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TCV High Resolution X-ray Imaging Diagnostic

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INTRODUCTION

A Multiwire Proportional X-ray (MPX) detector was used on the Tokamak a Configuration Variable (TCV) in a high spatial resolution X-ray imaging diagnostic. This vertically viewing 64 channel X-ray system has been designed to complement the existing TCV soft X-ray tomography system consisting of ten 20-channel pinhole cameras (spatial resolution ~ 3 cm) [1] by enhancing the spatial resolution of X-ray emissivity measurements. The objectives are the observation of magnetohydrodynamic (MHD) activity and transport barriers phenomena and an improved the determination of the Electron Cyclotron Heating (ECH) deposition profile. The diagnostic measures the plasma emission in the 3-30 keV range with a radial resolution of about 5 mm and a frequency bandwidth of a 50 kHz. This paper outlines the design of the system and also presents some initial results, which demonstrate the diagnostic potential.

THE DIAGNOSTIC DESIGN

The diagnostic consists of a vertically mounted helium-filled cylindrical camera with a rectangular aperture (Fig.1). The dimensions of the aperture are 2x40 mm^2. The camera is equipped with a planar MPX detector consisting of 64 non-separated channels. Each channel has a sensitive area of 2x40 mm^2. The spatial resolution of the diagnostic at the vessel mid-plane is about 5 mm. The camera is separated from the vacuum vessel by a first beryllium window of thickness 250 μm. The MPX detector has a second beryllium window of thickness 100 μm. Thus the diagnostic views the plasma through two beryllium foils totalling 350 μm thickness. An additional aluminium foil of thickness 308 μm was used in some of the experiments to observe a higher energy electron population, as discussed in the article.

The MPX detector is a modified version of a multiwire proportional chamber developed for the T-10 tokamak X-ray monochromator [2]. The construction of the MPX detector is similar to that of multiwire proportional counters [3] commonly used in charged particle physics. 64 parallel anode wires situated between two cathode grids in a common gas chamber filled by an argon-methane, krypton-methane or xenon-methane gas mixture at atmospheric pressure. The overall spectral sensitivity of the diagnostic for different gas mixtures and different foils used in the experiments is shown in Fig.2. The main advantage of the MPX detector is the high intrinsic gas amplification (10^2-10^5, depending on the applied voltage) and the negligibly small leakage current. This allows the use of simple operational amplifiers for matching the detector signal to the acquisition system input voltage range. The amplifiers are mounted directly on the detector to minimize parasitic capacitance and noise. They convert the detector current into voltage (conversion factor 100 nA/V) and limit the signal bandwidth to 50 kHz. The signals are digitized by a 12 bit ADC at a sampling rate of 200 kHz. The voltage value applied to the detector is selected remotely from the control room and provides a flexible change of gas amplification for optimal output in different TCV operation modes.

FIRST RESULTS

The X-ray intensity as a function of time for several channels of the MPX detector shielded by a 350 μm thick beryllium foil is shown in Fig. 3 for a discharge with elongation κ=1.8 and plasma current I_p=390 kA. Sawtooth oscillations can be seen in the stationary stage of the discharge. A clear m=1, n=1 mode is growing just before the sawtooth crash at t =1.16 s.

Periodic non-localized and localized bursts of the non-thermal X-ray radiation are observed in experiments with modulated Electron Cyclotron Current Drive (ECCD) in low density discharges (n_e=1x$10^{19}$$m^{-3}$, I_p=250 kA, P_{ECCD}=1.5MW). In these experiments the signal was filtered by an additional aluminium foil of thickness 308 μm and the detector was filled with the krypton-methane gas mixture (the spectral response is shown in Fig.2 (d)). Non-localized X-ray bursts appear at the end of the ECCD pulse and can be observed simultaneously on all channels of the MPX detector and on the hard X-ray runaway monitor (Fig 4). In some cases the ECCD pulse where followed by periodic localized X-ray bursts. These bursts appears in phase with an m=2, n=1 mode and can be observed only on the high field side channels close to the plasma center. In both cases the X-ray bursts are attributed to MHD activity which expels ECCD induced non-thermal electrons which then impinge on the plasma-facing components.

The high spatial resolution of the diagnostic allows an improved determination of the ECH power deposition profile. The ECH power deposition profile is determined from the time evolution of the X-ray intensity after the ECH power is switched on/off. In these calculations one assumes that the variations of the plasma density and effective charge are negligible during the analysis time (5 ms). It is then possible to reconstruct the variation of the electron temperature profile using the dependence on the local X-ray intensity from the electron temperature, taking the initial electron temperature from the Thomson scattering diagnostic. After Abel inversion of the line integrated X-ray signals and reconstruction of the time variation of the electron temperature the ECH power deposition profile is calculated using the COBRA code [4]. An example of such a calculation is shown in Fig.6. Fig.6(a) shows the X-ray intensity as a function of time for different chords (the ECH power is switched on at t=0.4 s). Comparison of the results of ray tracing calculations (solid line) with the ECH power deposition profiles calculated by COBRA code (dashed line) is shown in Fig.6 (b). It can be seen from Fig.6 that the experimentally determined ECH power deposition location is in good agreement with the results from ray tracing calculations. However the half-width of the experimental ECH power deposition profiles is always wider than the half-width of the profiles calculated by the TORAY code. This can be explained by noise in the experimental data and the finite number of polynomials used for solution regularization in the Abel inversion and COBRA codes.

CONCLUSIONS

A Multiwire Proportional X-ray detector has been implemented on TCV as a high spatial resolution X-ray imaging diagnostic. A vertically mounted helium-filled slot-hole camera equipped with a 64-channel planar MPX detector views the plasma core with a radial resolution of about 5 mm on the vacuum-vessel mid-plane. The diagnostic allows a considerably improved spatial resolution of the X-ray emission measurements and the study of MHD activity with a 50 kHz bandwidth. Periodic localized and non-localized bursts of the non-thermal X-ray radiation possibly caused by interaction of the ECCD induced non-thermal electrons with plasma-facing components are observed in low-density discharges with modulated ECCD. The diagnostic also allows improved experimental determination of the ECH power deposition profile.

REFERENCES

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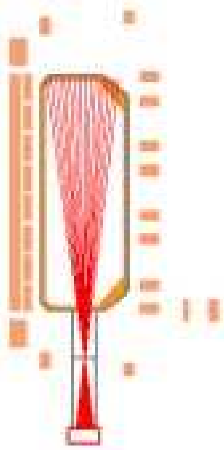

Fig.1 Geometry of the MPX diagnostic.

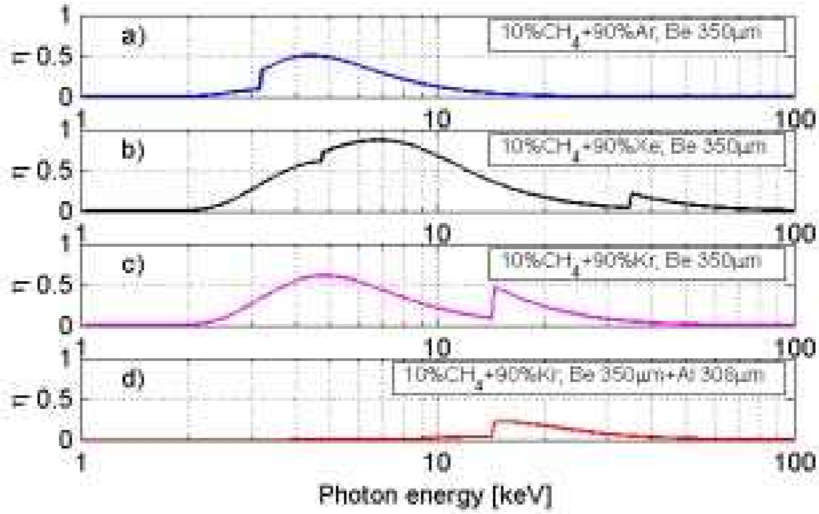

Fig. 2 Overall spectral sensitivity of the MPX diagnostic for different gas mixtures and foils.

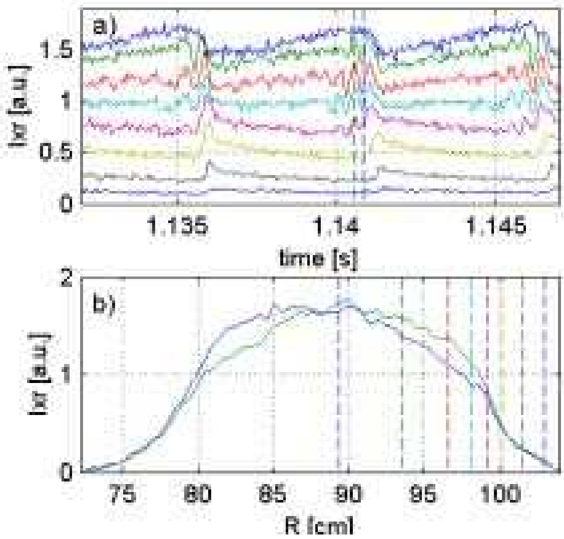

Fig. 3 X-ray intensity time traces (a) and poloidal profiles (b), dashed lines shows times and chords position (shot 22610).

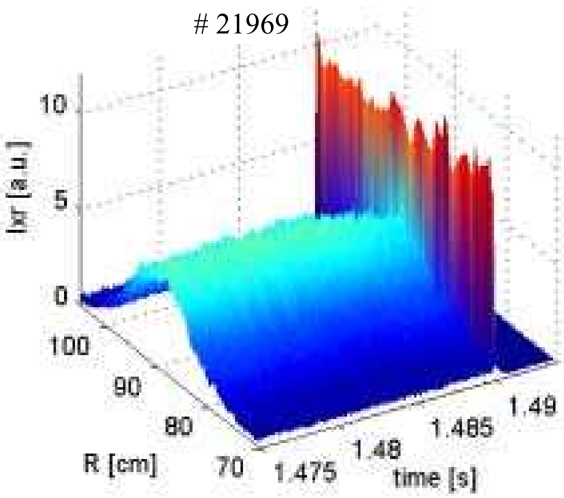

Fig.4 Non-localized X-ray burst.

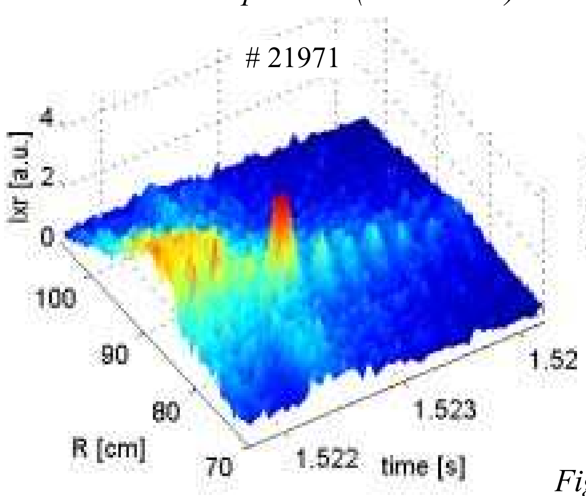

Fig.5 Localized X-ray bursts.

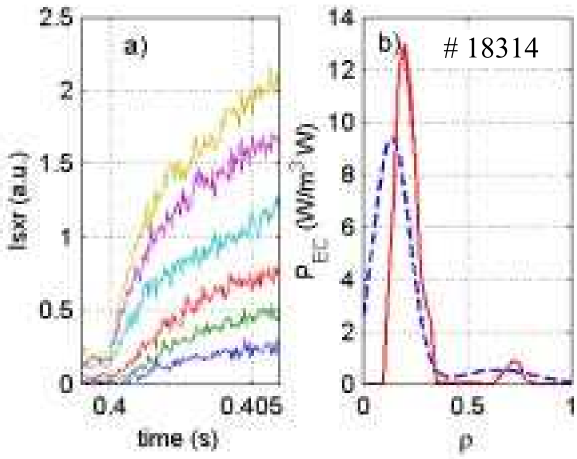

Fig. 6 X-ray intensity time traces ECH switched on t=0.4 s (a); ECH power deposition profiles (solid line TORAY, dashed COBRA) (b).