Turbulence Intermittency in the scrape-off layer of HL-2A tokomak

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1.   Introduction

It is one of the key issues to understand anomalous cross-field transport in the scrape-off layer of tokamaks [1]. The turbulent intermittency (burst or filament structures), which localize in poloidal and radial plane and extend along the magnetic field line, has been identified as a significant source of cross transport in fusion devices. This transport is responsible for the SOL expansion, the increasing particle flux, plasma recycling, divertor heat load, density limit, and impurity transport in the SOL[2-3]. Much theoretical attention was devoted to fast cross-field transport. Some models have predicted that the burst structures are born in the vicinity of LCFS with high density gradients, assumed by interchange instability, and move in radial direction due to the E×B drift [4]. Several experimental authors [2,3,5] have reported that the non-Gaussian distribution of density fluctuations is attributed to the intermittent bursts in SOL. In this paper, the intermittent properties in the SOL of HL-2A tokamak are investigated with reciprocating Langmuir probes. The PDF and the continuous wavelet transform are used to analysis the intermittent behaviors with different time scales.

2.   Experimental setup

Experiments are performed on the HL-2A tokamak (major radius R = 1.65 m and minor radius a = 0.4 m) with lower single-null divertor configuration. The position of LCFS is determined by EFIT code. Typical plasma parameters are I_p = 180 kA, B_t = 1.4 T, line-averaged density n_e = 3.8×10^{19} m^{-3}. A reciprocating Langmuir probe system[6], mounted on the outer midplane, is used to measure edge plasma parameters with a probe array of five carbon tips, as shown in Fig.1, labeled as 1-5 with 2 mm in length and 1.5 mm in diameter. Tips 1-3, ranged
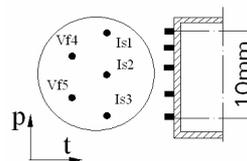

Fig.1.   Schematic arrangement of a probe array with 5 tips

poloidally with 5 mm each other, are used to measure saturation ion current I_{sat}, while tips 4-5 are for poloidal electrostatic field, $E_\theta=(V_{f4}-V_{f5})/d$, with a separation of d = 5 mm. Data acquisition frequency is 1 MHz.

3. Experimental results

Time evolution of I_{sat} at three radial locations in the SOL is presented in Fig.2. In the near LCFS ($\Delta r = r$-a =15 mm) positive and negative fluctuation amplitudes of I_{sat} are almost equivalent and their PDF is perfectly symmetric, as shown in Fig.3 (a). In middle SOL region ($\Delta r = r$-a = 20 mm), the PDF is dominated by larger positive bursts, illustrated in Fig.3 (b). In the far SOL ($\Delta r=r$-a= 25 mm), it is clear that the I_{sat} bursts have larger relative amplitude. The

corresponding PDF becomes strongly asymmetric with pronounced tail towards positive values, as shown in Fig.3(c). In order to quantify the non-Gaussian degree due to intermittence, we calculate the skewness (S) and kurtosis (K) of the I_s fluctuations, the

Fig.2. Time evolution of I_{sat} in SOL with n_e=3.8$\times 10^{19}$ m^{-3}

Fig.3. (a-c)The PDFs of Is at three different radial locations and (d) that of particle flux

third and fourth order moments of a PDF, which are defined as $S=M_3/\sigma^3$, $K=M_4/\sigma^4$-3, where $M_k = (1/n)\sum(x_i$-$x_m)^k$ [7]. Both the skewness and the kurtosis are equal to zero for a standard Gaussian distribution. The skewness and kurtosis of I_{sat} signals at different radial positions are calculated to compare the intermittent degree between the near SOL and the far SOL, as shown in Fig.3. It is obvious that the skewness and kurtosis increase with the radius. This figure clearly manifests that the intermittency becomes stronger and stronger from the near SOL to the far SOL, implying some blob existence in the far SOL. The PDF of particle flux ($\Gamma =<\tilde{n}_e\tilde{E}_\theta>/B$) induced by the intermittency has also similar feature in the far SOL region.

Though the small-scale components in turbulence are filtered, i.e. the short poloidal distance (<5.0 mm), the remained particle flux is still observed intermittency in the PDF, as shown in Fig.3(d), which implies that the intermittency is relevant to large scale bursts.
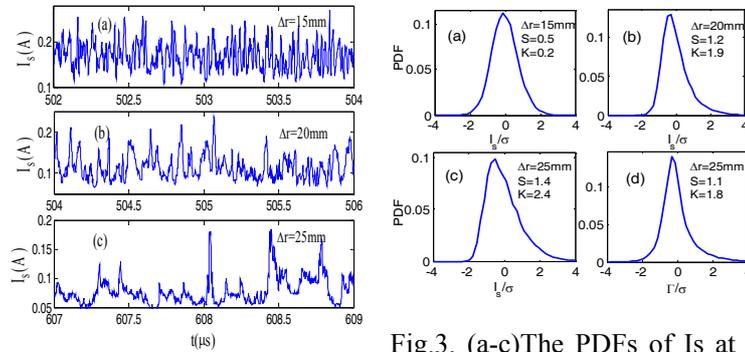
The statistics results of burst structure parameters at three different radial positions in the SOL is shown in Table 1. It is clear that the poloidal and radial speed decrease far away from LCFS, but the number of intermittent events decreases along radial propagation, meaning time interval between events increase. The increase of burst duration time is ascribed to the structure deceleration and size amplification.

Table 1. The statistics results of burst structure parameters at three different radial positions in the SOL of HL-2A tokamak

Position(mm)	Δr=15	Δr=20	Δr=25
Number of events	521	379	323
Waiting time (μs)	247	251	275
Burst duration (μs)	10	13	25
V_θ (km/s)	2.2	1.8	1.2
V_r (km/s)	0.9	0.65	0.6

The continuous wavelet transform with complex Morlet wavelet function [8] has been used to study the statistic properties of the fluctuations with different time scales and the coherent properties between two probes. In order to obtain the PDF of wavelet coefficient with different time scales, the saturation ion current has been analyzed using mother wavelet function W(t), $c(t,\tau) = \frac{1}{\tau}\int I_s(t')W(\frac{t'-t}{\tau})dt'$. Wavelet coefficient c(t, τ) represents the time behavior of characteristic fluctuations at each time scale τ, which is reverse proportion to the
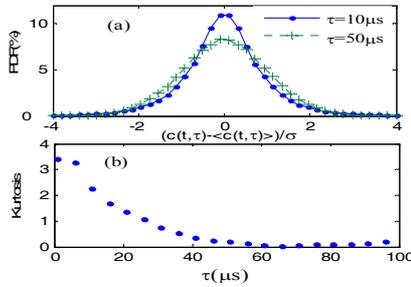

Fig.4. (a) PDF with different time scale fluctuations, X-axis is the normalized coefficients, σ is standard deviation, (b) Kurtosis versus time scale.
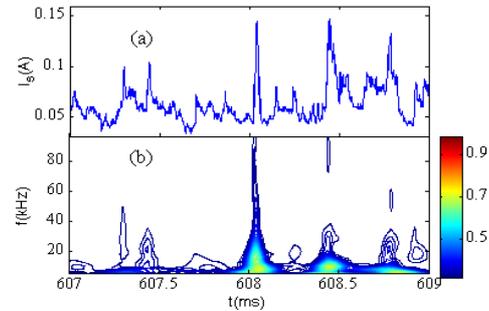

Fig.5. Time evolution of I_s of a probe (a), and of coherent coefficients with different timescales (b).

frequency τ =1/f . The PDFs of two normalized wavelet coefficients are shown in Fig 4(a), indicating the profiles with different shape and intermittent fluctuation level for two different time scales. In order to quantity this variation away from Gaussian distribution, the kurtosis with different time scales is evaluated, indicated in Fig.4 (b). The kurtosis is about 3.5 for small time scales, and decreases to 0 (Gaussian) for large time scales, which suggests that

the PDF depends on the time scales of fluctuations themselves. The deviation from the Gaussian PDF may attribute to the generation of coherent structures with different time scales. The signal correlation of two probes separated by 5 mm in the poloidal direction has been shown in Fig. 5. The one original signal of the two probes is also shown in Fig. 5(a). Fig.5(b) shows the temporal evolution of correlation coefficient between the probe signals. It is very clear that there are bursts with high correlation, corresponding to the sharp spikes in I_s. These results can be interpreted by the intermittent structures, which give rise to higher coherent coefficients than the other times. Therefore, wavelet analysis is useful to characterize the intermittent behavior.

4.   Summary

Analysis results of the turbulent intermittency in the SOL of HL-2A tokamak have been presented with reciprocating Langmuir probe data. From the near SOL (Δr=15 mm) to the far SOL (Δr=25 mm), saturation ion current is gradually dominated by larger, lower frequency bursts and characterized by strong PDF deviation, indicating that the intermittency becomes stronger and stronger away from LCFS. The poloidal and radial velocity, estimated with conditional averaging (CA), also decrease with increasing radius. Continuous wavelet transform manifests that the burst events with small time scales maybe lead to more large intermittent behaviors. The high correlation corresponds to large intermittency, coincident with the spikes in I_s. These results can be interpreted by strong intermittency across two probes. The investigation on the generation mechanism of burst events in SOL of tokomaks is future work.

Reference

[1]O.E.Garcia, et al, Phys. Rev. Lett. 92 (2004) 165003
[2]S.J.Zweben, et al, Plasma Phys. Control Fusion 49 (2007) S1
[3]G.Y.Antar, et al, Phys. Plasmas 14 (2007) 022301
[4]D.A.D'Ippolito, et al, Phys. Plasmas 9 (2002) 222
[5]O.Garcia, et al, Plasma Phys. Control. Fusion 48 (2006) L1
[6]L.W.Yan, et al, Rev. Sci. Instru. 77 (2006) 113501
[7]L.W.Yan, et al, Nucl. Fusion 47 (2007) 1673
[8]B.P.Millagen, et al, Phys. Rev. Lett. 74 (1995) 395