Fluctuation measurements with the Heavy Ion Beam Diagnostic on the tokamak ISTTOK

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Abstract

The Heavy Ion Beam Diagnostic (HIBD) on the tokamak ISTTOK (a = 8.5 cm, R = 46 cm and B_T = 0.5 T) has been used to measure profiles of plasma electron density and temperature and plasma potential. Recently, HIBD has been upgraded for the measurements of local fluctuations of the $n_e\sigma_{eff}$ product across the plasma cross-section. The HIBD upgrade has been performed on the Multiple Cell Array Detector (MCAD) and signal conditioning electronics. A new low noise amplification system allows for the measurements of the secondary beam current fluctuations in a range of up to 400 kHz. This contribution presents the first results of the radial profile of plasma $n_e\sigma_{eff}$ fluctuations and the validation of the measurements, including possible influence of the beam time-of-flight and path integral effect.

Introduction

The heavy ion beam diagnostic (HIBD) allows for the local measurements of the electron density fluctuations and can be used to investigate the plasma turbulence and macroscopic instabilities (e.g. [1,2]). For better understanding of the plasma fluctuation properties, the HIBD on the tokamak ISTTOK makes use of a Multiple Cell Array Detector (MCAD) [3] which allows for the simultaneous measurements of the plasma parameters at twelve different samples volumes along the primary beam trajectory in the plasma region of $-0.7a < r < 0.7a$ (minor radius a = 8.5 cm). The detected (secondary) beam intensity at j^{th} cell is described as

$$I^{2+}_{j(det)} = 2I^{+}_{0} \cdot F_p F_s \cdot n_e(r_j)\sigma_{eff}(T_e(r_j)) \cdot dl_j \qquad (1)$$

where I^{+}_{0} is the initial intensity of the primary beam, $n_e(r_j)$ is the average of plasma electron density over the j^{th} sample volume, $\sigma_{eff}(T_e(r_j))$ is the effective electron ionization cross-section ($I^{+} \rightarrow I^{2+}$), dl_j is the sample volume length, and F_p, F_s are respectively the primary and secondary beams exponential attenuation factors along the respective trajectories inside the plasma. Usually, the effective cross-sections have a weak dependence on T_e for T_e > 100 eV, thus determining a sole dependence of the secondary beam intensity on the plasma electron density in that range of electron temperature. In plasma regions with low electron temperature, fluctuations in secondary beam intensity can result from both electron density and temperature fluctuations through the product of $n_e\sigma_{eff}$. On ISTTOK the electron temperature at the plasma axis is $T_e(0) \sim 150$ eV. It is estimated that for $r > a/3$, the secondary beam intensity fluctuations are determined by the fluctuations of $n_e\sigma_{eff}$. For accurate and valid fluctuation measurements using HIBD, three factors have to be taken into account: signal to noise ratio, beam time of flight and path integral effect due to beam attenuation factors F_p, F_s in Eq.1.

Experimental set-up

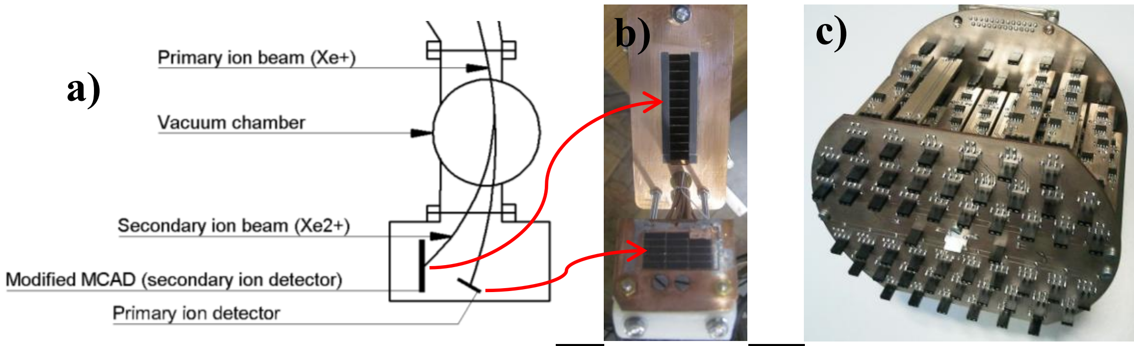

Fig.1: **a)** HIBD detectors and beam trajectories. Secondary ion detector: cell #1→ upper cell and cell #12→ lower cell; **b)** MCAD; **c)** Amplification system allowing up to 50 amplifiers.

The HIBD on the tokamak ISTTOK consists of the injector of Xe^+ ions produced by the plasma ion source (22 keV of energy, 15 µA of current and 3 mm of the beam FWHM) and the MCAD, Fig.1a. During the plasma shot, the primary beam current decreases due to scattering with the penetrated gas in the injector and, at the entrance in the plasma, it is estimated to be ~2 µA. In the modified 12-channel MCAD, the secondary beam cell presents an effectively Faraday cup-like structure with the rectangular 5×12 mm^2 input window and 10 mm of deepness, Fig.1b. The cells can be biased to suppress the secondary electrons created by plasma radiation reducing, in this way, the plasma background noise.

Small size and low cost trans-impedance two stages amplifiers with gain of 2×10^7 V/A, bandwidth up to 400 kHz (at -3dB attenuation) and equivalent input noise of 0.5 nA$_{rms}$ (when connected to the detector) have been developed. Reduced size Surface Mount Device (SMD) components allow multiple amplification channels in several individual modules that can be connected in stack and side by side on a Printed Circuit Board (PCB), Fig.1c. In order to reduce the noise, the small size amplification system is shielded by a Mu-Metal box and it is directly connected to the multi-pin connector on the MCAD mount flange. Signals are digitized at 2 MHz sampling rate and stored by the ISTTOK data acquisition system.

Results and Discussion

An example of the secondary beam raw signals (with background noise removed digitally) from cell #6 (central cell at vertical Z position of ~4.6 mm with Z position = 0 at vacuum chamber centre) is shown in Fig.2a for a plasma shot with I_p = 6 kA, $<n_e>$ = 6.5×10^{18} m^{-3}. The signals are 2 ms square-wave modulated by electrostatic steering of the primary beam across a slit in the injector part of HIBD. Such modulation allows for the effective signal-to-noise discrimination and for the application of algorithms to remove the beam attenuation effect when reconstructing the $n_e\sigma_{eff}$ profile [4]. As one can see from Fig.2a, a clear distinction is observed between the signal fluctuations and the noise.

Fig.2b presents frequency spectra of the signals from all cells (the level of the noise is also shown in Fig.2b for the comparison). Quasi-coherent fluctuations at 50-100 kHz are detected. High correlation at that frequency range with the Mirnov coils signals, Fig.2c, shows that the observed fluctuations can be due to MHD mode.

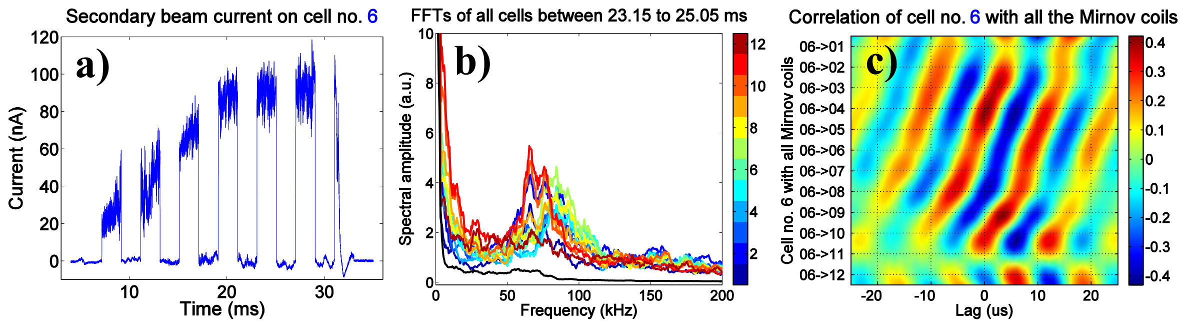

Fig.2: **a)** Secondary beam current on cell #6; **b)** FFTs of all HIBD signals. Black curve corresponds to the FFT averaged noise; **c)** Correlation between HIBD cell #6 signal and Mirnov coils (coil #11 not working).

Fig.3a presents the correlation of the signal from cell #2 with all the other cells signals. The signal from the cell #2 is highly correlated with the signals from the neighbouring cells #1 and #3, as well as with radially opposite cells #10 and #11. Such correlation structure suggests the presence of a rational flux surface in the proximity of the correlated cells. The radial profile of normalized $n_e\sigma_{eff}$ fluctuations, shown in Fig.3b, indicates that the amplitude of the fluctuations has a maximum near the edge plasma. The asymmetry on the profile suggests that the plasma is shifted up (positive Z position).

Inside the plasma, the primary beam time of flight (from *0.7a* to *-0.7a*) is ~630ns, and therefore, for the frequency range of the measured fluctuations (<200 kHz), the delay due to time-of-flight can be ignored. The influence of the path integral effect on the measurements has been verified in simulations for the typical parameters of ISTTOK plasmas and diagnostic beam current intensity. In this simulation, the simulated fluctuations, in close similarity with the experimental observations (same amplitude and frequency of 50 kHz)

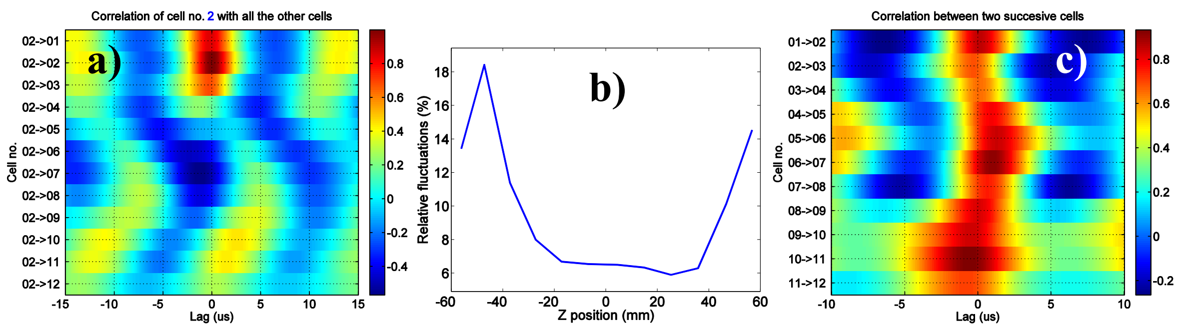

Fig.3: **a)** Cross-correlation of HIBD cell #2 signal with all the other cell signals; **b)** $n_e\sigma_{eff}$ relative fluctuation profile; **c)** Cross-correlation of HIBD signals from two successive cells.

have been introduced along the beam trajectory in the plasma. The results show that the path integral effect should not disturb significantly the results of the fluctuation measurements. The experimental confirmation can be obtained from cross-correlation of the detected signals between successive cells shown in Fig.3c. In a presence of strong integral path effect, each cell should be correlated at zero lag with the successive cell. However, high positive correlation (> 0.65) at a non-zero-lag is observed.

Conclusion

The heavy ion beam diagnostic on the tokamak ISTTOK has been upgraded for the measurements of fluctuations of the local $n_e\sigma_{eff}$ product across the plasma cross-section. Obtained results and comparison with data of Mirnov coils show that the $n_e\sigma_{eff}$ fluctuations are mainly due to MHD activity. The time of flight and path integral effect are not significant for the measurements and interpretation of the $n_e\sigma_{eff}$ fluctuations in the ISTTOK present plasma conditions.

Acknowledgements

This work was supported by EURATOM and carried out within the framework of the European Fusion Development Agreement. Additional support has been granted from IAEA technical contract CRP F1.30.14 on "Utilization of the Network of Small Magnetic Confinement Fusion Devices for Mainstream Fusion Research". IST activities also received financial support from "Fundação para a Ciência e Tecnologia" through project Pest-OE/SADG/LA0010/2011. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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