Characteristics of turbulence and electric fields in the peripheral plasma of the T-10 tokamak

R.Y. Solomatin, V.P. Budaev, S.A. Grashin, E.V. Dzyatko, L.G. Eliseev, A.V. Melnikov*, S.V. Perfilov, V.N. Zenin

National Research Center "Kurchatov Institute", Moscow, Russia
**National Research Nuclear University MEPhI, Moscow, Russia*

Measurements made in the Scrape-Off Layer (SOL) and in the vicinity of the Last Closed Flux Surface (LCFS) indicate that the particle transport across the magnetic field is highly anomalous [1, 2], leading to an essential increase of particle and energy flux reaching the wall of the vacuum chamber. This transport is determined by a strong intermittent turbulence associated with formation and radial propagation of the high density plasma structures ("blobs") [3, 5]. Investigations of the turbulence characteristics and the electric fields on the plasma periphery and in the SOL give the opportunity for understanding the mechanisms of particle transport and plasma confinement in tokamak. Investigation of the spectral characteristics of density and plasma potential turbulence clarifies the role of different types of oscillations like Geodesic Acoustic Mode (GAM) or MHD-modes in the particle and energy transport.

Turbulence and electric field characteristics were studied on T-10 tokamak by Movable Langmuir Probes (MLP) [3] and by Heavy Ion Bean Probe (HIBP) [4]. The average values and fluctuations of density, plasma potential and electric fields were measured in the core (by HIBP) and in the edge (by HIBP and MLP) plasmas. T-10 tokamak has a major radius of $R_0 = 1.5$ m, a circular poloidal graphite limiter with radius of 0.33 m and a rail graphite limiter installed at a radius 0.30 m. Experiments were performed in deuterium plasma with ohmic heating. In these experiments the average electron density N_e was in the range $1{\cdot}10^{19} \div 4{\cdot}10^{19}$ m^{-3}, the toroidal magnetic field $B_t = 2.3$ T, the plasma current $I_p = 0.2 \div 0.3$ MA.

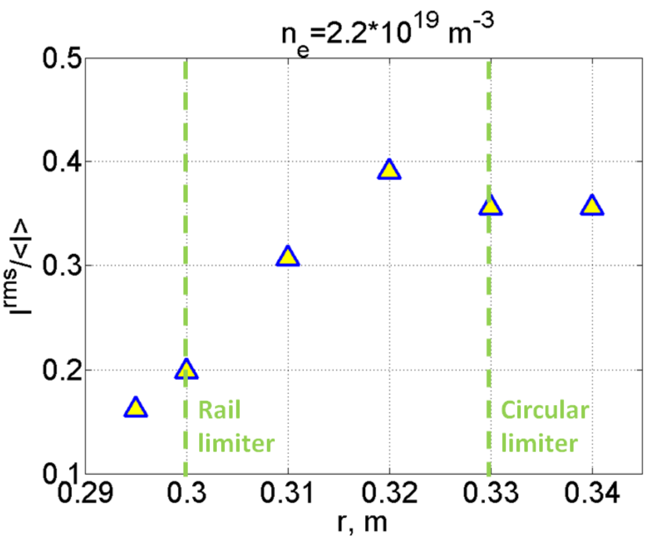

Fig. 1. Radial variation of the relative level of ion saturation current fluctuations. LP ion saturation current is proportional to electron density N_e.

Fluctuations of the plasma parameters (density, electric fields, turbulent particle flux) are highly intermittent in the SOL of

T-10 [3, 6]. Plasma structures with high density were observed in the SOL. The relative level of the fluctuations rises with the radius beyond the LCFS (Fig. 1), time interval between blobs and their duration increases (from 50 to 400 μs).

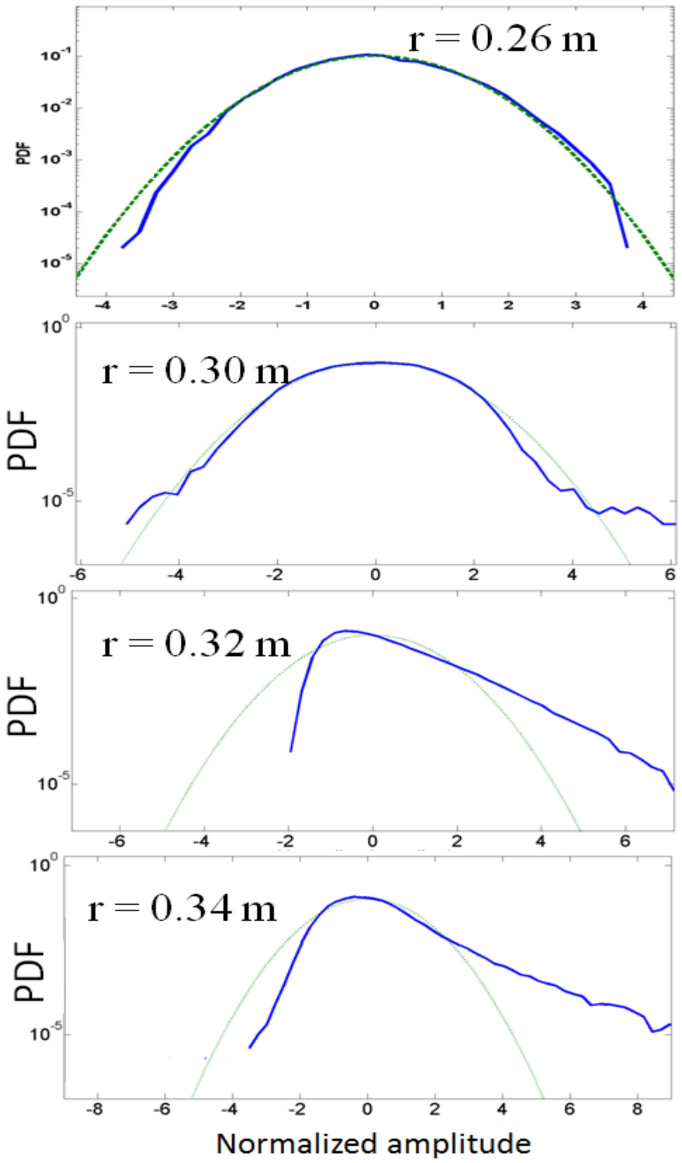

Fig. 2. Probability Density Function (PDF) of the density fluctuations measured by HIBP (r = 0.26 m) and LP (r = 0.30 - 0.34 m).

Measurements made by the MLP and HIBP indicate that in the periphery plasma (r = 0.25-0.3 m), where the level of intermittent turbulence is low, the statistics of plasma turbulence are close to the Gaussian one. In the SOL, the deviation of PDF from the Gaussian statistics rises (Fig. 2).

Radial electric field is positive in the SOL (up to 4 kV/m) and changes its sign near the LCFS (Fig. 3). Also the poloidal rotation velocity and the $E\times B$ drift velocity change their sign near the LCFS (Fig. 4). That can be connected with the change of particle transport behavior. For estimation of poloidal rotation velocity of the plasma structures were used a technique based on the time-delay of LP signals from the two poloidally separated probes. The measured poloidal plasma rotation velocity and the $E\times B$ drift velocity in the SOL are close to each other in value (-1.0-1.5 km/s) and have the same direction. In the SOL they directed towards the ion diamagnetic drift.

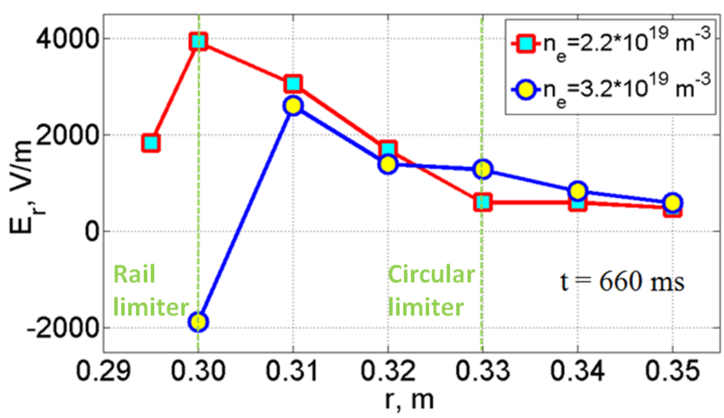

Fig. 3. Radial variation of the radial electric field.

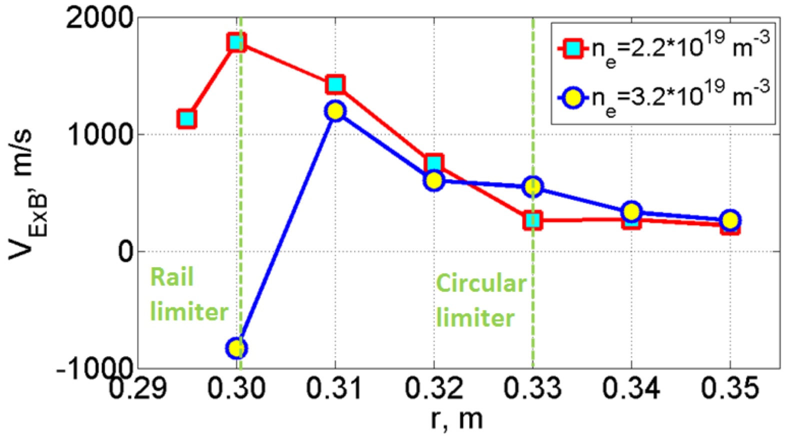

Fig. 4. Radial variation of the $E\times B$ drift velocity.

Measurements of the poloidal electric fields allows us to estimate the cross-field turbulent particle flux $\Gamma_\perp$.

$$\Gamma_\perp = \langle n_e V_r \rangle = \frac{c}{B}\langle \tilde{n}_e \tilde{E}_\theta \rangle = \frac{c}{B}\gamma_{nE}\tilde{n}_e\tilde{E}_\theta$$

where n_e, V_r and E_θ are the root-mean-square values of the density, the radial velocity and the poloidal electric field; γ_{nE} is a coefficient of the cross-correlation between n_e and E_θ fluctuations. Radial turbulent flux reaches the value of $5\cdot10^{21}$ m^{-2}s^{-1} near the LCFS and represents the significant part of the total particle flux across the plasma boundary.

In the vicinity of the LCFS Geodesic-Acoustic-Mode-like (GAM) oscillations were observed at 12-18 kHz on the floating potential and ion saturation current LP signals. GAM oscillations have the intermittent behavior. The only low-frequency (1-9 kHz) fluctuations observed at larger radii (closer to the wall of the tokamak) (Fig. 5). Measurements made by the LP and HIBP at the plasma periphery indicate also a quasi-coherent peak of oscillations with frequencies in the range 50-100 kHz.

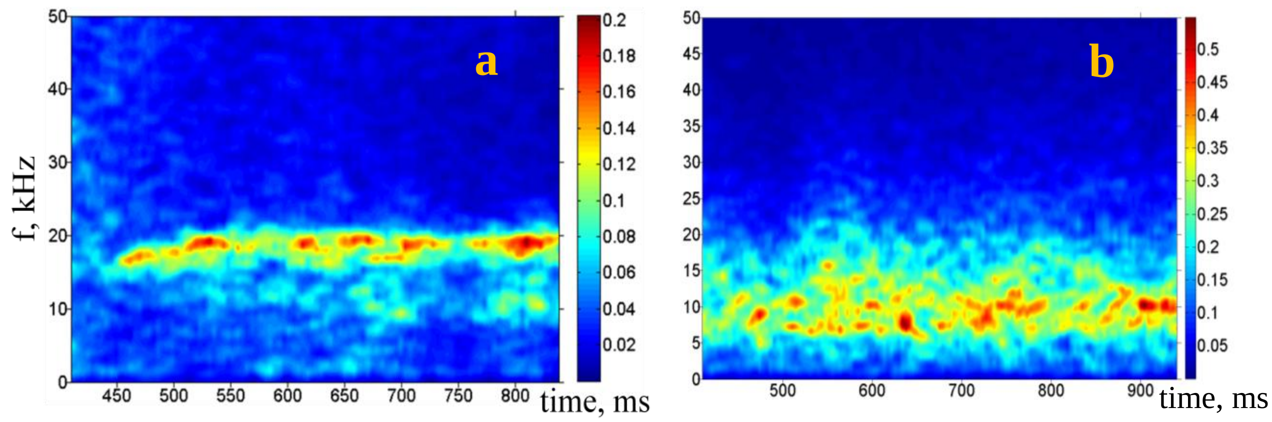

Fig. 5. Power spectral density of the floating potential oscillations in the SOL of T-10. B_t = 2.3 T, I_p = 220 kA, $N_e = 2\cdot10^{19}$ m^{-3}. **a.** r = 0.3 m. **b.** r = 0.32 m.

The frequency of the GAM oscillation rises with the electron temperature T_e (Fig. 6), according to the theoretical predictions for GAM [7].

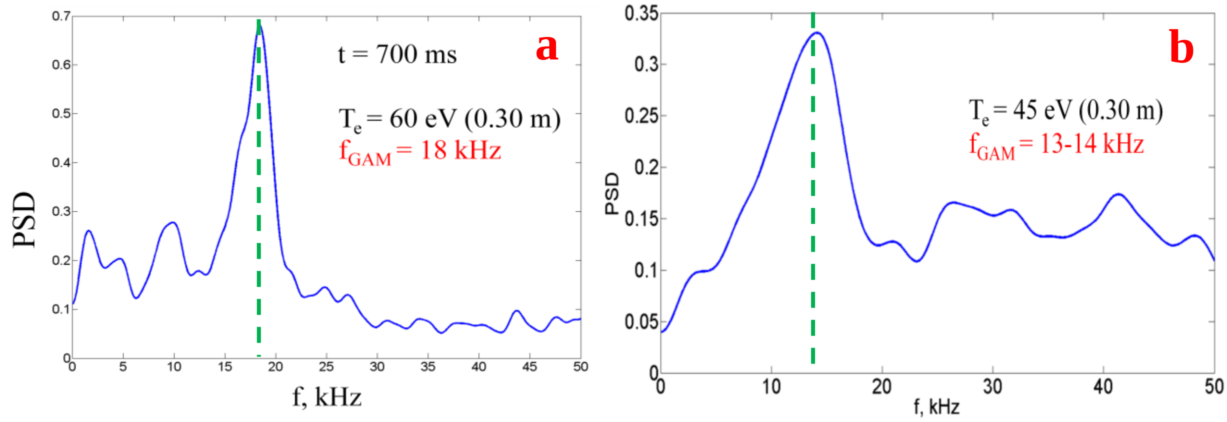

Fig. 6. Power spectral density of the floating potential turbulence near the LCFS of T-10. B_t = 2.3 T, I_p = 220 kA, r = 0.3 m. **a.** $N_e = 2\cdot10^{19}$ m^{-3}. **b.** $N_e = 3.2\cdot10^{19}$ m^{-3}.

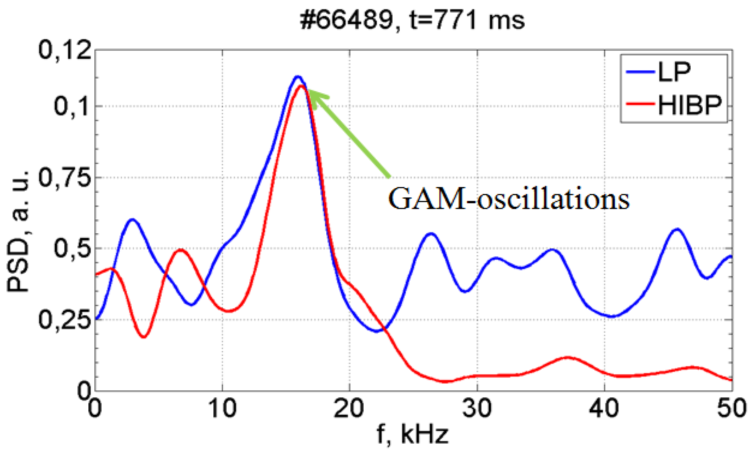

Fig. 7. Power spectral density of the MLP (r = 0.30 m) and the HIBP (r = 0.25-0.26 m) potential signals.

The GAM frequency measured by MLP corresponds to the HIBP measurements in the peripheral and core plasma (Fig. 7) [8]. In some cases the correlation between the MLP and HIBP potentials were found at the GAM frequency.

The work was carried out by Russian Science Foundation project 14-22-00193.

References.

[1]. Zweben S. J. et al. Plasma Phys. Control. Fusion **49** S1-23 (2007).
[2]. Kirnev G. S., Budaev V.P., et al. Journal of Nuclear Materials v.337-339, p.352-356 (2005).
[3]. R.Y. Solomatin et al. 41st EPS Conf. on Plasma Phys. and Nucl. Fusion, Berlin 2014, P4.038.
[4]. Melnikov A.V. et al. Nucl. Fusion **53** (2013) 092002.
[5]. Budaev V.P., Savin S.P., Zelenyi L.M. Physics-Uspekhi **54** (2011) 875–918.
[6]. Kirnev G. S., Budaev V.P., et al. Nuclear Fusion **45** (2005) 459-467.
[7]. P.M. Diamond et al Plasma Phys. Control Fusion **47** (2005) R35-R161.
[8]. A.V. Melnikov et al Nucl. Fusion **55** **(**2015) 063001.