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Longitudinal current fluctuations in the SOL of the CASTOR tokamak

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1. Introduction: The probe measurements of electrostatic fluctuations on the CASTOR tokamak [1] have identified turbulent structures of plasma potential with poloidal dimension $\sim\ 2\ cm$ and life time $5 \div 20\ \mu s$. Furthermore, the poloidal periodicity of potential structures with the wavelength $\lambda_p \sim 10\ cm$ is observed. Measurements on the ASDEX tokamak [2] reveal the similar character of the potential structures. Moreover, the parallel correlation length of these perturbations was found to be comparable with the geometrical length of magnetic field lines in SOL. The simplified representation of the experimental observations is schematically shown in Fig. 1.

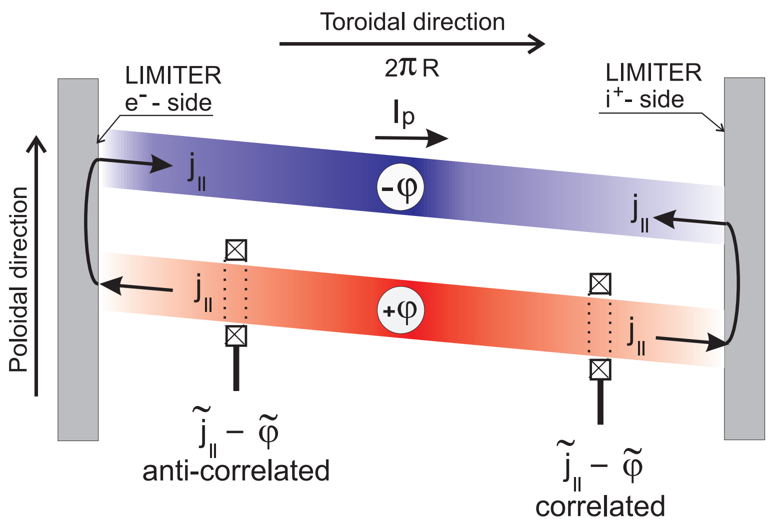


Fig. 1: *A schematic picture of two potential tubes connecting the electron and ion side of the poloidal limiter as seen from the side of the torus.*

This figure shows two potential structures, the first one (red) with the potential above and the second (blue) with the potential below a mean value. The poloidal distance between them corresponds to one half of the poloidal wavelength. This picture suggests that the extra charge of the potential tubes is balanced via currents $j_{\|}$ flowing along the magnetic field lines and finally over the limiter surface.

An existence of the current tubes fluctuating in SOL in phase with potential perturbations was predicted by model of Nedospasov [3] trying to explain the electrostatic turbulence in SOL by a flute-like instability. This model was modified by Endler [2] to explain the characteristic features of the density and potential fluctuations in SOL of the ASDEX tokamak. The expected characteristic features of the current tubes are as follows:

- A dipole poloidally spaced current/potential tubes should be located at the low field side of the torus (with a "bad" curvature of the magnetic field lines).
- The largest current density is expected near the limiter surface, while it should be zero at the opposite side of the torus.
- The correlation coefficient between current and potential fluctuations is expected to have opposite sign close to the ion side of the limiter compared to its value close to the electron side.

The amplitude of the current fluctuations is estimated as:

$$\tilde{j}_{\parallel} = enc_s V \frac{e\tilde{\varphi}}{k_B T_e}, \tag{1}$$

where c_s is ion sound velocity, m_i is mass of ions, V is a constant of the order 1 and $e\tilde{\varphi}/k_B T_e$ is the relative level of potential fluctuations.

Fluctuations of the parallel current may represent a link to magnetic fluctuations measured in SOL by magnetic probes. The perpendicular magnetic field, $\tilde{B}_{\perp} \perp \vec{B}$, associated with a current tube of a radius r_t is: $\tilde{B}_{\perp} = \mu_0 \tilde{I}_{\parallel}/2\pi r_t$, where $\tilde{I}_{\parallel} \sim \pi r_t^2 \tilde{j}_{\parallel}$ is the total current flowing through the current tube.

2. Experimental arrangement: Fluctuations of the toroidal current are monitored on the CASTOR tokamak by a miniature Rogowski coil (RC) with spatial resolution 7 mm (active area $S_{RC} = 0.385\ cm^2$), see Fig. 2. The output signal of the RC is proportional to the time derivative of the current flowing through its cross-section, $V = M\frac{dI}{dt}$, where $M = 5.2 \cdot 10^{-8}\ H$ was found to be constant in the frequency range 2 - 300 kHz.

Because of imperfect construction, the Rogowski coil is equipped with two stainless steel plates to estimate magnitude of the signal originating in currents flowing outside its active area. The plates block the active area of the coil as displayed in Fig. 2., case B. A single Langmuir probe (LP) located in the vicinity of the RC (see Fig. 2) measures either floating potential U_{float} or ion saturation current I^+_{SAT} in the center of 'current tube' associated with the Rogowski coil. The probe can be switched between these two regimes a few times in a single shot. All the signals are sampled up to 0.2 μs/sample.

The combined probe is located on the low-field side of the torus, where the highest level of current fluctuations is expected [3] and it is movable in the radial direction on a shot-to-shot basis. The measurements were performed at the two toroidal positions as displayed in the next figure.

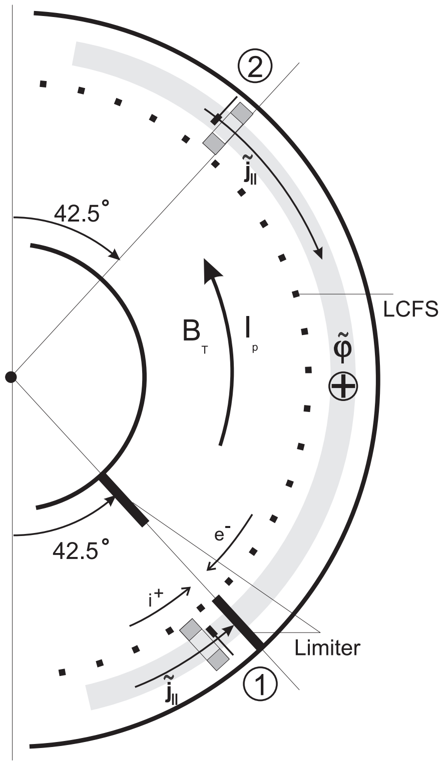
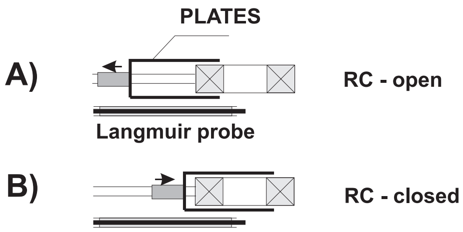


Fig. 2: *Top view of the torus. The two toroidal positions of the Rogowski coil are denoted as* **1** *and* **2**. *At the toroidal position denoted as* **1**, *the Rogowski coil is located close to the ion side of the limiter, while it is shifted toroidaly by 95° from the electron side of the limiter in the second series of experiments to the position* **2**. *These two cases should differ in the sign of $\tilde{j}_{\parallel}$ - $\tilde{\varphi}$ correlation.*
LCFS - Last Closed Flux Surface. Magnetic field lines behind the LCFS intersect the limiter surface.



3. Experimental results: Fig. 3. summarizes experimental results obtained in measurements at the toroidal position **1**. The top panels show radial profiles of floating potential (left) and ion saturation current density fluctuations (right). It is seen that maximum of $U_{\rm float}$ is shifted by 15 mm inwards compared to the position of material limiter. This suggests that the LCFS was not identical with material limiter during these shots.

The two middle figures display radial profiles of parallel current fluctuations $\tilde{j}_{\|}$. The noise level was determined in shots where the active area of Rogowski coil was closed by protective plates. It is seen that the signal is well above noise in the part of SOL region between material limiter and LCFS (maximum of $U_{\rm float}$) and also more inwards to the plasma core. The level of $\tilde{j}_{\|}$ turbulence in SOL is under 1 A/cm^2.

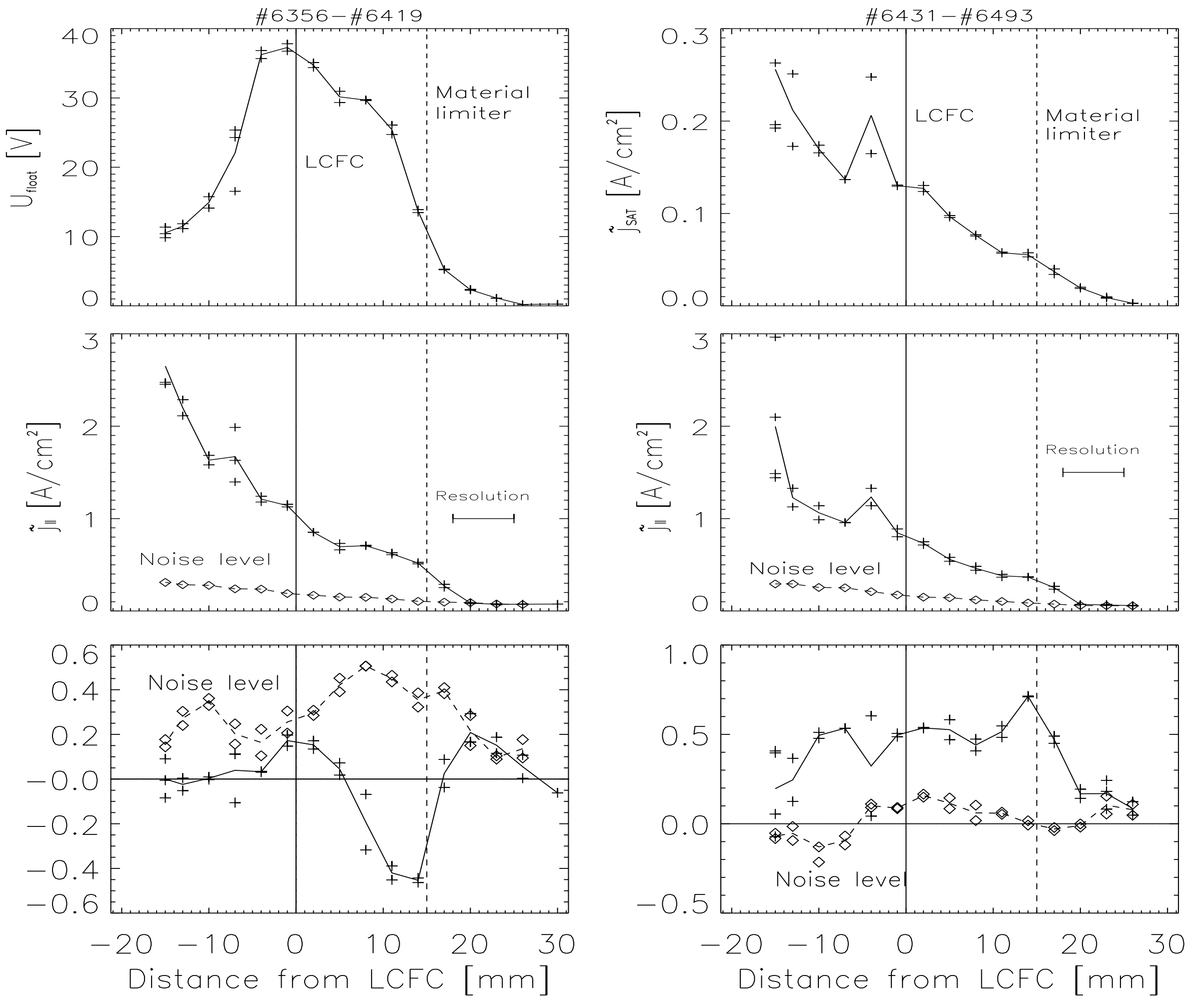


Fig. 3: *Radial profiles of:* **Left column:** *floating potential, parallel current fluctuations* $\tilde{j}_{\|}$ *and* $\tilde{j}_{\|} - \tilde{\varphi}$ *correlation coefficient,* **Right column:** *ion saturation current fluctuations* $\tilde{j}_{SAT}$*, parallel current fluctuations* $\tilde{j}_{\|}$ *and* $\tilde{j}_{\|} - \tilde{j}_{SAT}$ *correlation coefficient.*

The two bottom figures display radial profiles of $\tilde{j}_{\|} - \tilde{\varphi}$ (left) and $\tilde{j}_{\|} - \tilde{j}_{SAT}$ (right) correlation coefficient. The highest $\tilde{j}_{\|} - \tilde{\varphi}$ correlation (up to 0.5) is observed in the SOL region between material limiter and LCFS. In the shadow of the material limiter as well as in plasma core the correlation falls down to almost zero. The noise level, computed at the closed RC is similar in magnitude but it has reversed sign. This agrees with the model of current tubes. The closed RC 'feels' only current flowing outside its cross section especially in a nearby tube. The contribution of this tube to the RC signal has an opposite sign compared to the same tube flowing through the RC cross-section. This also suggests that diameter of current tube is comparable with RC resolution (7 mm). The similar results were obtained in measurements 95° toroidaly away from the electron side of the limiter (at the position **2**). Especially, no substantional decrease in $\tilde{j}_{\parallel}$ amplitude was observed, also, the sign of $\tilde{j}_{\parallel} - \varphi$ correlation remained negative. That can be explained by the fact that plasma column was shifted downwards during these measurements and therefore, taking into account the topology of magnetic field lines, the RC was in fact toroidaly closer to the ion side of the limiter also during these shots.

The radial profile of $\tilde{j}_{\parallel} - \tilde{j}_{SAT}$ correlation coefficient (right bottom figure) is constant over radius (especially in SOL) and with relatively high amplitude, up to 0.7. This indicates a very good relationship between fluctuating structures of current and density in SOL.

Conclusions: A novel diagnostic, a miniature Rogowski coil combined with Langmuir probe was designed, calibrated and tested on the small tokamak CASTOR. Fluctuations of toroidal current density $\tilde{j}_{\parallel}$, plasma potential $\tilde{\varphi}$ and density $\tilde{n}_e$ are measured simultaneously at the plasma edge. This allowed us to correlate the measured signals to get a better insight into possible causal relationship between these turbulent processes. Levels of $\tilde{j}_{\parallel}$ of 1 A/cm^2 are measured in SOL for the first time in tokamaks. Correlation measurements between current and potential fluctuations revealed a significant relationship between current and potential structures in the SOL (correlation up to 0.5) as expected from the Nedospasov model $\Longrightarrow$ current fluctuations may represent a link between $\tilde{B}_r$ and electrostatic turbulence. However, we did not observe any significant dependence of $\tilde{j}_{\parallel}$ amplitude on toroidal position as well as any switching from $\tilde{j}_{\parallel} - \tilde{\varphi}$ correlation to anti-correlation depending on toroidal position. Displacement of plasma column from the center of vacuum chamber is supposed to be responsible for observed phenomena.

Clear relationship between $\tilde{j}_{\parallel}$ and $\tilde{n}_e$ structures in the SOL was established (positive correlation up to 0.7).

References

[1] J. Stöckel *et al*: proceedings of 1996 International Conference on Plasma Physics, Nagoya, Vol.1, p.322

[2] M. Endler *et al*: Nuclear Fusion, Vol.35, No.11 (1995).

[3] A.V. Nedospasov: Phys. Fluids B, Vol.5, No.9, September 1993.