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Investigation of long-distance toroidal correlation of edge turbulence at TEXTOR

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1. Introduction

In magnetically confined plasma, it is well-known that the E×B shear flows play a crucial role in reducing turbulent transport via decorrelating turbulence eddies [1]. Shear decorrelation of turbulence can occur by mean E×B flows [2], but can also result from time-varying $\tilde{E}\times B$ flows, such as occurring in zonal flows (ZFs) identified as a toroidal and poloidal symmetric potential structure (m=n=0) with finite radial wavelength [3]. The ZFs are helpful for confinement as they extract energy from ambient turbulence via nonlinear interaction and in return quench them by shear decorrelation. Recently, investigations into the ZFs have been intensified [4, 5]. As the ZF has a n=0 mode, a cross-correlation of fluctuations over a long distance along the **B** field line is expected. The long-distance correlation (LDC) is therefore an important experimental indicator of the ZFs. In this paper, we report the experimental results of the LDC measured in both the ohmic and biasing H-mode regimes in the TEXTOR tokamak.

2. Experimental setup

The experiments were performed in ohmic deuterium discharges in TEXTOR with the following parameters: R=175cm, a≈48cm, B_T=2.25T, I_p=200kA and line-averaged densities $\langle n_{e0}\rangle$=(1.0-2.0)×10^{19} m^{-3}. For measuring the LDC of edge fluctuations along the toroidal direction, two movable Langmuir probe arrays were installed at two opposite locations of the torus (over a distance ~7 m) in the midplane of the low-field side. Both arrays were operated to detect the floating potential (V_f) and ion saturation current (I_s) and their fluctuations with a sampling rate of 500kHz. In each discharge, one array is stationary while the other is fast reciprocating. From shot to shot, the radial position of the stationary probe can be altered. The toroidal cross-correlation between the signals x and y on the respective probes is defined as $C_{xy}(\tau)=<[x(t+\tau)-\bar{x}][y(t)-\bar{y}]>/\sqrt{<[x(t)-\bar{x}]^2><[y(t)-\bar{y}]^2>}$, where τ is the time lag. In order to achieve an improved confinement regime, a biasing voltage (V_{bias}=300V) was applied during the stationary phase of the discharge between the limiter and a graphite electrode inserted at r≈41cm. Details on the biasing H-mode have been described earlier [2, 6].

3. Results and discussion

Figure 1 depicts the results of the LDC of V_f and I_s fluctuations between the two probes in an ohmic discharge. Figure 1(a) shows the time trace of the fast probe moving from the

SOL into the edge, while the stationary probe stays at a radial position of r=45 cm. In Fig.1(b), one can see a significant long correlation appears in V_f when the fast probe passed through the radial location of the stationary one. The LDC covers a radial range ~3cm. However, for I_s signals there is nearly no correlation. To verify that the LDC is caused by electrostatic modes, the possible impact due to MHD activities has been excluded by checking magnetic pick-up coil signals. Shown in Fig.1(d) are the power spectra of V_f fluctuations at the maximum C_{xy} position (≈45 cm) detected by the two probes. The spectrum shows similar characteristics with two coherent modes peaked around 1kHz and 10kHz. The corresponding C_{xy} in Fig. 1(e) displays a negligible time lag, implying a *n*=0 mode structure. These facts reveal that in ohmic discharges the LDC of V_f is dominated by zonal-flow-like coherent modes. It is found that the coherent modes and the LDC both decrease with increasing plasma density.

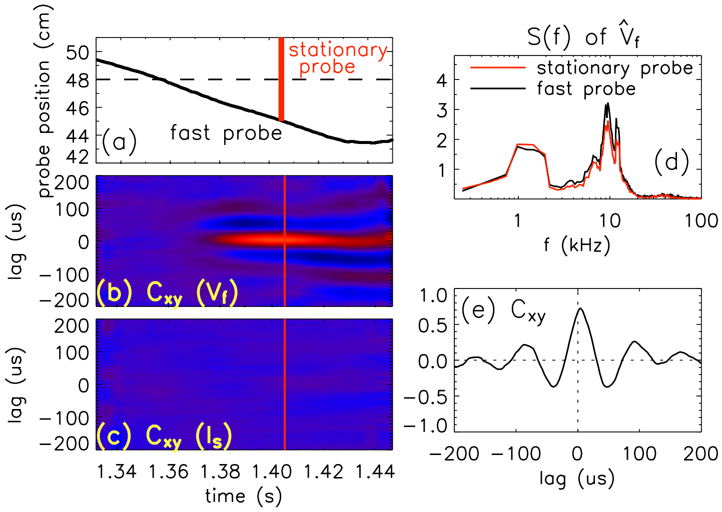

Fig. 1 Long-distance cross-correlation of edge fluctuations in an ohmic discharge (#108272). Time history of (a) fast/stationary probe (dashed line denotes limiter position); (b) contour-plot of C_{xy} on V_f signals;(c) contour-plot of C_{xy} on I_s signals. (d) Power spectrum of V_f fluctuations at the maximum C_{xy} location; (e) cross-correlation of V_f fluctuations at the maximum C_{xy} location.

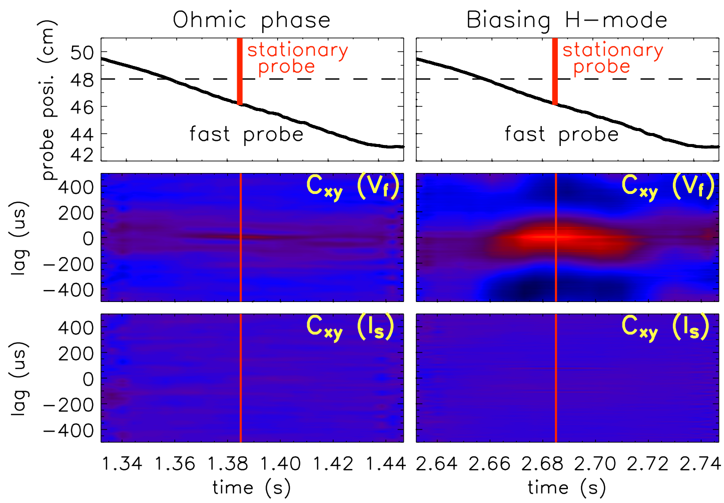

Fig. 2 Time history of fast/stationary probes and the contour-plot of cross-correlation between V_f (middle panels) and I_s (bottom panels) fluctuations measured before (left column) and during (right column) the biasing H-mode (# 108288). The vertical red lines in contour-plots denote the time when the two probes are at the same radial location.

Figure 2 plots the LDC results in a biasing experiment. The measurements were done in two phases for a comparison between the "ohmic phase" before biasing and the phase during the "biasing H-mode". Before biasing, the insertion of the electrode inside the last closed flux surface (LCFS) modifies the boundary conditions and hence reduces the LDC on V_f to a low level whereas for I_s the LDC remains small, as seen in the left column of Fig. 2 and Fig.1. Such an influence can also been seen in the power spectrum of V_f (see Figs. 3(a) and 1(d)). During biasing H-mode, a large LDC occurs on the V_f signals, covering a radial range ~3cm. Similar to that in Fig. 1, the maximum C_{xy} happens also when the two probes are around the same flux surface. The power spectra and C_{xy} of V_f fluctuations ($\tilde{v}_f$) detected at the maximum C_{xy} locus are plotted in Fig. 3. In ohmic case, the frequency spectra on both probes are broad and display small coherent modes around 2 and 10kHz. The corresponding C_{xy} on V_f is also wee (see Fig. 3(c)). With biasing, the fluctuation power of V_f at high frequencies (>4kHz) is reduced, in accordance with E×B flow shear decorrelation on small-scale turbulence. However, at low frequency parts (<3kHz), there is a strong enhancement of fluctuation power peaked at ~1.6kHz. The zero time lag in C_{xy} (see Fig. 3(d)) again points out a toroidal mode n=0, consistent with zonal flow (ZF) structures. The results indicate that with biasing the LDC is mainly attributed to the low frequency ZFs.

Further studies indicate that the ZFs are located within a certain radial range inside the E×B shear layer induced by the biasing [7]. Since the ZFs are helpful in regulating turbulence, we should estimate its contribution by calculating the fluctuating $\tilde{E}\times B$ flow shear rate and compare it with the mean E×B flow shear driven by biasing. In Fig. 4, the radial profiles of the *dc* radial electric field E_r and E_r shear (E_r') before and during biasing H-mode are plotted together with RMS (root mean square) levels of $\tilde{v}_f$. The E_r (E_r') profile is deduced from the first (second) radial derivative of the plasma potential (V_f+2.8T_e), measured by a triple-probe model [8]. In ohmic phase a naturally occurring E_r' layer causes a local reduction of fluctuation level around r=46cm. With biasing, a large *dc* E×B shear layer is developed. In the same region a ZF structure with fluctuating $\tilde{E}\times B$ shear flows is triggered. The maximum *dc* E×B shear rate (ω_{dc}= E_r'/B) at r=44.7 and 48.5cm are about $4\times10^5\ s^{-1}$ and $-3\times10^5\ s^{-1}$, respectively. The ZF structure decays in a radial

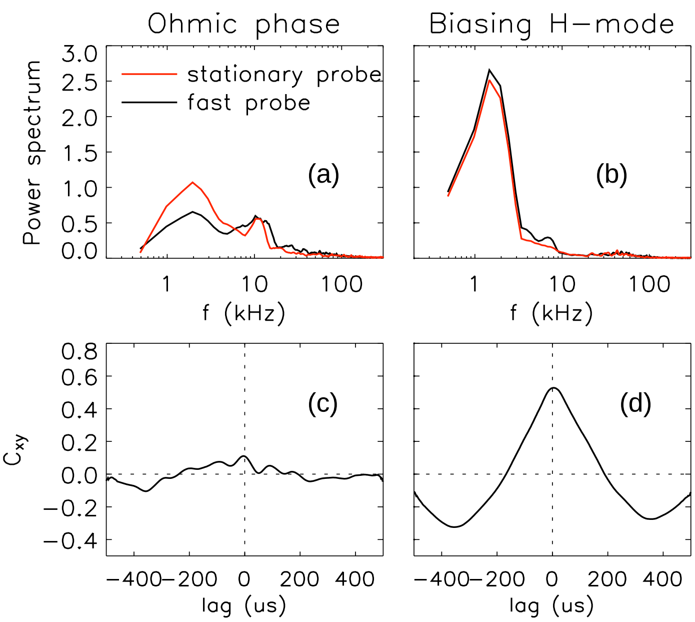

Fig. 3 Power spectrum of V_f fluctuations detected by fast and stationary probes at the maximum C_{xy} location in (a) ohmic and (b) biasing H-mode phase. The corresponding cross-correlation (C_{xy}) of V_f measured in (c) ohmic and (d) biasing H-mode phase.

length of $d_r \approx$1cm (see Fig. 2). The fluctuating V_f amplitude, $|\tilde{v}_f|$, of the ZF is about 12V [7]. Thus, the fluctuating $\tilde{E} \times B$ shear rate is estimated by $\omega_{ZF}=|\tilde{v}_f|/d_r^2B \approx 1\times10^5$ s^{-1}, which is smaller than but comparable with ω_{dc}. Its contribution to the turbulence self-regulation might be significant. In Fig. 4(b), we see an overall reduction of the fluctuation level of $\tilde{v}_f$ from the ohmic to H-mode phases. At the maximum ω_{dc} locations (r=44.7 and 48.5cm), the fluctuation reduction is the largest because of stronger ω_{dc}, while in between where ω_{dc} becomes weak the ω_{ZF} could play the major role in the fluctuation reduction. As $\omega_{ZF} < \omega_{dc}$, the decrease is relatively smaller here than on both sides.

4. Conclusion

In conclusion, long-distance toroidal correlations of edge fluctuations have been studied at TEXTOR in both ohmic and biasing experiments. In standard ohmic discharges, the LDC in V_f fluctuations is observed and the LDC is dominated by 1kHz and 10kHz coherent modes. During electrode basing experiments, in the ohmic phase before biasing the LDC in V_f is depressed due to the insertion of the electrode. During the biasing H-mode, the *dc* E×B flow shear triggers a zonal flow structure and hence a large LDC in V_f signals. The time-varying $\tilde{E} \times B$ flows related to this zonal structure could amplify and complement the fluctuation suppression linked to the *dc* E×B flow shear. These findings support the critical role of multiscale physics in the L-H transition process.

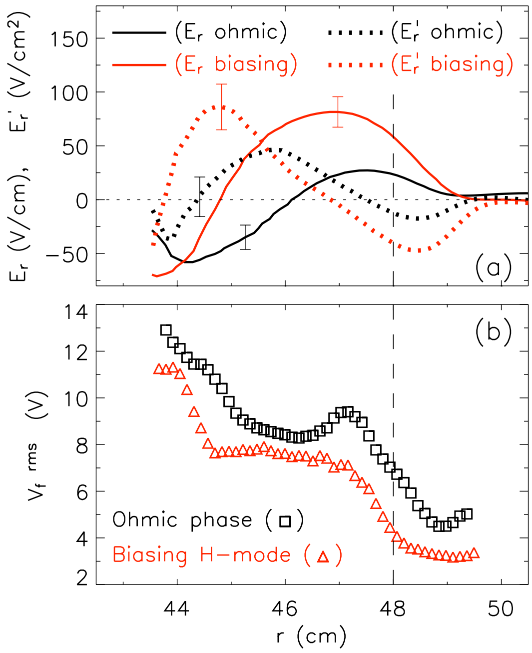

Fig. 4 Radial profiles of (a) E_r and E_r shear (E_r'); and (b) the RMS levels of V_f fluctuations before (ohmic) and during the biasing H-mode phases. The vertical dashed line denotes limiter position. The error bars in E_r and E_r' indicate the standard deviation about the mean for similar discharges.

In all above cases, no long-distance correlation is seen in the I_s signals.

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