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ABSTRACT.
Fluctuations in the phase velocity of fluctuations have been computed from floating potential fluctuations in the JET plasma boundary region. Experimental results reinforce the idea that, in some conditions, fluctuations in the phase velocity are linked with fluctuations in radial-poloidal electric fields opening the possibility to investigate turbulent transport in the plasma core region from measurements of density fluctuations. These results indicate that time dependent radial electric fields and E×B shearing rates might be computed in the plasma core from measurement of density fluctuations.

1. INTRODUCTION

In order to assess the role of both turbulence and E×B sheared flows on transport in the core of the plasma there is a need for improved diagnostics and analysis tools for fluctuating quantities. Recently wavelet-based cross correlation analysis has been used to obtain fluctuations of poloidal rotation velocity by means of beam emission spectroscopy and this approach offers potential for direct measurements of turbulent transport [1]. Measurements of E×B turbulent fluxes based on the measurement of fluctuations in the phase velocity of fluctuations have been recently reported [2]. Thus, the development of new fluctuating analysis tools, based on the measurements of velocity fluctuations, has opened the possibility to investigate turbulent transport and fluctuating radial electric fields in the plasma core region from measurements of density fluctuations.

This paper reports results on the characterization of velocity fluctuations, turbulent transport and the physics of E×B sheared flows in fusion plasmas.

2. EXPERIMENTAL SET-UP

Plasma profiles and turbulence have been investigated in the JET plasma boundary region using a fast reciprocating Langmuir probe system located on the top of the device. The experimental set-up allows the simultaneous measurements of fluctuations in radial electric fields and poloidal phase velocity. Plasma fluctuations were investigated using 500 kHz digitizers. Ohmic and L-mode plasmas produced in X-point configurations, with B = 1 - 2T, I_p = 2MA and plasma density in the range (2.9 – 6.7) × 19^{19} m^{-3} were studied in this paper.

3. DYNAMICAL RADIAL ELECTRIC FIELDS AND VELOCITY FLUCTUATIONS

Measurements of velocity fluctuations require to have information of density / potential signals at least at two radially / poloidally separated points. The velocity can be calculated by Δx/Δt, being Δt the time delay between two ion saturation current (Is) or floating potential signals (Φ_f) radially / poloidally separated Δx. Throughout this paper the time delay has been computed in sub-samples of the signals with a minimum of 50 points (100µs). Whether Is or ff are used will be specified.

Clearly, errors in the measurement of velocity fluctuations decrease as the sampling rate increases. In particular the upper limit in the maximum velocity which can be measured is given by Δx × sampling rate. In addition, errors in the measurement of velocity fluctuations increase as the time delay and coherence between signals decreases. As a consequence, the distance between probes should be chosen to get the maximum time delay (Δt) between fluctuating signals while keeping a significant coherence between them.

Fluctuations in poloidal phase velocity of fluctuations have been investigated by probes poloidally separated (Δx_θ) 0.25 and 0.5 cm with $f_s = 0.5$ MHz sampling rate. In order to investigate fluctuations at different time scales we have constructed time records with an average time window $\Delta N/f_s$ by averaging over blocks of ΔN elements from the original time series. Figure 1 shows the root mean square (rms) level of velocity fluctuations versus the average time window for probes poloidally separated 0.25 and 0.5cm. The level of fluctuations decreases as the averaging parameter (ΔN) increases and is about a factor of two smaller for the probes poloidally separated 0.25cm

Comparative studies of rms values of the poloidal velocity computed from fluctuations in radial electric fields, neglecting the influence of temperature fluctuations ($v_\theta^{E\times B} = E_r / B$), and fluctuations in the poloidal phase velocity (v_θ^{phase}) are shown in figure 2. Fluctuations in both $v_\theta^{E\times B}$ and v_θ^{phase} decrease with increasing ΔN. However, the rms value of $v_\theta^{E\times B}$ is smaller (about a factor of 2-3) than the rms value of v_θ^{phase}. This result might partially explain considering the influence of temperature fluctuations in the computation of radial electric field and the influence of the noise level in the computation of velocity fluctuations. Further experiments with improved time resolution in the computation of velocity fluctuations (e.g. using fast ADCs with 1 – 5 MHz sample rate) are needed to clarify the origin of this disagreement.

4. VELOCITY FLUCTUATIONS AND TRANSPORT

The $E \times B$ turbulent flux was measured using two different approaches: a) from the correlation between density and poloidal electric field fluctuations using the expression $\Gamma_{E\times B} = <\tilde{n}\tilde{E}_\theta>$ where $\tilde{E}_\theta$ is the fluctuating poloidal electric filed and $\tilde{n}$ is the fluctuating density obtained from the ion saturation current, and b) from the correlation between density fluctuations and fluctuations in the radial phase velocity of fluctuations ($\tilde{v}_r^{phase}$) using the expression $\Gamma_{phase} = <\tilde{n}\tilde{v}_r^{phase}>$. The radial velocity $\tilde{v}_r^{phase}$ is given by $\Delta r/\Delta t$, being Δt the time delay between two ion saturation current (I_s) signals radially separated $\Delta r = 0.5$cm. The time delay was computed using 200μs time window realizations. Figure 3 shows the probability distribution function of the time resolved radial turbulent flux ($\Gamma_{E\times B}$ and Γ_{phase}). There is a significant similarity in the statistical properties of both turbulent fluxes. This agreement is particularly remarkable for the outward turbulent flux. The average turbulent fluxes, ($\Gamma_{E\times B}$ and Γ_{phase}, are in agreement within a factor of four. This finding has been also observed using different time window realization (100 – 200μs) for the computation of fluctuations in the radial phase velocity.

5. DYNAMICAL EXB FLOW AND VELOCITY FLUCTUATIONS

Gyrofluid and fluid simulations have observed small scale fluctuating sheared $E \times B$ flows [3]. These flows are driven by fluctuations and they can substantially reduce turbulent transport. From this perspective, it is important to measure the level of fluctuations in the radial electric field and to clarify whether the effective shearing rate of fluctuating radial electric fields is high enough to control transport.

The radial profiles of fluctuations in the radial electric field have been investigated in the plasma edge region of the JET tokamak neglecting electron temperature fluctuations effects. The rms level of fluctuations increases as the probe is inserted into the plasma edge region, reaching values in the range of 1000 - 2000V/m in the plasma boundary region (Fig. 4). A rough estimation of the effective shearing rate of the fluctuating radial electric fields can be computed as

$$\tilde{\omega}_{E\times B} \approx \frac{(E_{radial})_{rms}}{B\,\lambda_c}\, f\left(\frac{\omega_f}{\Delta\omega_f}\right), \qquad (1)$$

where ωf and $\Delta\omega_T$ are the mean frequency of fluctuating radial electric field and the width of the turbulent spectra respectively, λ_c is the radial correlation of fluctuations and B is the toroidal magnetic field. The function $f(\omega_f/\Delta\omega_T)$ takes into account the reduction of the effective shearing rate when the time scale of the fluctuating radial electric field is faster than the correlation time of fluctuations [4]. In the case of JET edge plasma conditions, $(E_{radial})_{rms} \approx 1000$ V/m, $\omega_f \approx \Delta\omega_T$ and the average radial correlation is in the range of 1 cm. Using expression (1) the effective decorrelation rates are close to the critical value to regulate turbulent transport ($\omega_{E\times B} \approx 10^5\ s^{-1}$).

A more accurate computation of the fluctuating $\omega_{E\times B}$ shearing rate requires the simultaneous measurements of the radial electric field / poloidal velocities at different radial locations. The radial profile of the fluctuating shearing rate has been computed as the difference in poloidal velocity measured between two probes radially separated 0.5cm, i.e. $\tilde{\omega}_{E\times B} = \Delta\tilde{v}_\theta/\Delta r$. Fluctuations in the poloidal velocity ($\tilde{v}_\theta$) were computed from the time delay between two floating potential signals measured by probes poloidally separated 0.5cm by the method explained on the previous section and $\Delta\tilde{v}_\theta$ is the difference of the poloidal velocity computed at two radially separated positions. The investigation of the radial structure of dynamical $\omega_{E\times B}$ and fluctuations in the radial electric fields has shown evidences of radial structures in $\omega_{E\times B}$ which are correlated with the presence of flattening in edge plasma profiles (fig. 4) [5]. Furthermore, experimental results show that the effective decorrelation rates of time dependent E×B flows are in the range $10^5 - 10^6\ s^{-1}$ (fig. 5). This result shows evidence of fluctuating E×B flows with shearing rates close to the critical value to regulate turbulent transport.

CONCLUSIONS

The present experimental results reinforce the idea that, in some conditions, fluctuations in the phase velocity are linked with fluctuations in radial-poloidal electric fields. These result suggest the measurement of E×B turbulent transport in the plasma core region might be achieved from measurements of density at different radial locations and that time dependent radial electric fields and E×B shearing rates can be computed in the plasma core from measurements of density fluctuations with microwave reflectrometry or beam emission spectroscopy. However, it is important to emphasize that further experiments are clearly needed with over sample signals (2 – 5MHz) to increase the time resolution in the computation of velocity fluctuations.

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REFERENCES

[1]. M. Jakubowski et al., Rev. Scient. Instrum. **72** (2001) 996
[2]. B. Gonçalves et al., Czehoslovak Journal of Physics **51** (2001) 995
[3]. Z. Lin et al., Science **281** (1998) 1835
[4]. T.S. Hahm et al., Phys. Plasmas **6** (1999) 922
[5]. C. Hidalgo et al., J. Plasma Fusion Res. **4** (2001) 167

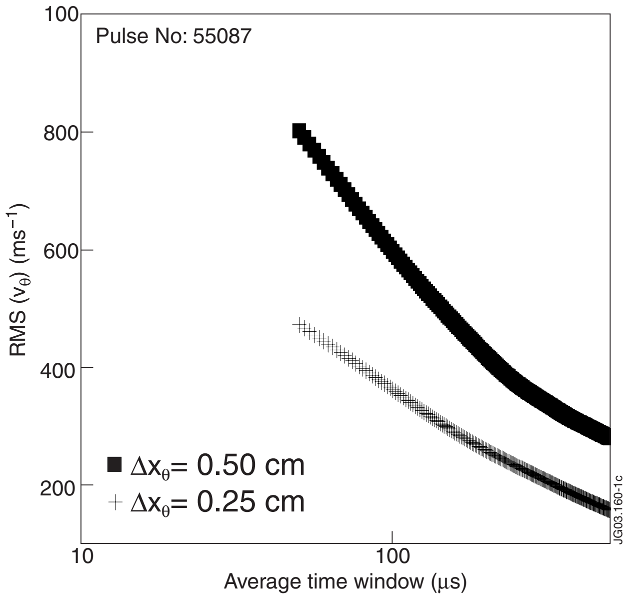

Figure 1: Root mean square (rms) value of fluctuations in the poloidal phase velocity for probes poloidally separated 0.25 and 0.5cm at different average time windows.

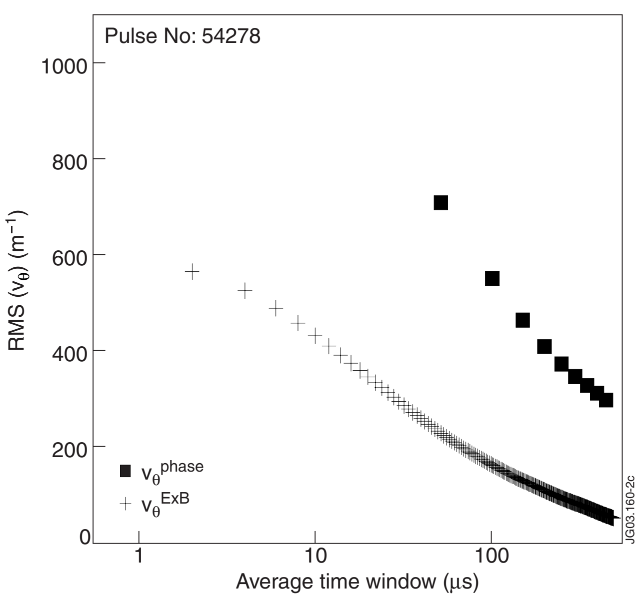

Figure 2: Comparison between rms values of the poloidal velocity computed from fluctuations in the radial electric field ($v_\theta^{E\times B}$) and from fluctuations in the poloidal phase velocity (v_θ^{phase}), obtained from the time delay between floating potential signals from probes poloidally separated 0.5cm, at different time scales.

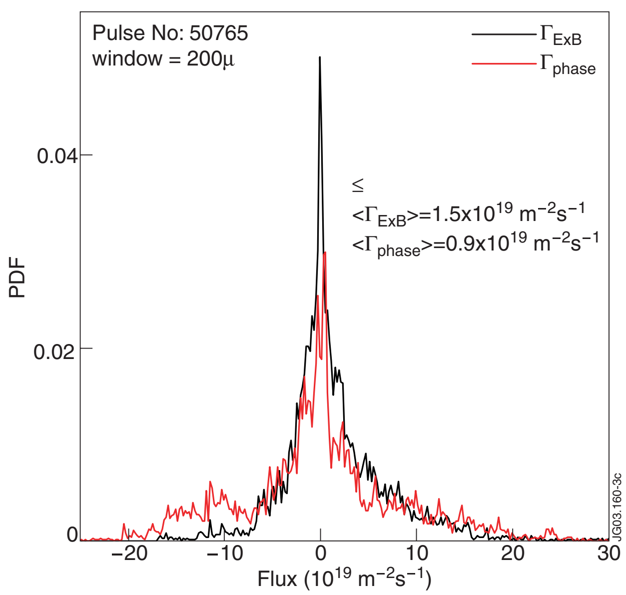

Figure3: Comparison of the Probability Density Function of turbulent flux calculated within the electrostatic approximation ($\Gamma_{E\times B}$) and with the radial phase velocity of fluctuations obtained from the time delay between ion saturation signals in probes radially separated 0.5cm (Γ_{phase}). Experiments were carried out in the JET plasma boundary region with ohmic plasmas (B = 1T, Ip = 1 MA).

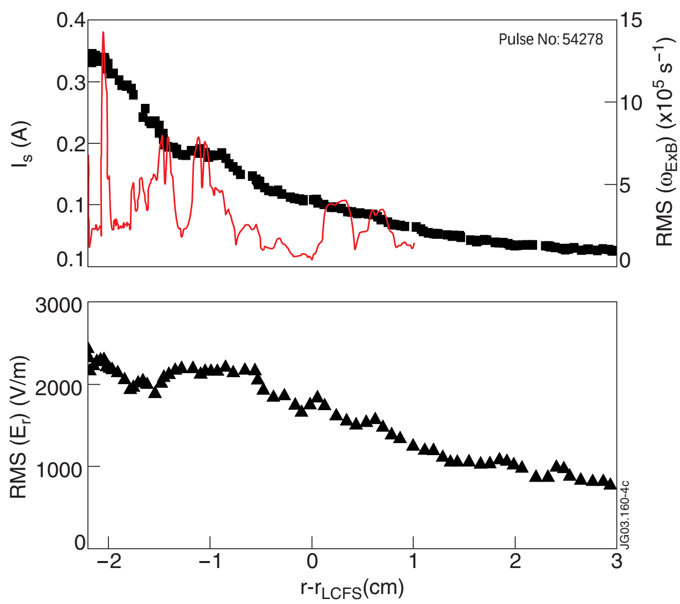

Figure 4: Radial profiles of the ion saturation current and rms values of $\omega_{E\times B}$ and E_r. The poloidal velocity was computed from the floating potential signals measured with a poloidal separation of 0.5cm. The radial separation between each set of probes is 0.5cm.

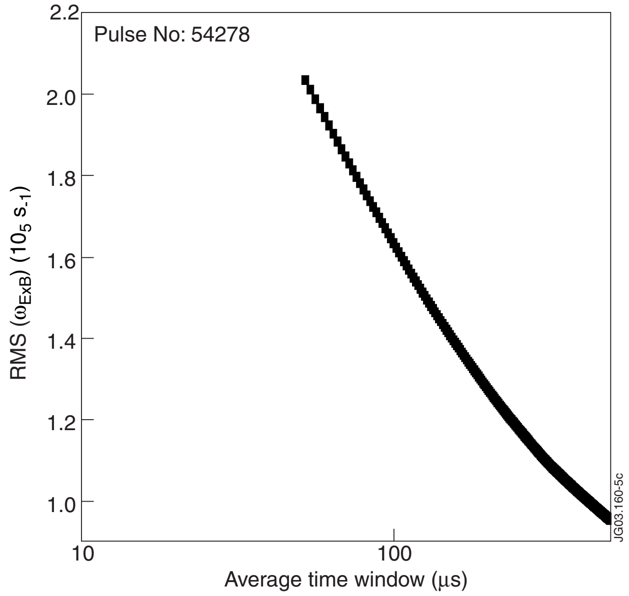

Figure5: Root mean square values of fluctuating shear rate at different time scales. The poloidal velocity was computed from the floating potential signals measured with a poloidal separation of 0.5cm. The radial separation between each set of probes is 0.5cm.