Sheared Poloidal Flows and Turbulence in the Edge Plasma Region of Stellarator and Tokamak Devices

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I. Introduction

It is known that a poloidal shear flow in a magnetically confined plasma has in general a stabilizing effect[1,2]. Recent calculations have shown that the dependence of the phase angle between density ($\tilde{n}_e$) and electric field fluctuations ($\tilde{E}_\theta$) on flow shear may be an important aspect of the $E_r \times B$ shear flow suppression[3]. Simultaneously it is known that poloidal acceleration will occur if there are radial gradients in the turbulent Reynolds stress[4]. The aim of the presented experiments is to investigate the effect of sheared $E_r \times B$ flow on turbulent fluxes (coherence and phase angles between density and electric field fluctuations) and the interaction between poloidal flows and turbulence. The radial behaviour of the Reynolds stress (both electrostatic and magnetic) in the proximity of the velocity shear layer in the TJ-IU torsatron has been investigated.

The turbulence (fluctuation levels, cross phase, cross coherence) in the proximity of the naturally occurring velocity shear layer in the TJ-I tokamak ($R = 0.3$ m, $\bar{a} = 0.1$ m, $\bar{n}_e \approx (1 - 3) \times 10^{19}$ m^{-3}, $B_t \approx 1$ T, $I_p \approx 30$ kA), in the TJ-IU torsatron ($P_{ECRH} = 200$ kW, $\iota(0) \approx 0.23$, $R = 0.6$ m, $\bar{a} \approx 0.1$ m, $\bar{n}_e \approx 0.5 \times 10^{19}$ m^{-3}, $B_t = 0.67$ T) and in the W7-AS stellarator ($P_{ECRH} = (200 - 400)$ kW, $\iota(0) \approx (0.24 - 034)$, $R = 2$ m, $\bar{a} \approx 0.17$ m, $\bar{n}_e \approx 2 \times 10^{19}$ m^{-3}, $B_t = (1.25 - 2.56)$ T) have been studied.

II. Turbulence and sheared poloidal flows

Data analysis has focused in the evaluation of the coherence and phase angle between $\tilde{E}_\theta$ and $\tilde{n}_e$ at the plasma edge of the W7-AS stellarator. Fig. 1a shows the radial profiles of mean values of ion saturation current (I_{sat}) and floating potential (ϕ_{fl}), measured with a fast reciprocating Langmuir probe and referred to the velocity shear layer position. The fluctuating poloidal electric field ($\tilde{E}_\theta$) is calculated as the difference of two ϕ_{fl} separated 4 mm in the poloidal direction and the density fluctuations are taken to be proportional to the $\tilde{I}_{sat}$ assuming negligible temperature fluctuations. Fig. 1b shows the

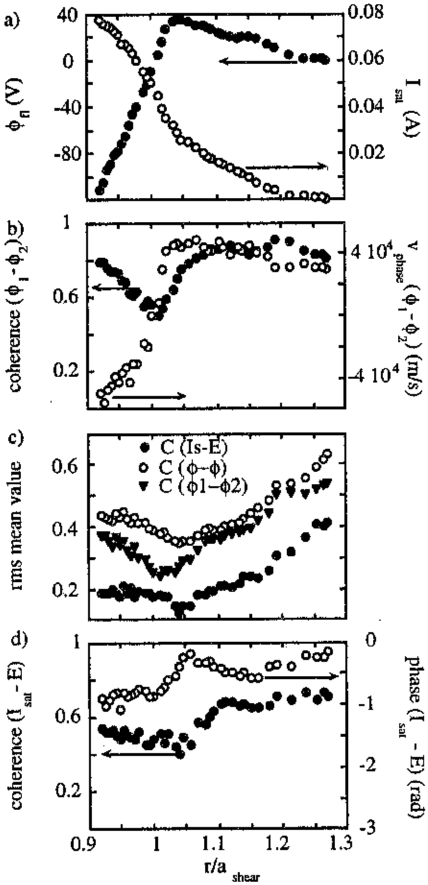

Figure 1: Radial profiles of plasma parameters measured with a fast reciprocating Langmuir probe at the plasma edge of W7-AS during a typical shot with 1.26 T and 180 kW ECR heating

poloidal coherence of the ϕ_{fl} measured with two tips placed 4 mm apart in the poloidal direction as well as phase velocity of fluctuations (v_{ph}) deduced from the ϕ_{fl} measurements. As expected, the poloidal coherence (fig 1.b) and rms cross-correlation $C(\phi1-\phi2)=\left\langle C^2_{\tilde\phi1\tilde\phi2}(\tau)\right\rangle^{1/2}$, being $C_{\tilde\phi_1\tilde\phi_2}(\tau)=\left\langle\tilde\phi_1(t)\tilde\phi_2(t+\tau)\right\rangle/\sigma\left(\tilde\phi_1\right)\sigma\left(\tilde\phi_2\right)$ (fig. 1.c) between floating potential signals decrease at the velocity shear layer location where $v_{ph} \approx 0$. It is interesting to note that the rms value of cross correlation $C_{\tilde I\tilde E}(\tau)$ (fig. 1.c) shows a minimum at the radial location $r/a_s \approx 1.05$ that cannot be explained as a Doppler shift effect because in the radial region $1 < r/a_s \leq 1.15$ the v_{ph} is rather constant within the error bars. Note that $\tilde I_{sat}$ and $\tilde E_\theta$ are measured at exactly the same poloidal position. Fig. 1d shows the coherence between $\tilde I_{sat}$ and $\tilde E_\theta$, and the cross phase between these magnitudes. A decorrelation and a phase change between $\tilde n_e$ and $\tilde E_\theta$ are observed related to the maximum change in E_r, whereas the level of fluctuations does not significantly change. The spectrally resolved analysis shows that these changes occur mainly for frequencies above 25 kHz.

Statistical analysis of the probability distribution function (PDF) of the $\tilde I_{sat}$ signal has been done and a clear departure from gaussian behavior is observed in the SOL. In the plasma edge the PDF tends to show a more gaussian behavior, in consistency with previous experiments in the TJ-I tokamak and the TJ-IU torsatron^5.

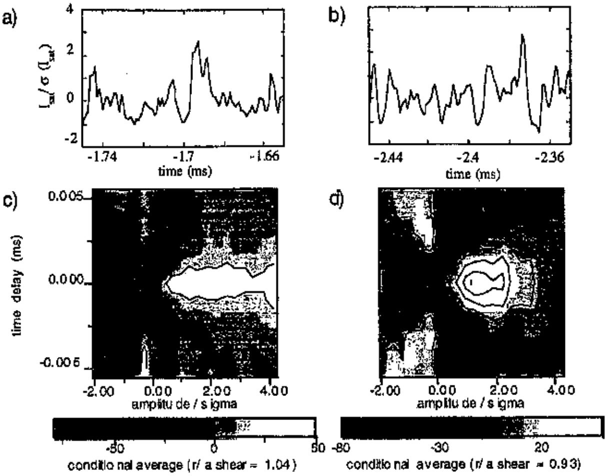

Figure 2: Normalized I_{sat} raw data and its conditional average at two radial positions at the SOL (a) and the plasma edge (b) in the TJ-I tokamak. At the SOL burst of turbulence growing faster than decaying are clearly observed. The conditional average plot abciss (c and d) display the amplitude of the pulses and ordinate the time delay with respect to the position of the maximum/minimum of the pulse. The raw data has been normalized removing the DC component and making the rms equal 1.

In the TJ-I tokamak the structure of the $\tilde{I}_{sat}$ fluctuations is strongly intermittent in the proximity of the velocity shear layer. That might suggest a competition between the driving and damping mechanisms of turbulence. A systematic analysis of the degree of asymmetry in the shape of the temporal pulses using a conditional averaging method has been done. Fig. 2 shows the raw data at two radial positions, the SOL and the plasma edge, and the resulting statistical average over different amplitudes of the pulses. The asymmetry (in the sense that low frequency pulses have faster growth than decay time constants) is significant in the SOL while the asymmetry disappears inside of the velocity shear layer. Similar features have

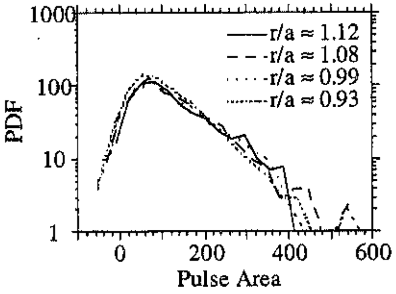

Fig 3. PDF of the I_{sat} pulse time integral at three radial positions in W7-AS showing an exponential decay at high amplitudes

been found in the TJ-IU torsatron and the W7-AS stellarator.

The better statistics of data from W7-AS have allowed the study of the PDF of pulse time integrals (areas). The decay of the PDF is aproximately exponential outside the velocity shear layer and at the plasma edge as can be seen in Fig. 3.

III. Reynolds stress measurements in the edge region of the TJ-IU torsatron

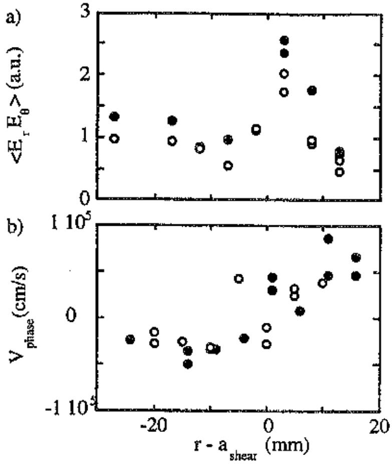

Fig. 4 Radial profiles of Reynolds stress and velocity propagation of fluctuations measured at the TJ-IU torsatron using a radial-poloidal array of Langmuir probes.

The radial profile of the cross-correlation between $\tilde{E}_\theta$ and $\tilde{E}_r$, and $\tilde{B}_\theta$ and $\tilde{B}_r$ have been investigated in the TJ-IU torsatron. The coherence between $\tilde{B}_\theta$ and $\tilde{B}_r$ is quite high (close to 0.8 for frequencies below 70 kHz). The magnetic component of the Reynolds tensor, proportional to $<\tilde{B}_\theta \tilde{B}_r>$, was measured and found to be negligible due the low fluctuation amplitude and the fact that the poloidal and the radial component of the fluctuating magnetic field are shifted by π/2. Fig. 4 shows the radial profile of $\left\langle \tilde{E}_r \, \tilde{E}_\theta \right\rangle$ (Fig. 4a) and v_{ph} (Fig. 4b) obtained from two floating potential measurements of tips placed 2 mm apart in the poloidal direction and 6 mm in the radial direction. It can be argued that the radial derivative of $\left\langle \tilde{E}_r \, \tilde{E}_\theta \right\rangle$ evolves in the proximity of the velocity shear position. Further analysis of the experimental results are in progress to quantify the importance of poloidal flow driven by (electrostatic) Reynolds stress.

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