only a small part of the plasma boundary. As shown in Figure 1, only the plasma emission of the lower part of the plasma on the high field side is strong enough to be detected.

In principle, to obtain a reasonable estimate of the distance between the plasma boundary and the limiter, the exact geometry of the camera field of view is required. In the ideal case, a perfect pinhole camera should have its axis normal to the object surface. In the case of the visible KL1 operation camera, the angle between the perpendicular to the camera detector and the poloidal plane containing the inner “guard limiter” is almost 90 degrees (95.108°). Therefore the projection of the plane containing the guard limiter on the camera plane implies an almost negligible elongation of the distances in the horizontal axis direction. In this object plane the conversion from pixels to centimeters was estimated to be $0.0057[\text{cm/pixel}]$.

With regard to the equilibrium code EFIT, recent studies on JET indicate that the use of internal measurements, for example polarimeter data, together with a relaxation of constraints on the edge current density, can significantly improve also the reconstruction of the separatrix. In this perspective, a preliminary study has been conducted with the aim of comparing the data of the boundary evaluated from the visible images with two different outputs of the EFIT code. The first magnetic reconstruction of EFIT has been obtained using only the magnetic coils (EFIT). In the second the internal measurements acquired from the polarimeter (EFTF) and kinetic pressure have been used as constraints.

3. DIFFERENT BOUNDARY ESTIMATES

As preliminary investigations, two different Pulse No's: 82080 and 82800 (a traditional H-mode and a ‘hybrid’ scenario) have been investigated. The images acquired with KL1 visible operation camera during the flat top of the discharges have been analyzed using the phase congruency method. An example of boundary reconstruction using a PhC method is reported in figure 2. In figure 3a and 3b an example of the boundary reconstruction at two particular times for Pulse No's: 82080 and 82800 are reported. To confirm the potential of the method adopted for the analysis, in figure

3 the coordinates of the internal guard limiter, as obtained from the internal survey of the vacuum vessel, (blue continuous line) are compared with the position of the Limiter evaluated on the basis of the visible images (blue crosses). Since the discrepancy between the estimate of the guard limiter position derived from the videos and its actual coordinates is always less than 2 cm, this can be considered the error to be associate with the developed image processing method applied to the available images. In figures 3a and 3b, the separatrix obtained from the equilibrium reconstructions using only external measurements and pressure constraints (red stars), the EFIT reconstructions of the separatrix with the additional internal measurements from the polarimeter (black stars) and the boundary derived from the visible images (green stars) are compared. To better evaluate the discrepancies between the optical and magnetic reconstructions of the plasma boundary, only the differences between the various estimates have been plotted in Figures 4 and 5 for various time slices.

4. RESULTS AND CONCLUSION

The optical reconstruction of the plasma boundary, using visible images, has been compared with the position of the separatrix obtained with EFIT. JET visible images show an increased emission around the separatrix only in the low part of the plasma on the high field side. From this region of high emission the position of the separatrix can be estimated. The accuracy of this evaluation has been estimated to be of the order of 2 cm. In this region, the two estimates for the two analyses shots present always a difference smaller than 10 cm. When the equilibrium reconstruction is run with the polarimetric internal measurements as constraints, the agreement between the output of EFIT and the evaluation of the boundary position from the camera improves systematically (practical for all time slices), in some cases by several centimeters.

The discrepancies between the two estimates of the boundary are unfortunately quite significant. Moreover the absolute value of the discrepancy can change significantly during a shot (see figures 4 and 5) and for the moment no clear correlation to explain such behavior has been found. To what extent the differences in the estimates of the separatrix position are due to problems with EFIT reconstruction and to what extent they are due to the fact that the halo of strong emission is not located exactly at the last closed magnetic surface is a matter of future investigations.

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Figure 1. A frame of the operation visible camera KL1. A halo of increased emission, which is believed to indicate the position of the plasma boundary is clearly visible. (Pulse No: 82080)

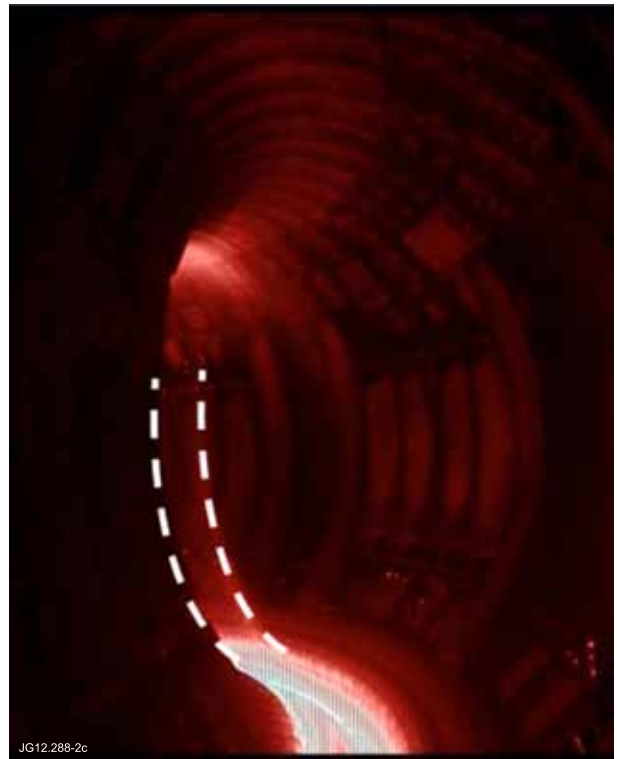


Figure 2. An example of PhC method for the boundary reconstruction. (Pulse No: 82080)

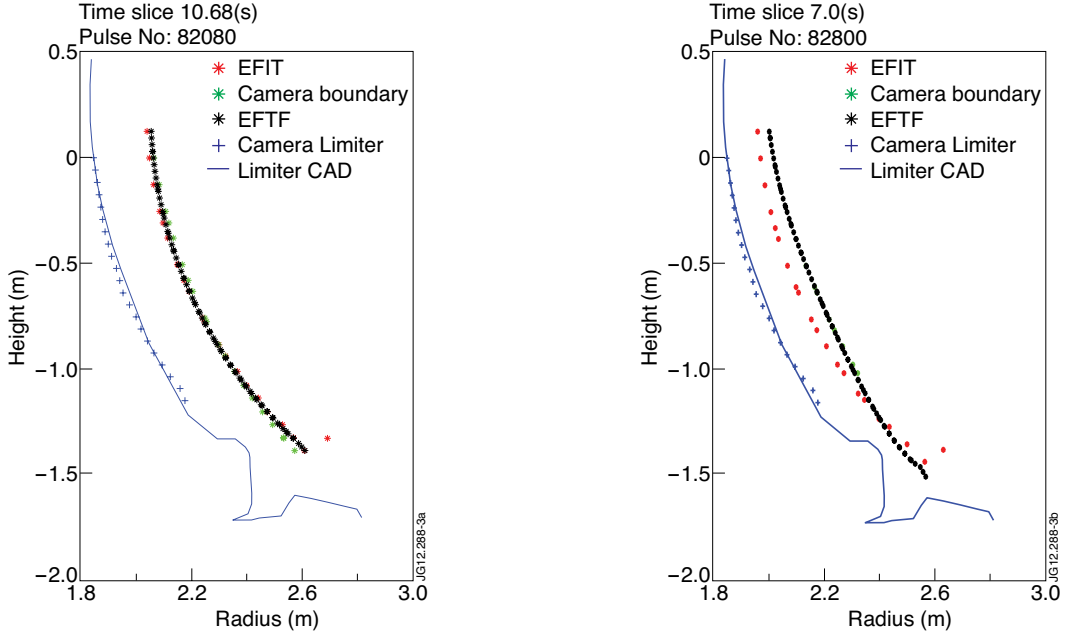


Figure 3: (a) (Pulse No: 82080). (b) (Pulse No: 82800). Comparison between the optical plasma boundary reconstruction and the last magnetic flux surface of the equilibrium code EFIT for a time slice. The coordinates of the inner guard limiter (blue continuous line) and position of the same guard limiter evaluated from the visible images (blue crosses) seem to be in good agreements and confirm the potential of the method adopted for the analysis. The two figures show the comparison of the optical boundary plasma reconstruction (green stars) and the equilibrium reconstruction using only magnetic coils and plasma pressure (– red stars) or magnetic coils, plasma pressure and polarimeter measurements (black stars).

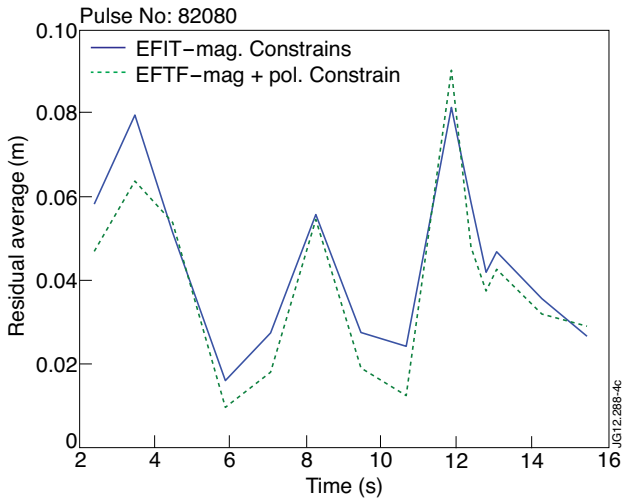


Figure 4. The difference, averaged over the region of the boundary depicted in figure 2, between the plasma boundary obtained with the visible images and the reconstructions of EFIT, for Pulse No: 82080. The blue line is the difference between the plasma boundary obtained with the visible images and EFIT reconstructions using magnetic coils plasma and pressure as constraints. The green line is the difference between the plasma boundary using the visible images and EFIT reconstructions using magnetic coils, plasma pressure and polarimetry measurements as constraints (EFTF).

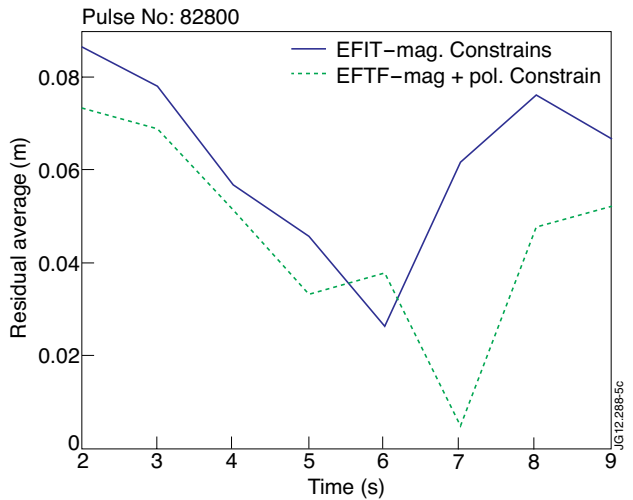


Figure 5. The difference, averaged over the region of the boundary depicted in figure 2, between the plasma boundary obtained with the visible images and the reconstructions of EFIT, for Pulse No: 82800. The blue line is the difference between the plasma boundary obtained with the visible images and EFIT reconstructions using magnetic coils and plasma pressure as constraints. The green line is the difference between the plasma boundary using the visible images and EFIT reconstructions using magnetic coils, plasma pressure and polarimetry measurements as constraints (EFTF).