Investigation of the turbulence characteristics and turbulent fluxes in the SOL of T-10 tokamak

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Highly anomalous particle transport in tokamak near the last closed flux surface (LCFS) leads to an essential widening of the scrape-off layer (SOL) [1]. Langmuir probe measurements of the SOL plasma parameters indicate [2] that intermittent convection rather than diffusion can define the cross-field transport. Intermittent plasma turbulence associates with formation and propagation of the coherent plasma structures ("blobs") with high plasma density. Intermittent transport is considered as the universal mechanism of the radial convective transport in the SOL of different magnetically confined devices [4]. Intermittent convective transport leads to an essential increase of particle and energy flux reaching the wall of the vacuum chamber [5]. Investigation of the turbulence characteristics and turbulent fluxes in the SOL and their correlation with the core turbulence clarifies the mechanism of particle transport as well as particle balance and particle confinement in tokamak.

Characteristics of the periphery turbulence and turbulent fluxes were investigated on the T-10 tokamak by the Langmuir probes and heavy ion beam probe (HIBP) [3]. T-10 tokamak have a major radius of R_0 = 1.5 m, a poloidal graphite limiter with radius of 0.33 m and a graphite rail limiter at a radius 0.30 m. Experiments were performed in deuterium plasma. 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 ÷ 0.3 MA.

Measurements of the SOL parameters were performed by using two probe systems. The movable probe system consisted of 10 tungsten pins, distributed in poloidal and radial direction. Distance between neighboring pins was 0.26 cm. The probe system moved radially on shot-to-shot basis. It was placed on the outboard side of the T-10. Second probe system included graphite probes mounted on the tip of the rail limiter. Time resolution of the data acquisition system was 1 μs.

The main SOL plasma parameters measured in the describing experiments were the values and fluctuations of the ion saturation current I_s, floating potential U_{fl}, electron temperature T_e, radial and poloidal electric fields and radial turbulent particle flux. The radial electric field E_r was estimated as

$$E_r \approx -\nabla U_{fl} - K\frac{\nabla T_e}{e}$$

The perpendicular turbulent particle flux $\Gamma_\perp$ was calculated as

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

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.

Fluctuations of all measured plasma parameters in the SOL of T-10 have highly intermittent character (Fig.1).

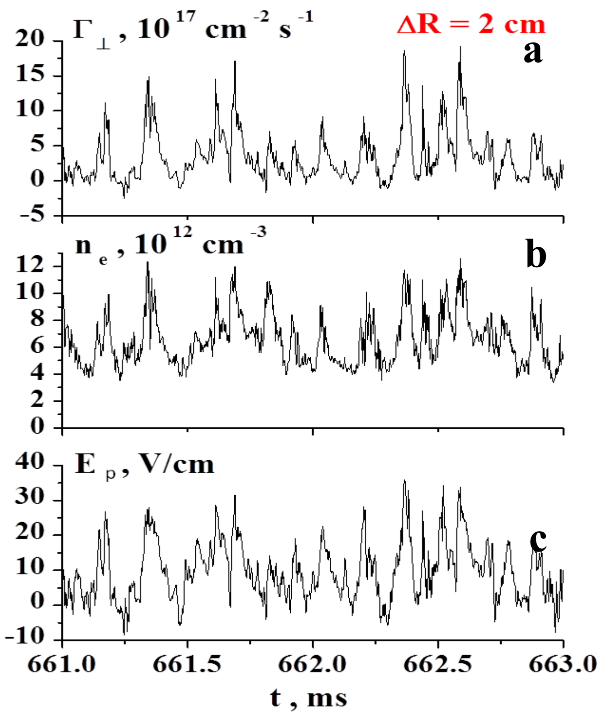

Fig.1. Intermittent behavior of turbulence in the SOL of T-10 for measured plasma parameters: **a.** radial turbulent flux $\Gamma_\perp$; **b.** electron density n_e; **c.** poloidal electric field E_p. $B_t = 2.3$ T, $I_p = 220$ kA, $N_e = 2e13$ cm^{-3}, $r = 32$ cm.

Formation of plasma structures with high density is observed in the vicinity of the LCFS. The relative level of the intermittent turbulence and duration of the bursts rises with the radius beyond the LCFS. Radial and poloidal size of the plasma objects is about 1-3 cm. Coherent plasma structures with high density move in radial and poloidal direction. Radial velocity is about 1 km/s nearby LCFS and predominantly directs to the vessel wall. Intermittency becomes negligible in the far SOL ($r \geq 36$ cm). Intermittent convective transport leads to an essential widening of the plasma parameter's profiles in the SOL (Fig.2). Radial turbulent flux reaches the value of $3\cdot10^{17}$ cm^{-2}s^{-1} near the LCFS and represents the significant part of the total particle flux across the plasma boundary. Comparison of the Langmuir probes and HIBP measurements reveals that the radial turbulent flux is strongly inhomogeneous in poloidal direction.

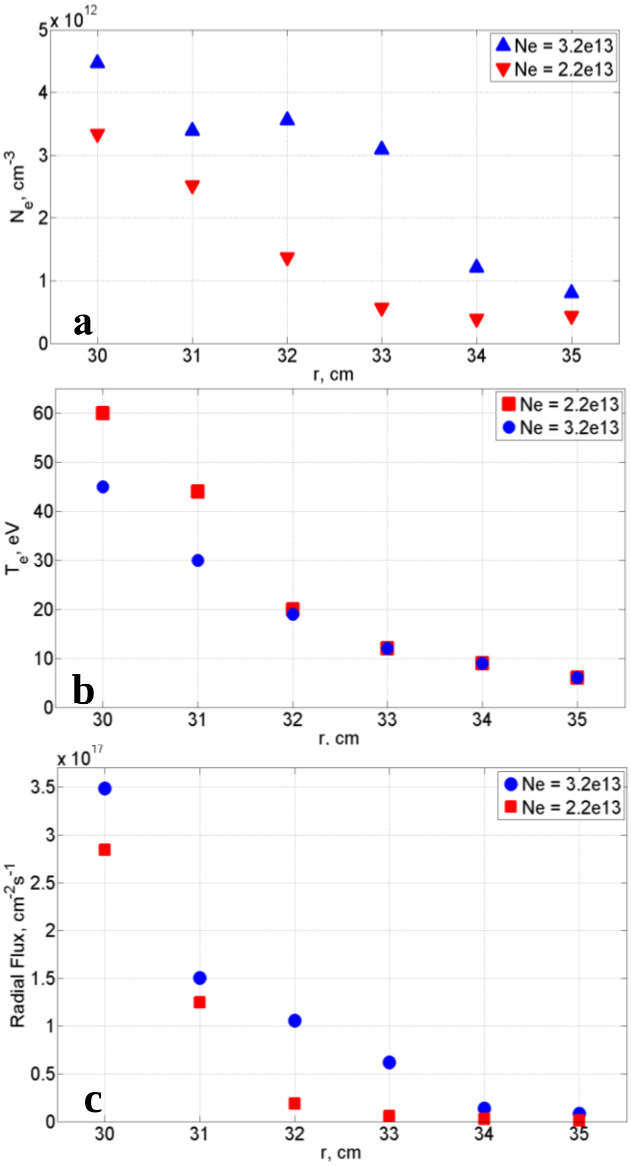

Fig.2. Radial distribution of the plasma parameters in the SOL of T-10: **a.** electron density; **b.** electron temperature; **c.** radial turbulent flux. $B_t = 2.3$ T, $I_p = 220$ kA, $t = 650$ ms.

In the T-10 we used a technique based on the time-delay of I_s signals from the two poloidally separated probes for estimation of poloidal velocity of the plasma objects. The velocity of the plasma poloidal rotation is 1-2.5 km/s and corresponds to the velocity of the poloidal $E_r \times B$ drift in value and direction (Fig.3). It can be directed towards the ion or electron diamagnetic drift.

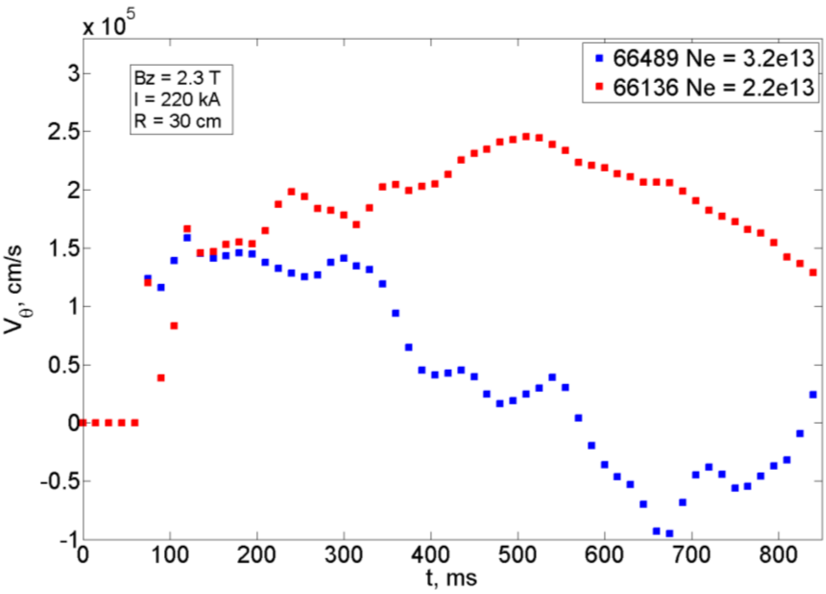

Fig.3. Velocity of the poloidal $E \times B$ drift at the LCFS of the T-10.

Spectral characteristics of the turbulence in the vicinity of the LCFS show the presence of the GAM-type oscillations of the density and potential (Fig.4). Moving closer to the wall of the tokamak, low-frequency fluctuations predominate. The frequency of the GAM oscillations is close to that measured by the HIBP in the periphery plasma. Frequency of GAM-type oscillations (14-18 kHz) increases with the electron temperature T_e rise (Fig.5). That corresponds to the dependence, predicted for GAM oscillations [6].

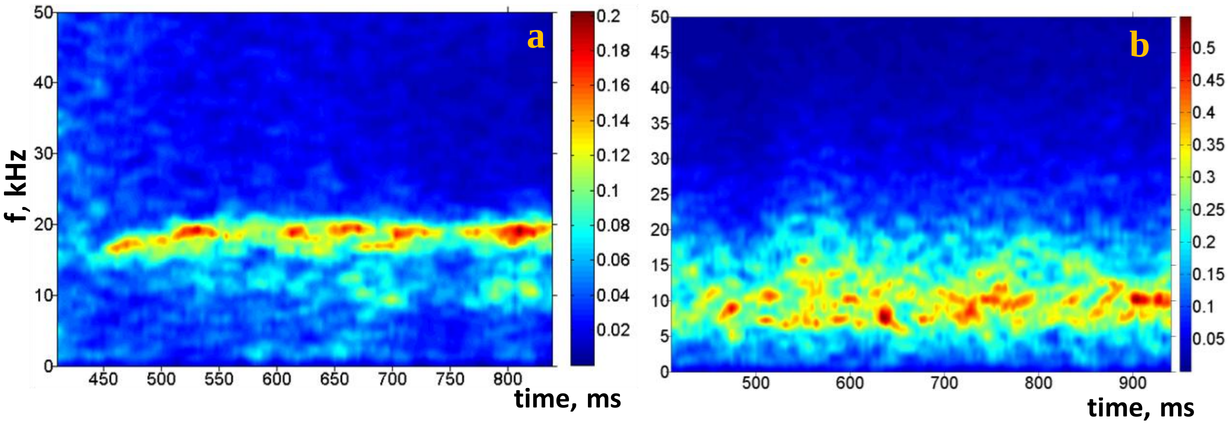

Fig.4. Spectral characteristics of the floating potential turbulence in the SOL of T-10. B_t = 2.3 T, I_p = 220 kA, N_e = 2e13 cm^{-3}. **a.** r = 30 cm, **b.** r = 32 cm.

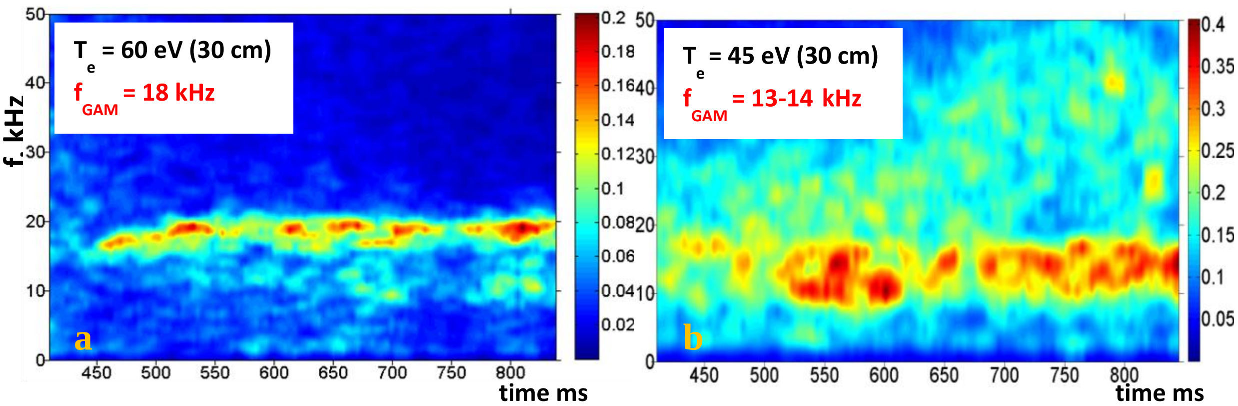

Fig.5. Spectral characteristics of the floating potential turbulence in the SOL of T-10. B_t = 2.3 T, I_p = 220 kA, r = 30 cm. **a.** N_e = 2e13 cm^{-3}, **b.** N_e = 3.2e13 cm^{-3}.

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