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Investigation of the Statistical Properties of the Periphery Fluctuations at L – H Transition on FT-2 Tokamak

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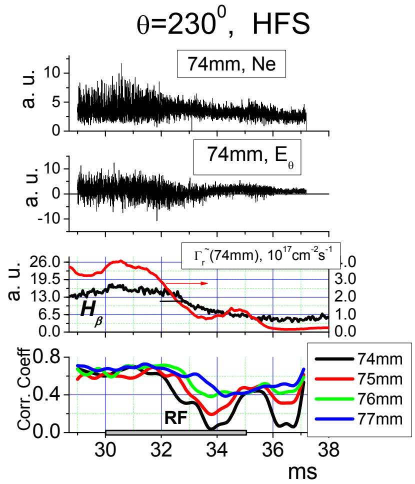
The considerable attention in experimental researches of the edge plasma's characteristics is paid to statistical analysis of fluctuation properties. Such investigations are important for the construction of the appropriate theoretical model of the turbulence and anomalous transport. In the theory of plasma turbulence it is assumed that the statistical properties of fluctuating processes are close to the properties of Gaussian random process [1]. Although there are observations of the edge plasma on the many fusion devices, that the time realizations of density and potential have "burst" structures, i.e. they contain the fast density spikes and holes [2, 3]. That is why the probability distribution function (PDF) of the fluctuations may be far from Gaussian PDF at the plasma edge where the large scale fluctuations are not rare events [4]. The PDF of the described intermittent transport is a useful characteristic to describe the dynamics of these large transport events.

Results of the fluctuations statistical properties analysis of the plasma density and radial drift of the particle flux are presented for FT-2 tokamak periphery. The data are obtained by 5 pin Langmuir probe measurements. The experiment is carried out with plasma under q = 6 (R=0.55m, a_L=0.079m, I_{pl} = 22kA and B_t = 2.2T, P_{LHH} = 90÷100kW), where the effective LHH and improved confinement transition are realised [5]. The RF pulse (Δt_{LH} = 5ms) is applied at the 30^{th} ms of a Δt_{pl} = 50ms plasma shot. During additional LHH the ITB is formed spontaneously a few ms after the RF pulse start. The L-H transition with Edge Transport Barrier (ETB) has been observed after RF pulse end. Energy confinement time increases from τ_E(OH) = 0.8ms up to τ_E(postLHH) = 2.8 ms when LHH is switched off and L - H transition is observed. As the experimental data of the probe measurements show, L – H transition and ETB formation are associated with negative E_r rise near LCFS after LHH pulse [6, 7]. Experimental scenario and multi pin Langmuir probe arrangement for measurement at Low (LFS, $\theta = 310^0$) and High (HFS, $\theta = 230^0$) Field Sides characteristic properties of the periphery plasma parameters are described in detail in [6, 7]. The poloidal angle θ shows the probe position in respect to the equatorial outboard midplane in the direction of the electron diamagnetic drift. The plasma core was slightly shifted upward (by 3÷4 mm) for measurements by probes in the deeper layers of the plasma core near LCFS and for some adjustment of the poloidal parameters symmetry. The probes can be moved shot be shot from limiter shadow and SOL (r ~ 80 – 76mm) up to LCFS region (r~76 – 74 mm). Observed suppression of the radial fluctuation induced flux

$\Gamma_r^{\sim}(t) = C_{n(\sim)E(\sim)}\, c\langle n^{(\sim)2}(t)\rangle^{1/2} \langle E_\theta^{(\sim)2}(t)\rangle^{1/2}/B_\varphi$, during LHH could be caused by damping of poloidal electric field E_θ, and density $N_e^{\sim}$ oscillations as well as by the reduction of the correlation coefficients $C_{n(\sim)E(\sim)}$. Fig. 1 illustrates the time behaviour of these fluctuation parameters at plasma periphery for LCFS region ($r = 74mm$) at HFS ($\theta = 230^0$). The correlation coefficient $C_{n(\sim)E(\sim)}$ is depicted for a few probe positions, $r = 74\text{-}77mm$. These data show a gradual decreases of the $\Gamma_r^{\sim}(t)$ on the plasma edge when ITB forms at the medium radii ($r = 4\text{-}5cm,\ t \sim 32ms$) and therefore after LHH pulse end. Radial fluctuation induced flux $\Gamma_r^{\sim}$ (averaged over 0.5 ms) at the periphery decreases concurrently with H_β radiation decrease. Suppression of radial fluctuation induced transport at plasma column periphery, starting from ITB formation at 32 ms, defines the mechanism of L - H transition, which is observed after LHH pulse end [6, 7].



Fig, 1
The time behaviour of the plasma fluctuation periphery parameters at HFS. $\Gamma_r^{\sim}$ is radial fluctuation induced flux averaged over 0.5 ms.

Change of the PDF of the observed intermittent transport is a fundamental characteristic to describe the dynamics of these transport processes. At the angle $\theta=230^0$ the three electrodes (1, 2 and 3) of the 5th pin Langmuir probe are located along tangential direction in respect to the plasma cross section [7]. The (4) and (5) pins are located in radial direction. The middle pins (2) and (4) of those electrodes have been used for ion saturation current δI_{sat} measurements. The edge pins (1), (3) and (5) were at floated potential. In this case, neglecting by electron temperature fluctuations, one can suppose, that : $\delta I_{sat} \propto \delta n$, $\delta\phi_f \propto \delta\phi_s$ and density of the radial fluctuation induced flux $\Gamma_r^{\sim}(t)$ is $\delta\Gamma_r \propto \delta I_{sat}\,(\delta\phi_{1f} - \delta\phi_{3f})$, where $\delta\phi_{1f}$ and $\delta\phi_{3f}$ are floated potentials at the edge pins (1) and (3). The 10th digit analogue-to-digital converter with 1 MHz timing generator is used for probe signal registration. The

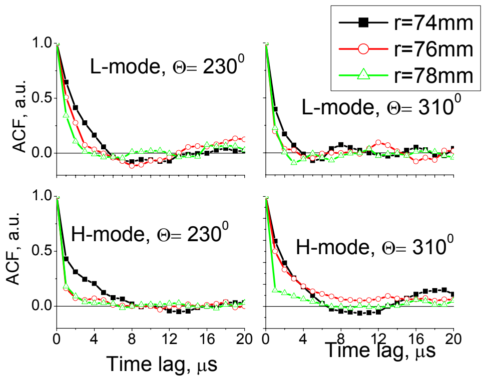


Fig. 2
Change of the Auto Correlation Functions of the saturated ion current oscillations measured at r = 74mm (near of the LCFS), r = 76mm and r = 78mm on HFS and LFS.

data are analyzed using the 1 ms (29÷30 ms) time samples of the ion saturation current or fluctuation induced flux for OH (L – mode) and (35÷36) one on the post LH heating period (H-mode). It has been checked if the fluctuations' temporary realizations correspond to the both criterion of a stationary and the criterion of an events' independence.

Analysis of the 1 ms time samples of the ion saturation current and radial fluctuation induced fluxes using the criterion of the inversions shows that hypothesis about stationary could be accepted with 5% significance level [8]. Verification on an events' independence was carried out using the Auto Correlation Functions (ACFs). The Fig 2 illustrates the change of the ACFs of the ion saturation currant oscillations measured at r = 74mm (near of the LCFS), r = 76mm and r = 78mm on HFS and LFS. One can see, that the Full Width at Half Maximum (FWHM) of the ACFs weakly change during L – H transition and remains ~ 2÷3 ms, which is congruent with 1 mks timing generator numeralization. So, temporary realizations correspond to the criterion of an events' independence. At the same time the ACF FWHM on the HFS is approximately two times wider than the ACF FWHM on the LFS. There is a decrease of the ACF FWHM's during displacement outward from the plasma core boundary. The PDF of the ion saturation currents and fluctuation induced fluxes are shown in Fig.3 and Fig. 4 for four space points. For the L-mode phase the PDF of the saturated ion currents are characterized by the wide and asymmetric distributions with clear positive non-Gaussian long lag tail, which point out at high event probability of the positive dense plasma spikes. The L – H transition results in the PDF peaking with decrease of the positive non-Gaussian long lag tails. It is typical that the left "tail" of the PDFs (r = 78mm) has the cut-off because the plasma density could be only positive. At the same time at L-H transition there is a symmetrisation of the PDFs near the LCFS (r = 74mm), Fig. 3a and 3b. For both sides (HFS and LFS) the PDFs near LCFS are closer to the Gaussian distribution (Skewness S ~ 0 and Flatness K~3 [3]) than near limiter (r = 78mm) where S > 0 and K-3 > 0.

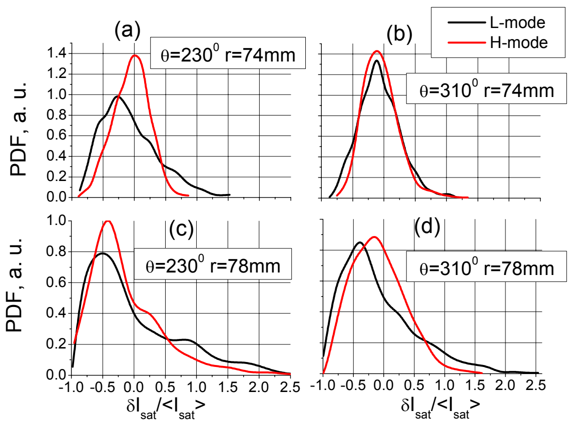


Fig. 3
The PDF of the saturated ion currents for four space points on HFS (a. c) and LFS (b, d).

The PDF peaking and symmetrisation as a result of a L – H transition is observed for radial drift fluctuation induced fluxes (Fig. 4). However the shape of the distribution functions on the LFS and the HFS at L – mode is essentially different. On the HFS at L – mode the positive non-Gaussian long lag tails are observed, that indicates at high probability of the extremely large spikes of the outward particle flux. On the LFS the non-Gaussian long lag tails are negative (Fig. 4b and 4d), i.e. moving inward. The presence of the periphery plasma waveform with higher density (filaments, blobs) moving inward to the plasma core has been registered on the LFS of the FT-2 earlier [9].

So, statistical properties analysis of the Langmuir probe measurements permits to determine that statistical properties of the periphery ion saturation current fluctuations and radial drift fluctuation induced fluxes are significantly inhomogeneous both in poloidaly and radial directions. In the L-mode the PDFs of the fluctuations measured at different radial positions and poloidal angles are essentially different from normal (Gaussian) distribution. L – H transition results in significant changes of the statistical characteristics of the periphery fluctuations. The PDFs of the investigated values are peaked and become more symmetrical. The ion saturation current fluctuations PDF (density of the charge particles) are transformed to the ones corresponding to the normal law (criterion of χ^2 [8]) only in the region directly near to the LCFS (r = 74mm). So, a frequently used in theoretical models assumption that fluctuating parameters correspond to the normal law [1] becomes restricted at the plasma edge. The new experimental investigations and new original procedures developed for the analysis of experimental results are needed. In particular, there is an idea for interpretation of the experimental PDF as a number of the same normal (Gaussian) distributions of turbulent fluxes with help of EM – algorithm [4]. Such approach permits to obtain the information about numerous processes, which stimulate the turbulence, and estimate theirs characteristics.

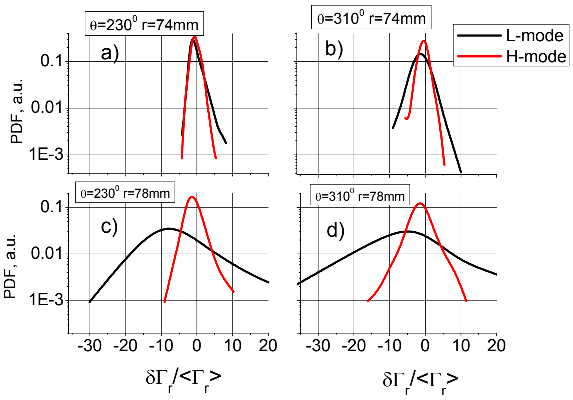


Fig. 4
The PDF of the fluctuation induced fluxes for two space points on HFS and LFS.

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