Poloidal flow velocity measurement at the edge of the TEXTOR tokamak using quasi-twodimensional Lithium Beam Emission Spectroscopy

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Quasi twodimensional Li-beam system on TEXTOR

A Lithium Beam Emission Spectroscopy (Li-BES) system has recently been installed on the TEXTOR tokamak with the possibility of fast poloidal beam hopping between two positions separated by a few cm. The beam enters the plasma at the outer equatorial plane, while the observation system looks from the top in the plane of the beam movement as shown at the end of this paper in *Fig. 3.* Poloidal beam hopping results in poloidal displacement of the measurement volumes thus a two-point poloidal resolution is added to the 14 radial observation points along the beam. This method has been described in detail elsewhere[1].

On TEXTOR the light collection optics and detectors has been thoroughly optimized resulting in typically 1-3% relative photon statistical noise level at 1 MHz bandwidth. These high quality signals enable beam hopping frequencies up to 417 kHz, which means one period time is shorter than the typical turbulence autocorrelation time of 5-10μs. The 2.5 MHz sampling of the light signals is synchronized to beam movement and samples in one period are averaged when the beam is in the upper and lower position. The series of such averaged samples provide two poloidally displaced virtual signals for each optical channel with 417 kHz sampling frequency. Beam penetration depth limits this measurement to the edge of the plasma therefore the 14 optical channels are distributed into the r/a=0.8...1.05 radial range with about 1 cm radial resolution.

Flow velocity measurement methods

The dominant density fluctuation phenomenon at the plasma edge region of TEXTOR is the Quasi-Coherent (QC) mode whose poloidal propagation velocity is dominated by the plasma ExB flow velocity[2], therefore it is suitable for poloidal velocity measurement. Several methods have been published in the literature for the calculation of the propagation time delay from two-point measurements (see e.g. [3]). Two of these have been benchmarked for the TEXTOR situation where the photon statistical noise level is comparable to the fluctuation amplitude. The first we call Cross Correlation Function Maximum (CCFM) where the displacement of the maximum of the crosscorrelation function is calculated. The second method we call Cross Phase Slope (CPS) where the slope of the crossphase spectrum is calculated in the QC mode frequency range. Additionally a third method was tested which enables relative velocity modulation calculation from a one-point measurement. This is a cross-breed of the Auto Correlation Function Width (ACFW) [4] method and CCFM in the sense that the relative displacement of the first minimum of the autocorrelation function is analysed. If we assume that the poloidal wavelength (λ_{QC}) of the QC mode is constant in time the minimum in the autocorrelation function appears at $\lambda_{QC}/2v$, where v is the poloidal flow velocity. This method we call Auto Correlation Function Minimum (ACFM). The mean velocity (and thus λ_{QC}) can be determined from the two point measurement.

These techniques can be used for two closely related aims. On the one hand the radial profile of the poloidal velocity and changes during a discharge can be studied[5], on the other hand high-frequency flow modulations like zonal flows, Geodesic Acoustic Modes (GAM) can be investigated. In this paper we concentrate on GAM studies as the Li-beam seemed to be capable of detecting such phenomena at the TEXTOR plasma edge.

The sensitivity of the above 3 methods was studied in a numerical experiment. A random spatial fluctuation signal with the properties of the QC mode was generated along the poloidal coordinate and moved across the two poloidally displaced measurement volumes with temporally varying poloidal velocity. The spatial fluctuations had infinite temporal lifetime as it was shown before that the structure lifetime is longer than the decorrelation time due to poloidal movement[2]. Parameters of the simulation were adjusted in a way that the

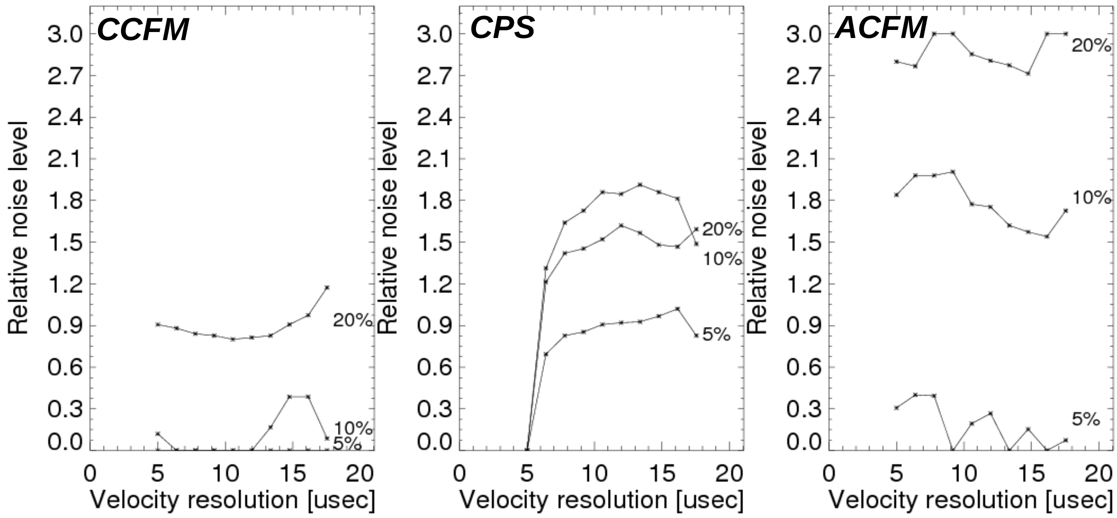

Figure 1. Maps of GAM detection limits for the 3 numerical methods. The horizontal axis is the time resolution (ΔT), the vertical is the relative noise level (1/SN). GAMs with 5, 10, 20% relative amplitudes can be detected up to the corresponding lines.

autocorrelation functions and the mean time delay fit the experimental ones. White noise was added to these signals with a variable Signal to Noise (SN) amplitude to simulate photon statistical noise in the experiment. The poloidal velocity was generated by adding to a DC velocity a spectrally filtered random signal with 15 kHz mean frequency, 2 kHz FWHM and variable amplitude. These parameters were selected to simulate the effect of GAMs observed at the edge of TEXTOR by reflectometry[6]. The resolving capability of GAMs was analysed by running a series of simulation runs with different relative GAM amplitudes (A_{GAM}) and SN. Thereafter the velocity was calculated by all 3 methods (CCFM, CPS and ACFM) with a series of different time resolutions (ΔT). For each point in this threedimensional (A_{GAM}, SN, ΔT) space the autopower spectra of the extracted time delay signals were calculated. Proceeding along increasing noise level (1/SN) on each point in the (A_{GAM}, ΔT) parameter plane the limiting noise amplitude was determined where the peak in the power spectrum emerges from the noise by 2σ. The resulting maps are shown for the three methods in *Fig. 1.* In the actual measurement the relative noise level (1/SN) is between 0.5-2, therefore we conclude that the ACFM method is the most likely to detect GAMs, but the relative sensitivity of the methods is strongly dependent on the velocity modulation amplitude.

GAM measurements

GAM related velocity fluctuations have been previously found in TEXTOR by reflectometry[7]. In those studies GAMs with 15-20 kHz frequency could be detected for r<41 cm (r/a=0.91). The frequency was observed to continuously drop towards the edge. No

GAMs were detected at the outer 4 cm of the plasma which was attributed to increased collisional damping at the densities where the diagnostic could measure at the edge.

Measurements were performed with the Li-beam diagnostic in Ohmic discharges at various plasma parameters: I_p=250-400 kA, B_t=1.9-2.25T and $n_e(0)$=1-3.5 $10^{19}m^{-3}$. Autopower spectra of poloidal velocity modulations were calculated with all the above three methods. GAM-like peaks were detected *only* with the ACFM method, examples are shown in *Fig. 2 (top)*. As the CPS method would also be expected to detect these oscillations our simulation should have same statistical difference from the measurement. This discrepancy will be futher studied in the future. As it will be shown below these velocity modulations are correlated with the reflectometry-measured GAMs, therefore below they will also be called GAM.

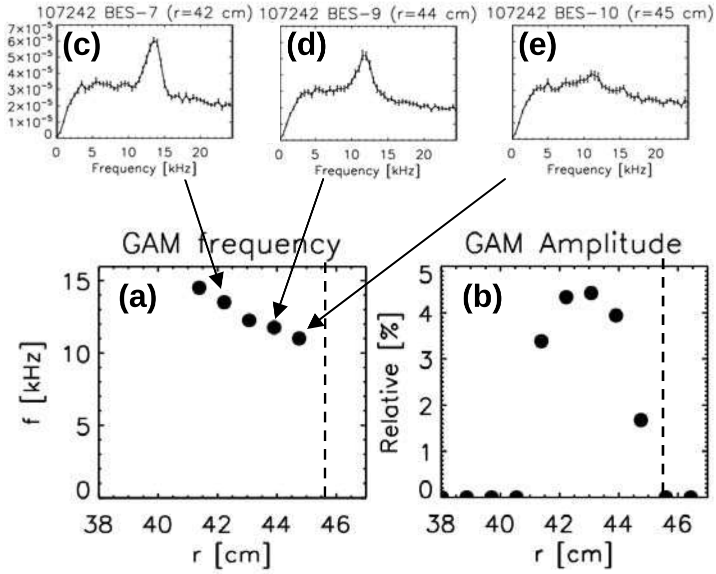

Figure 2. GAM measurements wih the Li-beam diagnostic. (Shot 107242, I_p=350kA, B_t=2.25T, $\langle n_e \rangle$=2 10^{19} m^{-3})
(a)-(c): Autopower spectra of time delay signals calculated from single point Li-beam measurements with the ACFM technique at three radial locations. Bottom: (a) GAM frequency and (b) amplitude distribution at the plasma edge. The approximate LCFS position is shown by the vertical dashed line. The radial coordinates are relative to the centre of the vessel.

The mean frequency, the width and the relative RMS velocity modulation of these peaks in the velocity spectra were determined by subtracting a fitted second order noise background. As shown in *Fig. 2(b)* GAMs extend right out to the LCFS. However, there are cases when the GAMs disappear in the outer 1-2 cm. From the present limited number of measurements it is not clear what parameters drive this difference, but the most likely candidate is edge q. In some Langmuir probe measurements 10 kHz floating potential fluctuations were detected at the equatorial plane at 45-46 cm minor radius without related ion saturation current modulations[8]. These observations fit to the Li-beam results at the very edge in *Fig. 2(e)*.

Inside r=41 cm no GAM-like velocity modulations could be detected with the Li-beam. In this region the SN drops considerably due to the drop in the fluctuation amplitude towards the core plasma and according to the simulation results this makes the Li-beam insensitive to velocity fluctuations.

From the LCFS (r=45 cm) toward the plasma core the GAM frequency gradually increases from 10-11 kHz to 15-17 kHz at r=41.5 cm. The frequency appears to change continuously with radius and the tendency fits perfectly to reflectometry observations[7]. Around 41 cm the two diagnostics overlap and the frequencies are very close. In a few recent measurements the Li-beam and the reflectometry was operated in the same discharge in a synchronized way. First analysis results indicate significant coherency around 15 kHz between the time delay signals determined from the Li-beam at r=41cm and the reflectometry signals recorder on the other side of the torus on the top of the plasma. The cross-phase is close to zero. As these reflectometry signals were previously shown to be related to GAMs this observation proves the overlap between Li-beam and reflectometry GAM measurements at r=41 cm.

The typical GAM relative time delay modulation seen by the Li-beam measurement is 3-5%. According to the simulation results this should correspond to 15-20% real velocity modulation amplitude. A tendency is observed that both the relative modulation amplitude and the frequency drops with increasing plasma density, what is also consistent with theory[9].

The broadband part of the power spectra in *Fig. 2.* shows some increase toward low frequencies. It might be tempting to interpret this as signature of low frequency zonal flows, but the noise spectrum of the velocity calculation method itself might also cause such an effect. This feature must be studied in more detail before deriving any conclusion.

The Li-beam diagnostic can capture the radial structure of GAMs as well. A small but significant coherency is observed between time delay signals separated by up to 3 cm, but at present it is not clear whether this is a result of the smearing effect of atomic physics in the Li-beam diagnostic or GAM physics.

GAM related density modulations can also be studied with the Li-beam diagnostic in a straightforward way: correlating the Li-beam signals themselves with the time delay signals calculated from them. This study gave the interesting result that the optical signal power spectra do contain a peak at the GAM frequencies but it is present with the same amplitude when the Li-beam is off. That is, there is no GAM related density fluctuation at the equatorial plane (as expected) but this oscillation is most probably collected from GAM related fluctuation of the Bremsstrahlung continuum radiation collected by the detection optics close to the bottom of the plasma as shown in *Fig.3*. However, there is a discrepancy between the 2-3% relative fluctuation amplitude as GAM related density fluctuations at the top of the plasma were estimated to be well below 1%[5]. This observation gives an interesting new diagnostic alternative to GAM studies in fusion plasmas, if the discrepancy in the amplitude measurements is resolved.

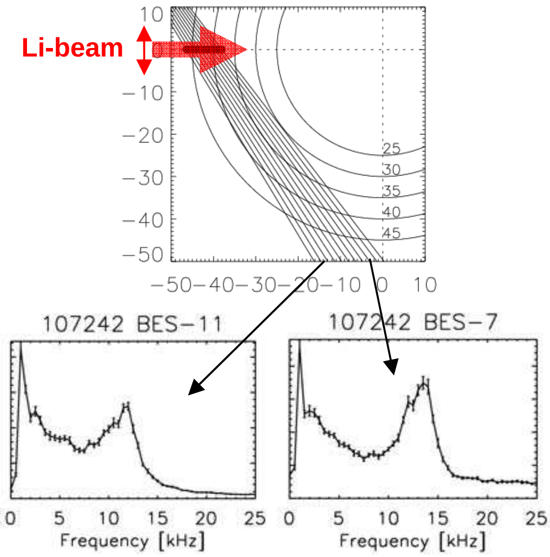

Figure 3. GAM related peaks in background light fluctuation spectra and the measurement geometry.

Conclusions

GAM related velocity oscillations were detected at the edge of TEXTOR plasmas by the Li-BES diagnostic. The results fit to and correlate with reflectometry measurements deeper in the plasma and show agreement with expected GAM properties: long-range correlation with m=0,n=0, few cm radial extent, zero density modulation at the equatorial plane. The limited parametric scaling of the GAM frequency and amplitude also match expectations with GAM theory. Further experiments and supporting simulations are planned in order to characterize GAMs at the outer 10% of the plasma minor radius in TEXTOR.

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