Turbulence and Transport with Spatial-Temporal Biasing in the Scrape-off layer of the CASTOR Tokamak

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Abstract. Experiments with a full poloidal array of 32 plane electrodes, performed on the CASTOR tokamak, provide information on the complete poloidal structure of the electrostatic turbulence in the scrape-off layer. A quite regular structure of the edge turbulence with a pronounced poloidal periodicity is identified. The dominant poloidal mode number has the same value as the edge safety factor. In addition, the edge turbulence is actively modified either by DC biasing a poloidally localized electrode or by applying standing and propagating waves of potential to the ring of the electrodes. A significant modification of the edge turbulence is observed with both the arrangements.

1. Introduction

An active control of edge turbulence is an important tool for efficient tokamak operation. A reduction of edge fluctuations within the separatrix is required to form edge transport barriers, while their enhancement in the scrape-off layer (SOL) is beneficial for broadening the deposition profiles and consequently reduce the power density load on the limiter/divertor plates.

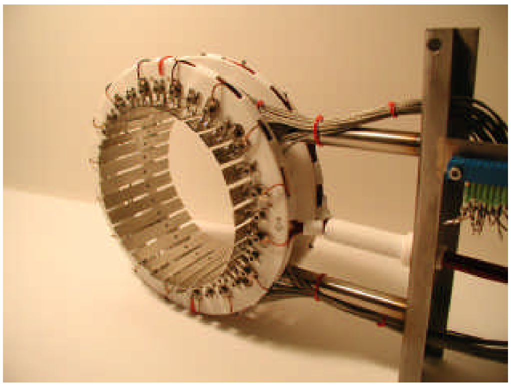
Recently, the CASTOR tokamak (R = 0.4 m, a = 0.085 m, B_t = 1 T, I_p = 5-10 kA) was equipped with a full poloidal array of 32 plane electrodes (see Fig.1) with the aim of actively controlling the edge turbulence, along the line of successful experiments performed on the linear machine MIRABELLE [1]. Two types of experiments were carried out with this equipment:

- *Passive measurements* - individual electrodes of the ring are used as Langmuir probes to investigate the full poloidal structure of edge electrostatic turbulence. The measurements are carried out both in standard Ohmic discharges and under edge biasing [2].
- *Active measurements* - a properly phased AC voltage, matching in frequency the edge fluctuations, is applied to the individual electrodes of the ring in order to try to synchronize the turbulence with it.

Here, we present some results achieved in both the arrangements, additional information is available in [3] and [4].

2. Experimental set-up

The plasma minor radius in CASTOR is usually defined by a poloidal ring limiter. However, for the present experiments the radius was reduced by the poloidal ring of electrodes down to 60 mm. This system consists of a poloidal array of 32 steel plates mounted on a support structure. Each plate, made of stainless steel, is 7 cm long in the toroidal direction and 1 cm wide in the poloidal one and equipped with a flush mounted probe. The respective position of the ring and the Last Closed Flux Surface (separatrix) is schematically shown in Fig.1.



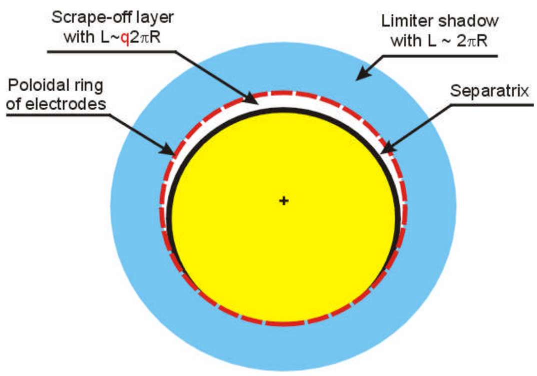


Fig. 1 Picture of the poloidal ring and its schematic position with respect to the Last Closed Flux Surface (separatrix)

In CASTOR, the plasma column is slightly shifted downward, which is apparent from the distribution of the floating potential along the poloidal ring, shown in Fig. 2. The positive floating potential measured by an electrode indicates its position in the SOL. On the other hand, the negative potential is a signature of its apparent position within the separatrix, which is the case of 10 electrodes localized at the bottom quarter of the ring. This has to be taken into account in the interpretation of data measured at this range of poloidal angles. The observed poloidal asymmetry has an important consequence: the connection length at the upper part of the SOL is significantly longer than the circumference of the torus and may reach the value q2πR, where q is the edge safety factor. The poloidal asymmetry is also confirmed independently by measurements of the radial electric field (made with a rake probe) and flow velocities (made with a Gundestrup probe [5]).

In addition to standard Ohmic regimes, the radial electric fields can be amplified in the proximity of the separatrix. For that purpose, a graphite electrode is inserted into the SOL from the top of the torus and biased positively with respect to the vacuum vessel to 100-300 V. Then, the poloidal ring of electrodes, if used as an array of floating Langmuir probes, provides unique information on the poloidal distribution of the potential at biasing. An example of such measurement is shown in Fig. 2. It is seen in the figure that only the upper part of the plasma column is biased to a potential comparable with the biasing voltage. The bottom plates remain unbiased which means that they are effectively deeper into the plasma than the electrode. It is also seen that even the upper part is not biased uniformly, since four distinct peaks are observed. Their poloidal separation corresponds to the angle of rotational transform for the given combination of B_t and I_p.

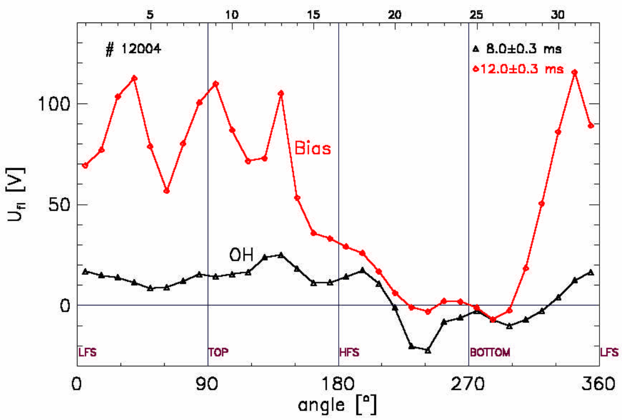


Fig. 2 Poloidal distribution of the floating potential as measured by the poloidal ring of electrodes in Ohmic (black triangles) and biased (red points) phase of a discharge.

Therefore, we interpret these peaks as a signature of the existence of a biased flux (or current) tube, which goes q-times around the torus and connects the biasing electrode with the bottom part of the grounded limiter. Consequently, *steady state poloidal electric fields* are formed. They modify locally the net radial particle flux via $E_{pol} \times B_{tor}$ drift. This particle flux is inward or outward, depending on the poloidal angle.

3. Edge turbulence at DC biasing

The edge turbulence has been investigated with the poloidal ring, by using the individual plates as large Langmuir probes. Consequently, the small size turbulent structures (with dimensions less than the poloidal extent of a plate) are spatially smoothened. Large structures become better “visible”, even by plotting the raw signals [3]. Here, we present the result of the cross-correlation analysis of the floating potential fluctuations, using a plate at the top of the torus as the reference one. The result, shown in Fig. 3 - left**,** clearly demonstrates the existence of a quasi-coherent turbulent structure, propagating poloidally with $v_\theta \sim 3$ km/s. This velocity is in agreement with the value and sign of the radial electric field at the ring position, as confirmed by the rake probe measurements. It is important to note that the observed correlation patterns are nearly poloidally symmetric.

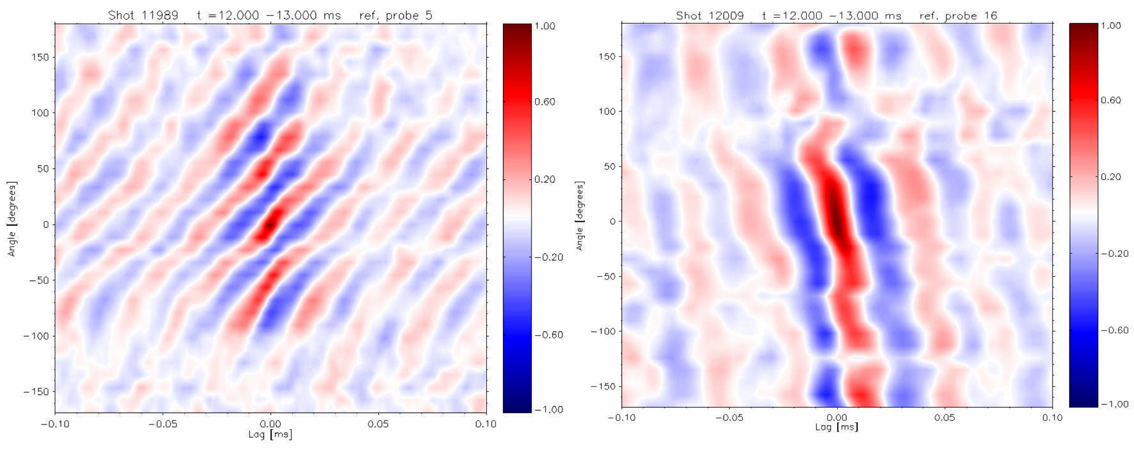


Fig 3 Spatial - temporal cross correlation function of potential fluctuations. The reference signal is taken from the plate located at the top of the torus. Left - standard Ohmic discharge, Right - discharge with edge biasing.

The striking feature is the evident poloidal periodicity of the cross correlation function, with a well-defined poloidal mode number. It is found that the dominant mode number is determined by the magnetic field helicity and is consequently equal to the value of the edge safety factor q, as confirmed by measurements in discharges with the plasma current ramping down [3,4]. A possible interpretation of this observation is that, at a given time instant, only a *single* turbulent structure, elongated along the magnetic field lines, is formed in the SOL. It starts on one side of the poloidal limiter and terminates on the other side. Consequently, its length should be equal to the connection length between the electron and ion side of the limiter, i.e. $q2\pi R$. This hypothesis seems to be supported by measurements of the toroidal correlation. The rake probe measurements show that the radial extension of the structure is comparable to the poloidal one. No mode with a similar poloidal mode number has been found by analyzing the Mirnov coils signals, therefore the observed feature seems to be de-correlated from any MHD activities.

The mode analysis, preformed in [3,4] shows also the presence of more poloidal modes (mostly with $m < q$) on a background of broadband fluctuations. So, the full picture of the SOL turbulence is evidently more complex and its understanding requires further investigations.

The structure of the edge turbulence is dramatically changed with electrode biasing, as demonstrated in Fig. 3. In this particular shot, the biased electrode is located behind the poloidal ring, which consequently happens to be in the region of a strong negative electric field. Therefore, the propagation velocity of the turbulent structure not only increases, but also reverses. As it is seen, the poloidal mode number is significantly reduced down to m = 1-2. This implies, assuming again only a single structure in the SOL, that the toroidal extension of the structure is reduced down to (1-2)*2πR. In this case, however, the turbulent structure would no longer follow a magnetic field line and its parallel wavenumber $k_{\|}$ should differ from zero. Clearly further experimental effort is needed to confirm this picture.

In contrast to poloidally localized electrode biasing, a lower DC voltage (~+20 V) is applied to the 16 plates at the upper half of poloidal ring in a second series of experiments. Measurements of the turbulent particle flux clearly demonstrate that even relatively low biasing voltages have a strong impact on the edge fluctuations, if a large part of the poloidal cross section is biased. As it is seen in Fig. 4, the local turbulent flux is reduced and, in particular, large bursts, directed outward, are suppressed during the biasing period.

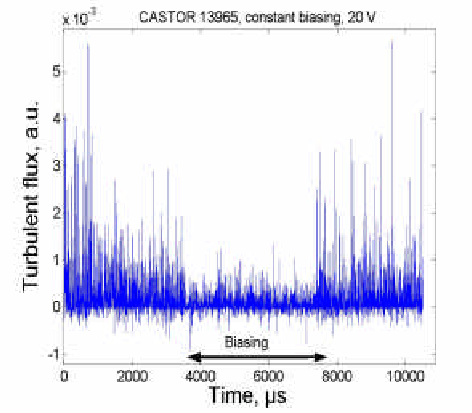


Fig. 4. Time evolution of turbulent flux in a discharge with DC biasing of 16 poloidal plates located at the top of the torus.

4. AC biasing

As a next step, an AC voltage has been applied to the plates. The existing power supply consists of 8 amplifiers, which deliver the AC voltage in the frequency range f = 10-50 kHz. The amplitude of the modulation voltage (<40 V) is comparable to the local plasma potential. A current of several amps can be drawn from each channel. In addition, a DC offset voltage (-20 - +20 V) can be used. Such equipment allows to apply a propagating wave of potential with prescribed poloidal periodicity (spatial-temporal modulation) to the ring of the electrodes.

The aim of this experiment was to provide mode selective synchronization of the edge turbulence. Therefore, the propagation velocity of the potential wave is chosen according to the relationship $\omega = k_\theta v_\theta$,.where ω of and k_θ are selected within the wave number and frequency range of the edge turbulence as determined by passive measurements. The resulting spatial-temporal structure of potential fluctuations (measured by Langmuir probes embedded in the array) is shown in Fig. 5.

The potential wave is applied to the 16 top plates of the poloidal ring and propagates in the same direction as turbulent structures. The patterns of the prescribed mode structure (m = 6) and the driving frequency f=12 kHz are clearly visible. Figure 6 documents that the turbulent flux is significantly modified in this biasing scheme. The large amplitude bursts propagating outwards are not suppressed but inward bursts are amplified, so the net flux is reduced. The reduction is mainly due to de-phasing of the fluctuations of ion saturation current I_{sat} and poloidal electric field fluctuations E_p, while their RMS values remain practically unchanged. It should be also mentioned that counter-rotating waves do not produce any reduction of the local turbulent flux.

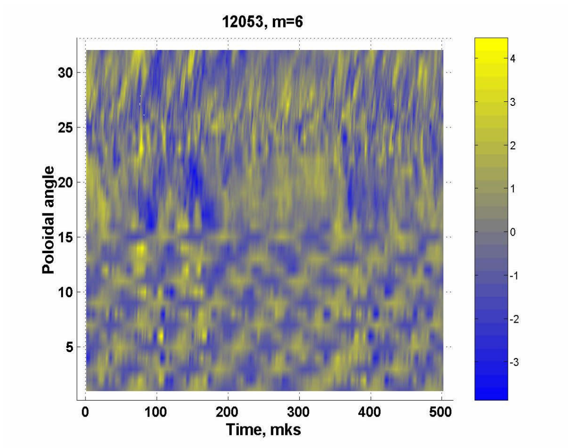


Fig. 5. Spatial-temporal structure of the floating potential fluctuations with AC biasing, , V_{amp} = 40 V, V_{offset} = 0,

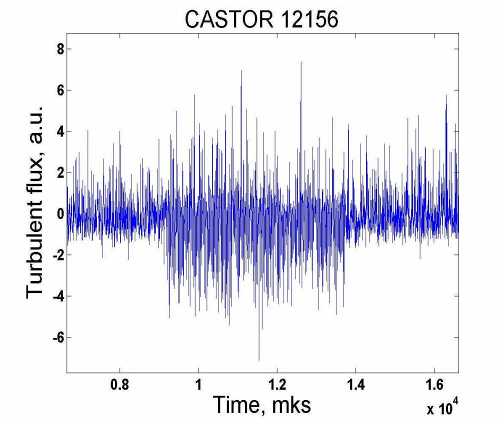
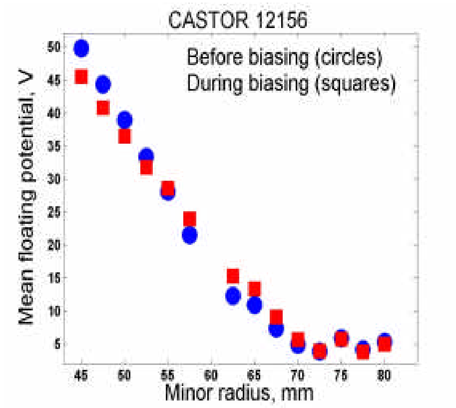


Fig. 6. Evolution of the turbulent flux in a shot with AC biasing.
V_{off} = 20 V, V_{amp} = 20 V, f = 30 kHz, m = 5

In contrast to the DC case, AC biasing does not change the radial electric field, as seen in Fig. 7, where the radial profiles of floating potential are compared. Consequently, the modification of plasma properties occurs in this case due to the interaction of oscillating fields with the turbulent structures.

Fig. 7. Typical radial profile of the time-averaged floating potential with AC biasing.



5. Summary

Several interesting features have been observed in experiments with the poloidal ring of electrodes/probes on the CASTOR tokamak:

- formation of steady state poloidal fields in the SOL, if a poloidally localized object (electrode) is inserted there and positively biased;
- a coherent turbulent structure with the poloidal mode number m≅ q is identified in the SOL, if the connection length is much longer than the circumference of the torus;
- manipulation of the SOL turbulence by DC and AC biasing has been demonstrated.

More detailed analysis of the SOL plasma, in particular at AC and DC biasing, will be the subject of future experiments with more sophisticated electronic equipment.

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