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PROBE ARRAY DIAGNOSTICS FOR SPATIALLY RESOLVED FLUCTUATION MEASUREMENTS

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We describe in this paper the first experimental investigation of the full poloidal structure of electrostatic turbulence in the tokamak edge. The diagnostic used for this work has been developed as part of a project aimed at attempting an active control of the edge turbulence, along the line of successful experiments performed on drift wave turbulence on linear machines [1]. In this paper only passive measurements are reported, both in standard Ohmic discharges and under edge biasing performed with an insertable electrode.

The experiments have been carried out on the CASTOR tokamak in Prague. CASTOR is a small size tokamak with a major radius of 0.4 m and a minor radius of 0.1 m. In the present campaign it was operated with a 1 T toroidal magnetic field and a plasma current of 8 kA. Usually, the plasma minor radius in CASTOR is 85 mm, and is defined by a poloidal ring limiter. However, for the present experiments the radius was reduced to 58 mm by an additional poloidal ring limiter. A poloidal array of electrodes and probes was used for the measurements. This system, which is shown in fig. 1, consists of a poloidal array of 32 steel plates mounted on a support structure. Each plate is 7 cm long in the toroidal direction and 1 cm long in the poloidal one. All plates are isolated from each other, as well as the probes embedded in them. The radius of the array is 61 mm, so that it was nominally located in the Scrape Off Layer (SOL). However, due to a plasma column downshift of 6-7 mm, the bottom part of the array (located around $\theta = 270$ degrees in the coordinates used) was indeed touching the Last Closed Flux Surface (LCFS). Either the plates or the probes have been used to measure the floating potential, without any appreciable difference in the results. The signals have been sampled at 1 MHz. The poloidal array was supplemented by a rake probe inserted from above. This is made of 16 pins with a pin-pin distance of 2.5 mm. The rake probe was also used to measure the floating potential at a 1 MHz sampling rate, so as to gather information on the radial structure of the observed fluctuations. In all cases, a moving average

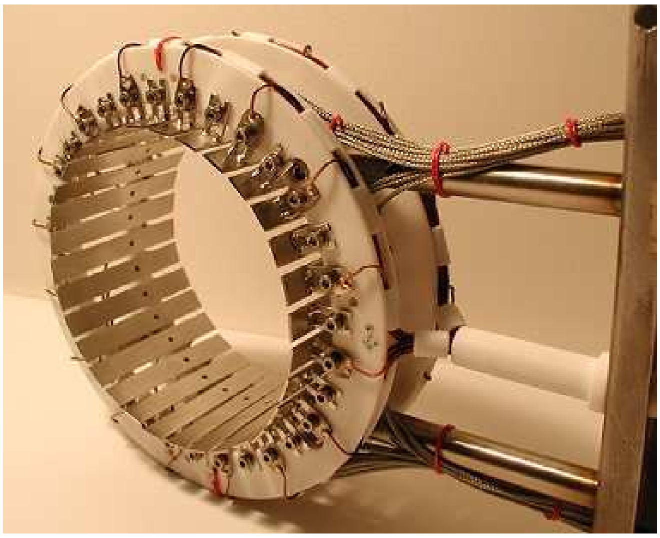
Fig.1: Poloidal array of electrodes and probes.

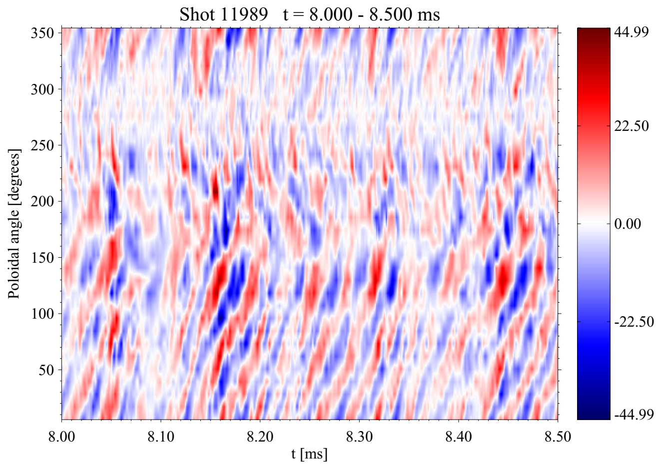

Fig. 2: Floating potential fluctuations plotted as a function of time and poloidal angle.

with a sliding window of width 51 samples is computed on each signal, so as to obtain the slow trend due to the discharge evolution. The result is then subtracted from the signal itself, so as to obtain the fluctuating component.

The typical behaviour of the edge electrostatic turbulence as measured by the system described above is shown in fig. 2. In this graph, which shows floating potential fluctuations as a function of time and poloidal angle, it is possible to see over most of the poloidal circumference a wave-like behaviour, with a dominant mode number and a period of 30 μs. The wave amplitude is not constant, but is modulated with a typical period of 100-150 μs. The phase velocity is around 2 km/s, consistent with the **E**×**B** plasma flow. It is important to observe that the observed pattern persists also on the high field side (around $\theta = 180°$), so that the fluctuations do not show a ballooning character. Indeed, the main poloidal asymmetry is due to an attenuation of the fluctuations in the bottom region of the torus (around $\theta = 270°$), where the poloidal array touches the LCFS. It is worth noting that in the bottom region a propagation in the opposite direction than in the rest of the torus can be sometimes observed. Again, this suggests that this part of the ring lies on different flux surfaces.

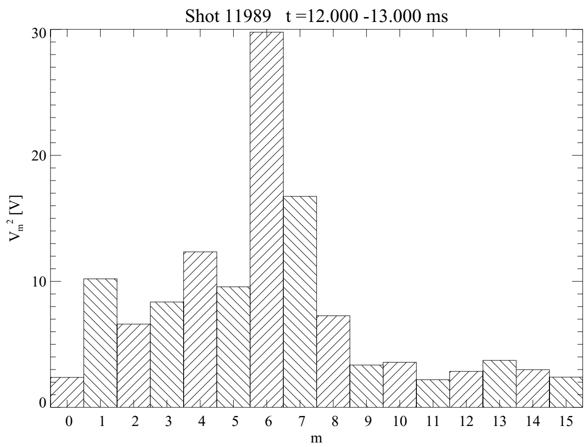

Fig. 3: Time-averaged poloidal mode spectrum.

A poloidal Fourier analysis of the data shown in fig. 2 has been performed, and an histogram of the resulting time-averaged mode amplitudes is shown in fig. 3. As it was apparent to the eye, a dominant mode, namely the $m = 6$ mode, is found. Other modes are also present, although it is important to bear in mind that the downward shift of the plasma certainly causes a blurring of the real spectrum that would be measured if the probes were all on the same flux surface. By defining a noise level as that observed on the last part of the spectrum, it is possible to state that modes from $m = 1$ to $m = 8$ are found, with dominance of $m = 6$.

A simple interpretation concerning the dominant mode number stems from the fact that CASTOR is typically operated with an higher value of the safety factor at the edge q_a than normally used in other machines. In particular, in the experiments under study the q_a value was around 6-7. This would imply that the edge safety factor at the edge determines the dominant poloidal wavenumber. In order to test this conjecture, some experiments with a ramping-down plasma current have been carried out. In these shots the q_a value increased with time. In fig. 4

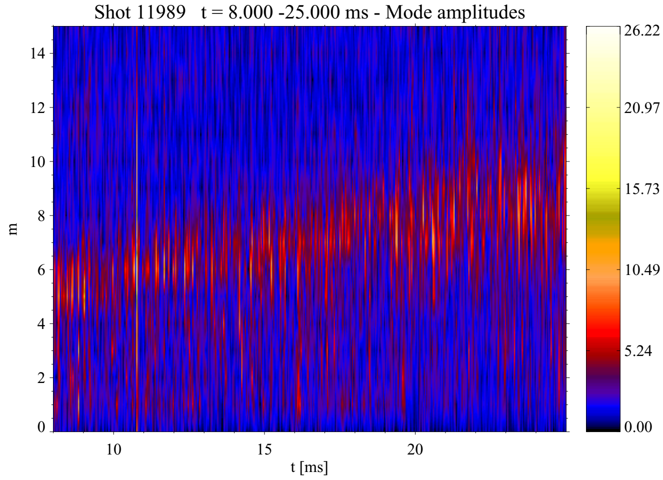

Fig. 4: Time evolution of the mode amplitudes in a discharge with ramping-down plasma current.

the amplitude of all the modes as a function of time and of mode number is shown for one of these shots. During the same time interval, the q_a value increased linearly from 4.5 to 8. It is clearly seen that the peak in the spectrum changes together with q_a. This confirms that the peak is given by the mode which is resonant near the plasma surface.

An important question to be raised is whether the relatively coherent activity observed with the poloidal array of probes is related to some MHD phenomena taking place into the plasma. For this reason, the signals of a poloidal array of 16 Mirnov coils placed on the poloidal plane of the machine have been sampled and analyzed during some of the discharges of this campaign. These data showed a spectrum dominated by an m = 1 or m = 2 mode, a behaviour already seen in CASTOR (at least for the m = 2 case) [2]. No clear trace of the edge-resonant mode found with the electric probe was found, indicating that the instability giving rise to the observed waves is electrostatic in nature. On the other hand, the mode measured by the Mirnov coils is similar in frequency, wavenumber and propagation direction to the pattern sometimes observed on the probes of the poloidal array located on the bottom side of the torus. This suggests that near the LCFS large scale MHD-driven fluctuations might be the dominant feature.

The simultaneous analysis of the data given by the poloidal array of probes and by the radial one, allows one to visualize the radial structure of the observed fluctuations. An example is shown in fig. 5, where the top panel displays the data of the poloidal array, as in fig. 2, and the bottom panel displays the signals measured with the radial array, as a function of time and radial position. The dashed line in the top panel marks the position of the rake probe, while that in the second panel shows the radial position of the poloidal array. The general observation which can be made is that the wave fronts observed on the poloidal array have a radial extension of several centimeters. Furthermore, they appear to be inclined in the r-t plane. This might be interpreted as the effect of an outward radial propagation superposed to the poloidal one. However, previous results obtained in the

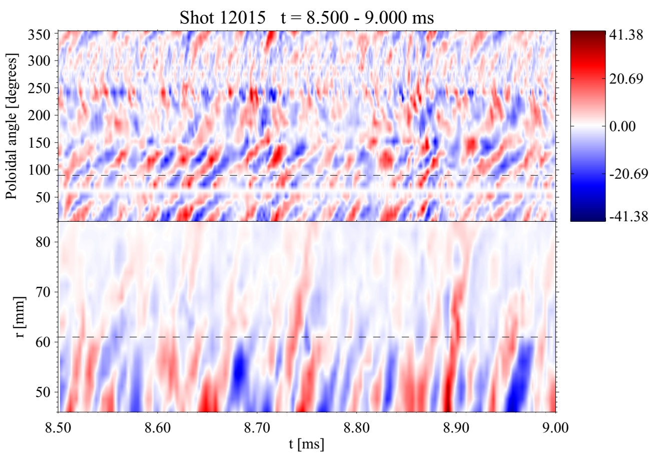

Fig. 5: Top: floating potential fluctuations plotted as a function of time and poloidal angle. Bottom: floating potential fluctuations plotted as a function of time and radial position. The dashed lines mark the intersection of the two arrays.

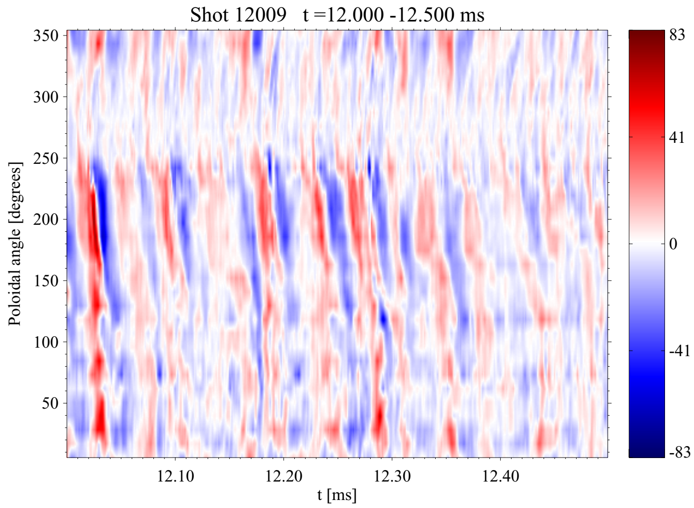

Fig.6: Floating potential fluctuations, plotted as a function of time and poloidal angle, during edge biasing.

same machine with a 2D array of 8 by 8 probes placed on the poloidal plane did not show any radial propagation [3]. Indeed, these measurements displayed the presence of coherent large scale structures propagating poloidally. The present results show that such structures were nothing else than the peaks and valleys of the wavefronts. Concerning the interpretation of the rake probe data, it seems likely that a periodicity is present not only in the poloidal direction, but also in the radial one, with a typical wavelength of the order of 1 cm. It is also interesting to observe the attenuation of the fluctuation level outside the surface delimited by the poloidal array.

An edge biasing experiment was carried out while the poloidal array was mounted on the machine. An insertable graphite electrode, which has been described elsewhere [4], was inserted from above to the position $r = 58$ mm, i.e. at the same position as the ring limiter and 3 mm beyond the poloidal array. The electrode was used to bias the edge with a voltage of +150 V (the reference is the vacuum vessel). It is well known that edge biasing may modify the radial structure of the $\mathbf{E}\times\mathbf{B}$ flow, with the result of generating a velocity shear which can reduce turbulent transport. A typical example of the edge biasing effect on the poloidal array measurements is seen in fig. 6. The wave structure is radically changed: the edge-resonant wave is suppressed, while an $m = 1$ mode appears. This mode propagates in the opposite direction compared to the previous one. This $m = 1$ mode appears to be similar to the fluctuations sometimes observed in standard conditions in the bottom of the torus, where the poloidal array touches the LCFS. Thus, a possible interpretation is that the edge biasing shifts the LCFS, so that most of the array comes closer to it, and measures the MHD-driven mode present in its proximity.

In conclusion, we have shown that the SOL of CASTOR features quasi-coherent electrostatic waves with a dominant mode number equal to the edge safety factor. A possible explanation for this mode number is that the parallel connection along the magnetic field lines acts so as to select this preferred periodicity. In any case, the similarity between these observations and the drift waves measured in linear machines [1] looks promising for the implementation of active control techniques in the CASTOR edge.

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