DENSITY AND POTENTIAL FLUCTUATIONS IN THE EDGE PLASMA OF THE URAGAN-3M TORSATRON

E.L. Sorokovoy, V.V. Chechkin, L.I. Grigor'eva, A.V. Chechkin, V.Yu. Gonchar, E.D. Volkov, N.I. Nazarov, S.A. Tsybenko, A.V. Lozin, A.P. Litvinov, A.Ye. Kulaga, Yu.K. Mironov, V.S.Romanov, S. Masuzaki, K. Yamazaki**

National Science Center "Kharkov Institute of Physics and Technology", Akademicheskaya st. 1, 61108 Kharkov, Ukraine
**National Institute for Fusion Science, Oroshi 322-6, Toki 509-5292, Japan*

Ion saturation current and floating potential fluctuations are recorded by movable array of 4 Langmuir probes near the boundary of the confinement region in the l = 3/m = 9 Uragan-3M torsatron with an RF produced and heated plasma. On the basis of these data main spectral and time characteristics of the low frequency electrostatic turbulence have been derived. The existence of the radial electric field shear and reversal of poloidal phase velocity of the fluctuations at the plasma boundary have been confirmed. The time function of the turbulent $E\times B$ particle flux contains intermittent bursts with the amplitude multiply exceeding the average flux. Up to 70% of the total fluctuating flux is carried in these bursts.
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1. INTRODUCTION

An increased attention is paid at present to find out the temporal structure of the electrostatic turbulence of edge plasma in various toroidal facilities [1-3]. Such an approach largely facilitates understanding of the nature of anomalous transport at the boundary of the confinement region. When studying statistic characteristics of fluctuations in different plasma devices, a lot of common features has been revealed. In particular, an essentially non-Gaussian character of the turbulence is observed [4]. This is a consequence of electric field and plasma density fluctuations at the plasma boundary to contain intermittent bursts of large amplitude. The nature of these bursts has not been found out yet and needs further studies. In the present work, some basic characteristics of the edge electrostatic turbulence are studied in the l = 3 Uragan-3M (U-3M) torsatron with a natural helical divertor. With an RF-produced and heated plasma, an intermittent character of the fluctuation-caused particle flux at the plasma boundary has been confirmed and first results of flux studies have been given.

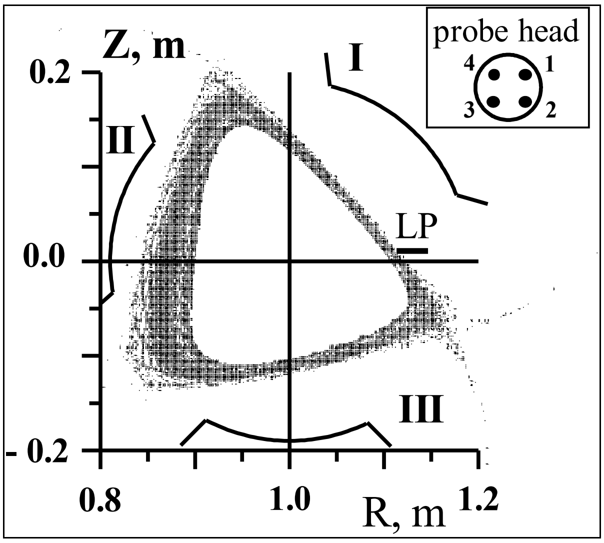

Fig. 1. Relative lay-out of helical coils I, II, III and calculated edge structure of field lines in the poloidal cross-section where measurements are made. The range of probe displacement LP is indicated by bold straight segment. The disposition of probes 1, 2, 3, 4 is shown in the inset as seen from the center outward.

2. EXPERIMENTAL CONDITIONS AND MEASUREMENT TECHNIQUES

In the U-3M torsatron with a helical divertor (l = 3, m = 9, R_0 = 1 m, $\bar{a}$ ≈ 0.1 m, B_ϕ = 0.7 T, $\iota(\bar{a}) \approx 0.4$) a hydrogen plasma is produced and heated by RF field in the $\omega \le \omega_{ci}$ range of frequencies. In the chosen regime of device operation, the RF power absorbed in the plasma was 240 kW. The central chord averaged electron density was $\bar{n}_e \sim 10^{18}$ m^{-3}. The temperatures of the main groups of ions and electrons were $T_i \approx 80$ eV and $T_e(0) \approx 400$ eV, respectively. To study electrostatic turbulence at the plasma boundary, a movable array of 4 Langmuir probes is used, which record fluctuations of ion saturation current (ISC) I_s as density fluctuations and of floating potential (FP) V_f as space potential fluctuations. The probes 1,2,3,4 (Fig. 1)are located in the angles of an 3 mm side square, oriented normal to the major axis of the torus and can be moved parallel to the major radius at the distance of 1 cm from the torus midplane. As a recording facility, a 4-channel 12-bit ADC is used with the sampling rate 1.6 μs per channel. This allows to record fluctuations with the frequency up to 300 kHz.

3. SPECTRAL CHARACTERISTICS OF POTENTIAL AND DENSITY FLUCTUATIONS

For the chosen RF discharge regime, the plots of rms values of ISC fluctuations δI_s (probe 2) and FP δV_f (probe 3) against the distance Δ from the vertical axis of poloidal cross-section along the line of probe array displacement are shown in Fig. 2 together with profiles of time-averaged ISC and plasma potential (the latter is estimated as $V_p \approx V_f + 2.5(T_e/e)$). The plasma potential possesses a maximum at Δ = 11 cm, thus indicating existence of radial electric field shear. Also, a maximum of potential fluctuation amplitude is located in this region (Δ = 11.25 cm).

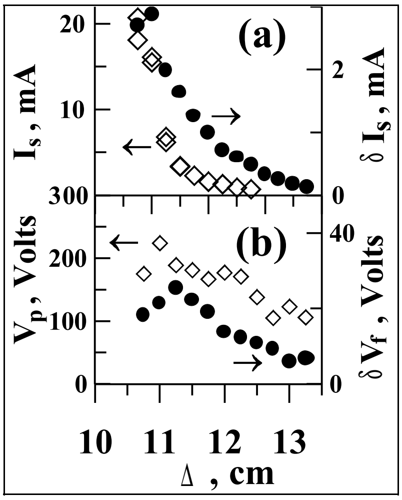

Fig. 2. (a) average ISC I_s (◊) and its rms fluctua-tions δI_s (●) as functions of distance Δ; (b) same for plasma potential V_p (◊) and its fluctuations δV_f (●)

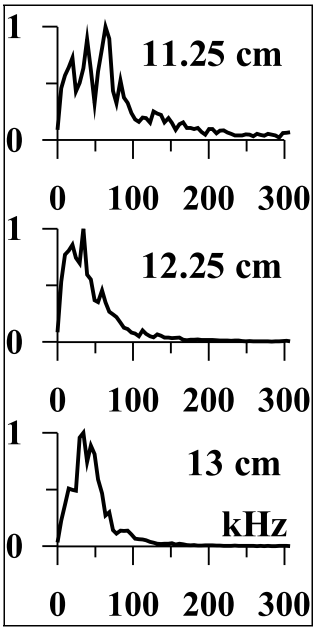

Fig. 3. Normalized power spectra of ISC fluctuations for various distances Δ

The power spectra of density fluctuations are shown in Fig. 3 for three probe positions in the edge region. The major part of the power is concentrated in the 0 - 100 kHz range of frequencies. Close to the boundary of the confinement region, the spectrum becomes more broad, and an appreciable part of it is formed by 100 - 200 kHz fluctuations.

Using cross-spectral characteristics of potential fluctuations, recorded by the probes 3 and 4, the poloidal phase velocity of fluctuations is plotted against Δ in Fig. 4. This dependence confirms the effect of phase velocity reversal in the vicinity of radial electric field shear near the plasma boundary[5].

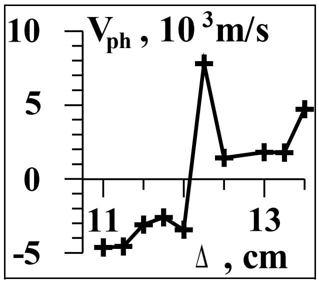

Fig. 4. Poloidal phase velocity of fluctuations V_{ph} as a function of distanceΔ

4. CHARACTERISTICS OF TURBULENT PARTICLE FLUX

It has been shown earlier that the particle flux through the plasma boundary is largely associated with density and electric field fluctuations in the U-3M torsatron [6,7]. In particular, this infers from consideration of spectral function of flux. In the present work, to understand better the structure of the turbulent flux, it is considered in the real time. To create the time function of the turbulent $E\times B$ flux, $\tilde{\Gamma}_T = \tilde{n}\tilde{E}_\theta / B_\phi$, fluctuating signals are taken from the probes, probe 2 (ISC) and 3,4 (FP), similar to what has been done in [1]. As a quantity proportional to the poloidal electric field fluctuations, the difference between FP fluctuations recorded by the probes 4 and 3 is taken, $E_\theta \propto V_{f4} - V_{f3}$, and as a quantity proportional to the density fluctuations $\tilde{n}$, ISC fluctuation $\tilde{I}_s$ is used. The time traces of local turbulence flux are presented in Fig. 5

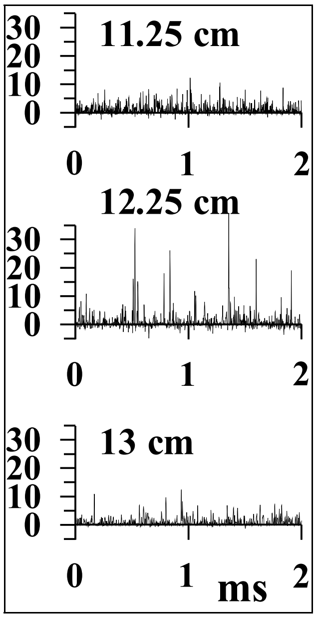

Fig. 5. Time function of turbulent E×B particle flux for various distances Δ

for the same three distances Δ as in Fig. 3. Proceeding from the form of flux function, we may conclude that the flux is mainly positive, that is, it is directed outward. Its time structure is characterized by the presence of relatively rare intense short time bursts, similar to what have been observed in [1-3]. The amplitude of these bursts can exceed the averaged flux by an order of magnitude. The largest bursts are observed in the vicinity of poloidal phase velocity shear, Δ = 12.25 cm. It is of interest to estimate which part of the flux is transported by bursts with the amplitude exceeding some given level [1]. At first, the flux is normalized so that its average value is 1, $\sum_{n=1}^{N} \Gamma_n / N = 1$, where $\Gamma_n \equiv \Gamma_T(t)/<\Gamma_T(t)>$, n is the point number in the time function of the flux, $1 \le n \le N$. In the case considered, $N = 1250$, which corresponds to the 0 ÷ 2 ms interval. For the normalized time flux, the probability density function (PDF) $p(\Gamma_n) = N_{\Gamma_n}/N$ can be created, where for each set of data N_{Γ_n} is the number of Γ_n values, which fall into the $\Gamma_n \pm W/2$ range, W being the width of the interval centered at Γ_n. Setting Γ_n to lie in the -40 ÷ +40 interval, we divide this interval into 160 sells of $W = 0.5$ width. The number of points falling into each sell is divided by the total number of points N. Also, the flux fraction function (FFF) $F_F(\Gamma_n) = p(\Gamma_n)^*\Gamma_n$ is calculated, which allows to estimate fractions of the total turbulent flux carried by bursts of various amplitude in the selected time interval. To estimate which fraction of the flux is carried by the bursts, whose amplitude exceeds some given value, the FFF should be integrated from this value to the highest defined one, $F_{>\Gamma_n} = \int_n^\infty d\Gamma'_n p(\Gamma'_n)\Gamma'_n$. This is illustrated in Fig. 6. Here, the cumulative probability of a flux event is plotted along the Y axis, and the flux fraction carried by the given flux events, i.e., by bursts whose amplitude exceeds some given value, is plotted along the X axis.

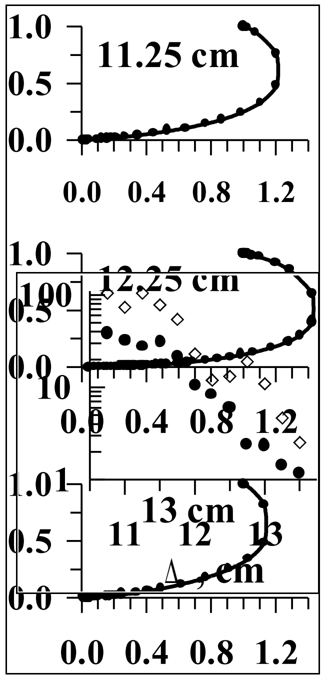

Fig. 6. Cumulative probability of flux events (axis Y), which carry the given fraction of the average particle flux (axis X).

It follows from Fig. 6 that in the vicinity of phase velocity shear, Δ = 12.25 cm, 2.5% of the largest flux events carry 50% of the total turbulent flux. For Δ = 11.25 cm and Δ = 13 cm this percentage amounts 7.5% and 8.5% respectively. In Fig. 7 the total turbulent flux and its fraction, which is carried by bursts with 5-fold excess over the averaged level, are plotted against the distance Δ. The total flux has a local minimum in the vicinity of phase velocity shear. In this position, the flux fraction carried by bursts with 5-fold excess attains 70%. It can be concluded from Fig. 7 that presumably a dominating fraction of plasma objects transported across the magnetic field lines in the form of intermittent bursts does not leave the stochastic region and finally enters the divertor.

Fig. 7. Δ - dependence of total turbulent $E\times B$ particle flux (◊) and of its fraction, carried by bursts with 5-fold excess of the amplitude over the average level (●).

5. CONCLUSIONS

Main spectral and temporal characteristics of the low frequency electrostatic turbulence have been studied in the edge plasma of the Uragan-3M torsatron. In particular, the reversal of the poloidal phase velocity of the fluctuations occurring near the radial electric field shear has been confirmed. Similar to what has been observed in some tokamaks and stellarators, the time function of the $E \times B$ turbulent flux possesses short time intermittent bursts, their amplitude multiply exceeding the average level. Taking only a small part of the flux in time (2.5 - 9 %), these bursts can carry up to 70 % of the total turbulent flux. The character of the burst amplitude - distance from the boundary plots allows to suppose that the major part of the plasma objects carried by the bursts into the stochastic layer enters the divertor.

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REFERENCES

[1] Carreras B.A. *et al* 1996 *Phys. Plasmas* **3** (7) 2664.
[2] Sanchez E. *et al* 2000 *Phys. Plasmas* **7** (5) 1408.
[3] Rudakov D.L. *et al* 2002 *Plasma Phys. Control. Fusion* **44** 717.
[4] Gonchar V.Yu. *et al* "Stable Lévy distributions for plasma density and potential fluctuations in the edge plasma of a torsatron" submitted to *Rus. J. Plasma Phys.*
[5] Endler M. 1999 *J. Nucl. Mater.* **266-269** 84
[6] Sorokovoj E.L. *et al* 1996 *Controlled Fusion and Plasma Physics (Proc. 23rd Eur. Conf. Kiev, 1996),* vol. 20C, part II (Geneva: European Physical Society), p. 523.
[7] Chechkin V.V. *et al* 1996 *Nucl. Fusion* **36** 133.