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Experimental investigation of plasma structure dynamics in a rotating magnetized plasma

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The role of bursty structures out of the background turbulent state in magnetised plasmas has received much attention in recent years. Plasma density blobs, possibly contributing to the anomalous transport transverse to the magnetic field have been extensively documented in several magnetised plasmas, including tokamaks [1], reverse field pinch [2], stellarators [3], magnetised tori [4] and different linear devices [5]. Here we present experimental results on the spatio-temporal evolution of structures which develop in the edge region of a rotating column of plasma.

In the Mistral device a diffuse plasma can be produced in a cylindrical vacuum chamber (1.2 m long, 0.4m diameter) by a nearby multipolar source, operating an argon discharge at low pressure by hot tungsten filament emission. Details on the experimental setup can be found in a recent publication [6]. The plasma column, here restricted to 14 cm in diameter by a limiter made of a grounded metallic diaphragm, is longitudinally uniform and sharply defined at the edge. The plasma column ends on a metallic plate, which could be independently biased to change the collected fluxes. Inside the column it is possible to induce a potential well in the poloidal cross-section which appears almost symmetrical around the cylinder axis, so producing an ExB rotation of the central plasma. Rotation rate can be modified by changing the depth of the potential well. Here it has been achieved by changing the end plate bias.

Averaged and fluctuating plasma parameters in the quiescent and in the turbulent state have been measured by means of Langmuir probes made of shielded cylindrical tips (length 4 mm, diameter 0.5 mm). By changing the bias, the average shape and amplitude of the plasma column is almost unaffected, as it is displayed in Fig. 1, while the rotation frequency f can be varied between 2 and 20 kHz. At high rotation speed, regular plasma state has been discovered with a rotating spiral structure corresponding to m=2 and m=1 poloidal states [7]. Decreasing the angular velocity a transition to a turbulent state is observed. It is also worth to notice that the density gradient peaks in correspondence of the limiter position, while mean floating potential profiles are approximately parabolic inside the limiter leading to an almost rigid body rotation of the central plasma column. On the other hand, the floating potential profile flattens behind the limiter. It is important to note that the argon ions are poorly magnetized because the magnetic field is below 0.02 T. In this situation, the instability leading to the turbulent state cannot be described by a simple Kelvin-Helmholtz model. The flute modes appear to be the nonlinear stage of the instability described early by Mikhailovsky and Chen [8]. The fact that the ions drift at an angular frequency close to the cyclotron frequency in a small cylinder combined with the large radial excursion of the ion across the shear layer during their cyclotronic trajectory leads to a slower drift of the ions compared to the electrons. In return, a poloidal electric field is created inside the density perturbations at the edge of the plasma column leading the radial convection of the structures. This electrostatic mechanism is the reason for the recorded violent destabilization of the system that could not be achieved in a classical Kelvin-Helmholtz situation. An inspection of the electron saturation current time series recorded in the region outside the limiter shows the appearence of intermittent pulses very large with respect to the mean values there. These correspond to large plasma density blobs appearing in the almost empty edge region.

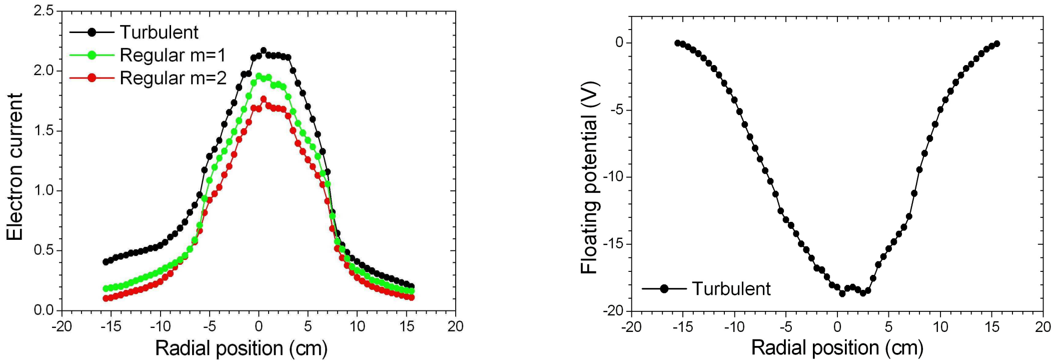


Fig. 1 Radial profiles of the mean electron saturation current (left) and of the floating potential (right).

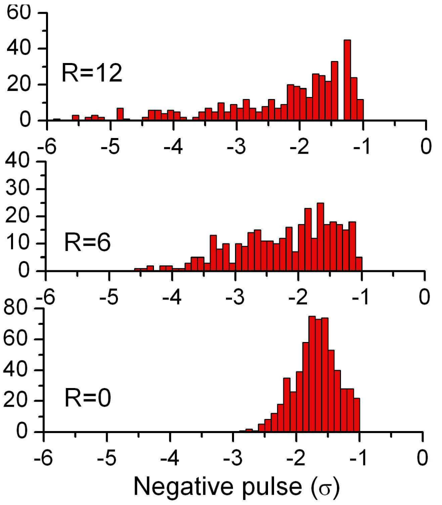
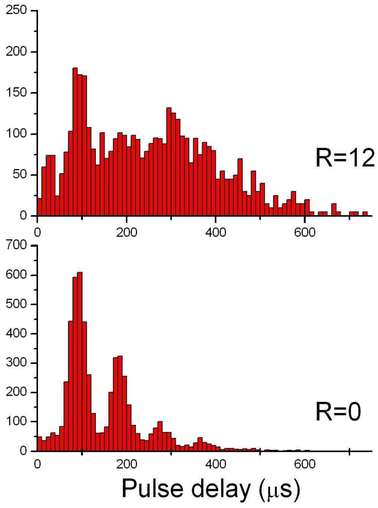


Fig. 2 – PDF of the negative pulse amplitude (left) and of the delay between subsequent pulses (right).



On the other hand, in the internal region, fluctuations appears to be smaller and with a more regular, oscillating and quasi-periodic pattern. A few data displaying such character of the fluctuations is shown by the PDF displayed in Fig. 2.

An enhanced conditional sampling analysis has been performed in order to study the spatio-temporal evolution of structures in the turbulent regime [6]. The selection and averaging of an hundred time windows (500 us long) out of the recorded time series has been performed automatedly requiring that a well defined pulse pattern happens in the reference probe time series. This leads to a sharper definition of the structures and to a reduced smearing, drawbacks partially affecting conditional sampling analysis [9]. The results of the conditional sampling analysis for a discharge operated at a pressure of 8.5 10^{-3} Pa is shown in Fig. 3. Time step was 1 μs and space resolution was 2 cm. Here the reference probe was located in the very edge region (at 14 cm from the centre, 7 cm away from the limiter shadow).

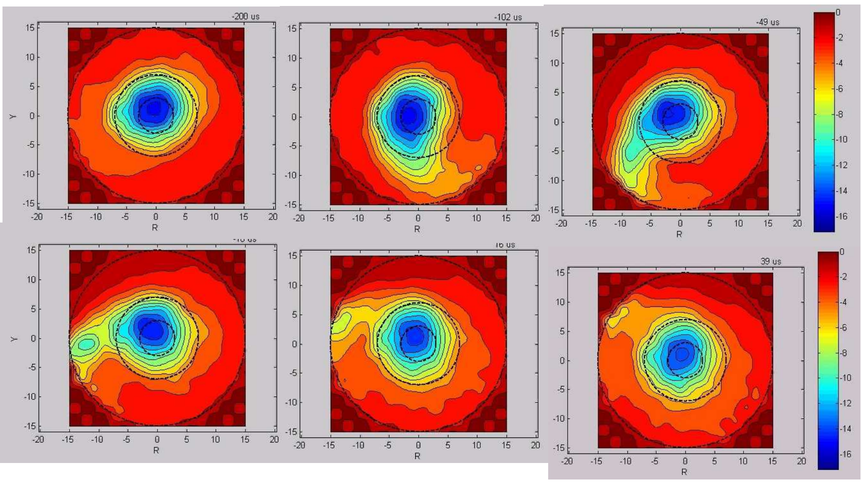


Fig. 3 – Conditionally sampled electron saturation current distribution in the poloidal cross-section. Plots correspond to delays of -200, -100, -50, -10, +15, +40 μs respect to the trigger in the reference probe.

A rotation of the whole plasma column (with approximately a 300 μs period) could be grasped from the slightly eccentric motion evidenced also by the wandering of the plasma column peak. However the most striking feature is the development of a tail of plasma out of the central column. The tail extends radially outwards and bends evolving along a spiral trajectory around the column. The bending results in the formation of a spiral arm that could be understood as due to a rotation velocity decrease outside the limiter radius. The tail breaks and a plasma blob fades away after reaching the walls, a picture strongly suggesting that plasma could be radially convected to walls inside such a structure.

To circumvent the drawbacks of conditional sampling analysis, imaging of plasma in the Mistral device was developed. Pictures have been obtained with an ultra-fast intensified gated camera (4 QuickE, Stanford Computer Optics). Preliminary results show that the correlation with the findings obtained from electrostatic probe diagnostics is quite encouraging. This was demonstrated studying the regular m=2 flute mode [7]. The signal from the reference probe was used to trigger the passage of the spiral arm in the edge region and to start an adjustable delay of the gated camera (10 μs exposure time). In this way several frames (12x10 cm) of the plasma column edge have been recorded and shown in Fig. 4. There is a clear evidence of the structure rotation and the spatial structure is in fair agreement with that reconstructed from the conditional sampling. It should be noted that for the first time, a low frequency mode is directly seen in a magnetized plasma column. Further developments are in progress in the case of the turbulent regime. The development of these techniques can be envisaged in the case of the turbulence studies at the edge of tokamaks in order to get a better understanding of the anomalous transport in these devices.

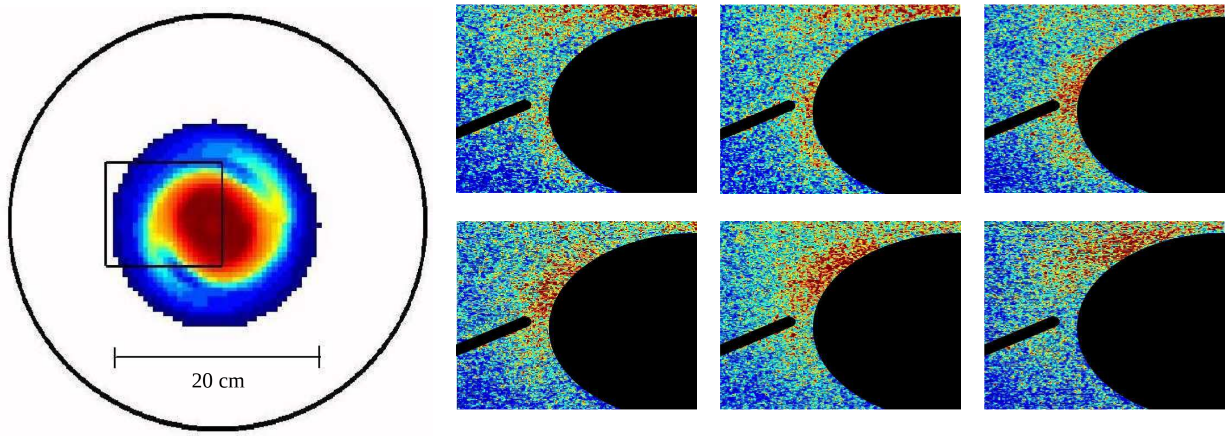


Fig. 4 – 4QE pictures of the edge region of the plasma column (each frame delay is increased by 10 μs).

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