Edge features of RFX-mod experiment operated in tokamak configuration

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The RFX-mod experiment is a fusion devoted device mainly operating as Reversed Field Pinch (RFP), with a major radius R= 2 m, and minor radius a = 0.459 m, with a first wall fully covered by graphite tiles. The high versatility of the device recently allowed to operate also in a Tokamak configuration, in such a way that a switch from one magnetic configuration to the other one can be rather easily provided. The new magnetic configuration obtained is a circular ohmic tokamak with limiter, and allows the unique possibility of comparing two different configurations, namely the RFP and the tokamak, in the same device [1]. Scope of the present contribution is providing the first characterization of the edge region in this new operation mode in term of average profiles of flow, parallel to the local average magnetic field and on cross-field plane. Measurements are performed by inserting, up to r/a = 0.91, probe heads combining electrostatic and magnetic measurements, so that beyond standard electrostatic parameters also direct measurement of parallel vorticity and parallel current density fluctuation features are provided. A representative tokamak shot of the series subject of the present analysis is shown in fig. 1. The maximum plasma current, I_p, is 150 kA, and the toroidal magnetic field at edge is about 0.53 T. The electron density, n_e, is in the range 0.5 ÷1.3 $10^{19}m^{-3}$. It is worth noting that during the shot shown in fig.1 insertable probes were placed deep into the plasma at r/a = 0.92 corresponding to about 40 mm insertion, without evidencing significant perturbation on the main plasma parameters. Thanks to a feedback controlled I_p [2], it was possible exploring during the same discharge a variable plasma

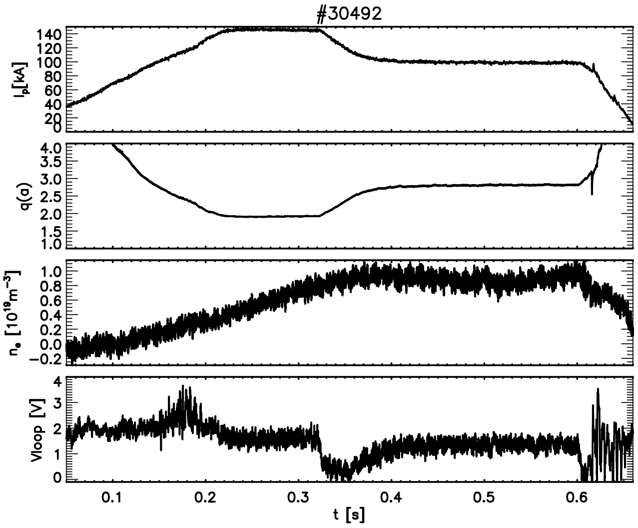

Fig. 1 General discharge parameter time behavior for a typical RFX-mod tokamak shot used for the present analysis. From top to bottom panels: plasma current, I_p; edge safety factor, q(a); electron density, n_e; loop voltage, V_{loop}.

equilibrium and in particular two “flat-top” phases can be easily identified, corresponding to a q(a) = 2, from 220 to 320 ms, and q(a)=3, from 400 to 550 ms in this case.

The different components of the plasma flow at the edge and their shear are obtained by combining and comparing information provided by two insertable probe systems, placed 30° toroidally apart from each other. The first one, dubbed “U-probe”, placed at φ=217°30’ consists in a probe head including 2D arrays of both electrostatic and magnetic sensors. Simultaneous measurements of electrostatic quantities, such as radial profiles of plasma density, electron temperature, T_e, E×B flow and magnetic fluctuations are provided [3]. For the shot series used in the present analysis the probe was turned by 90°, with respect to the usual RFP configuration, in order to maintain the 2D arrays in the cross-field plane also in the tokamak discharges, in particular concerning the electrostatic pins a 2D array of floating potential was available, without local measurements of density or temperature. The second system is a Gundestrup probe head [3], placed at φ=247°30’, equipped with 8 directional pins located on a 23 mm diameter circle perpendicular to the radial direction, which allows obtaining the evaluation of both parallel, M_{par}, and perpendicular, M_{perp}, Mach numbers at a given radial position. This probe has been used with all the pins measuring floating potential, V_f, and the flow has been reconstructed according to the relationship $V_f=V_p - T_e \ln(I_{es}/I_{is})$, where V_p is the plasma potential and I_{es} and I_{is} are the electron and ion saturation current respectively [2,4]. All signals are digitally sampled at a frequency of 5 MHz so that high time resolution measurements are obtained.

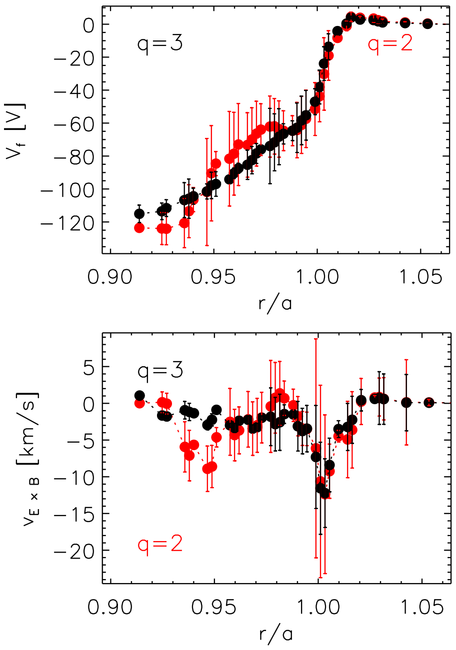

Fig. 2 Average radial profiles of floating potential, V_f (top panel) and of poloidal component of E×B flow (bottom panel). In both cases the average profiles obtained during the standard q(a)=3 phase (black dots) and during the q(a)=2 phase (red dots) of discharge are compared. Measurements from U-probe.

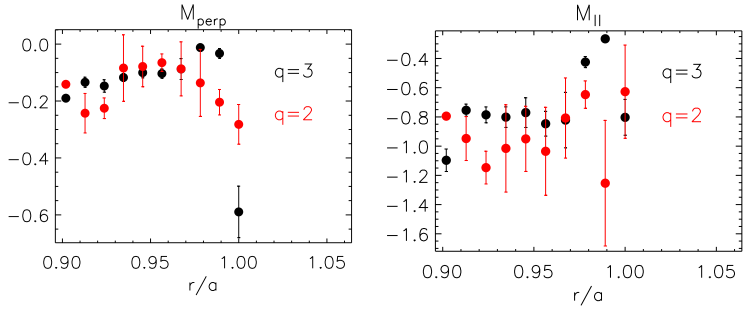

Fig. 4. Perpendicular and parallel Mach number. Measurements from Gundestrup probe.

Measurements are performed by inserting probe heads up to r/a = 0.91 and radial profiles of different quantities are obtained on a shot-to-shot basis. In fig. 2 are shown the average radial profiles of floating potential, V_f, and of the poloidal component of the E×B flow, $v_{E\times B}$, as obtained in the approximation of $\nabla_r V_p \approx \nabla_r V_f$.

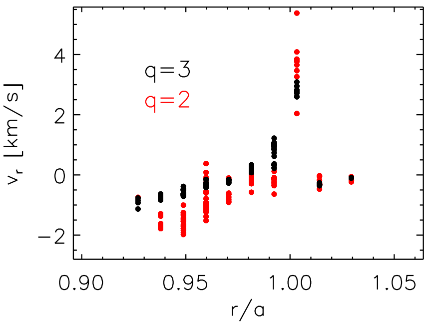

Fig. 3 Average radial profile of E×B flow radial component. The q=2 (red dots) and q=3 (black dots) phases of discharge are compared.

The radial variation of V_f detected in the edge region reflects on a strongly sheared, up to 10^6 s^{-1}, edge radial profile of the poloidal $v_{E\times B}$, with a double sheared layer structure, similar to the one detected in tokamak experiments (see for instance [5]). In fig.2 the average profile of both quantities during the q(a)=2 phase is compared (red dots). It can be observed that the double shear layer in the very edge is quite similar in the two equilibria explored, however during the q(a)=2 phase a further double shear is observed at r/a<0.94. As for comparison in fig. 3 the radial component of E×B flow, v_r, is shown. As expected it is much lower than the poloidal one, but also in this case the two equilibria exhibits similar profiles except for the inner region. The q(a)=2 and q(a)=3 phases were investigated also with the Gundestrup probe, which can provide information on (poloidal) M_{perp} and M_{par}, Mach numbers. Results are shown in fig. 4. It has to be pointed out that M_{perp} and poloidal $v_{E\times B}$, values cannot be directly compared given that local measurements of ion sound velocity, c_s, was not available, however the M_{perp} radial profile reveals a trend similar to the one described for $v_{E\times B}$, including the additional double shear layer characterizing the q(a)=2 phase, at the inner position. An analogous behavior, even if less clearly evident, can be observed also in the M_{par} profile.

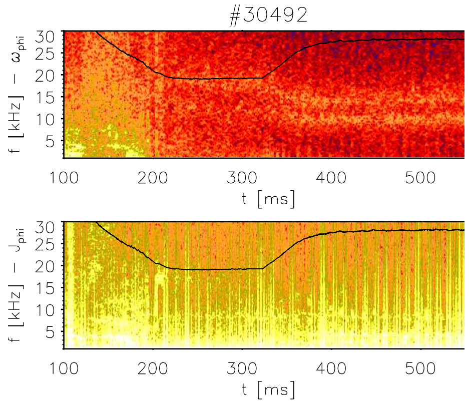

Fig. 5 J and omega spectrograms, the time trace of q(a) is also show (black line), measured at r/a=0.94(?).

In order to gain insights on possible reasons for the difference of the flow radial profiles during q(a)=2 and q(a)=3 phases, single shot analysis of the transition was carried out. An example is given in fig. 5 where the spectrograms of parallel current density, J_{phi}, and parallel vorticity, ω_{phi}, are shown. These quantities are measured directly by the U-probe [6] and can be considered as representative of local magnetic and electrostatic cross-field patterns respectively. The two spectrograms reveal the presence of common modes during the discharge, that seem related to the time evolution of q(a) (black line) and clearly recognizable in particular during the q(a)=3 and q(a)=2 phases. More specific details can be obtained through the mode analysis, thanks to the sensors of the ISIS system [7]. To this scope a complete poloidal array of 8 magnetic coils measuring radial magnetic field fluctuations was used for distinguishing the presence of modes with different poloidal number m. As expected the m=2, n=1 mode dominates the phase at q(a)=2, see fig. 6. In the same figure the radial electric field, and ultimately the poloidal $v_{E\times B}$, measured at two different radial positions is shown. It is interesting to note that a clear correlation is observed between the m=2 peaks and the E_r minima, only for the deepest measurement, corresponding to the radial region of the second double sheared layer (see fig. 2). This result provides then information on the radial region of the plasma where the mode affects the flow profiles.

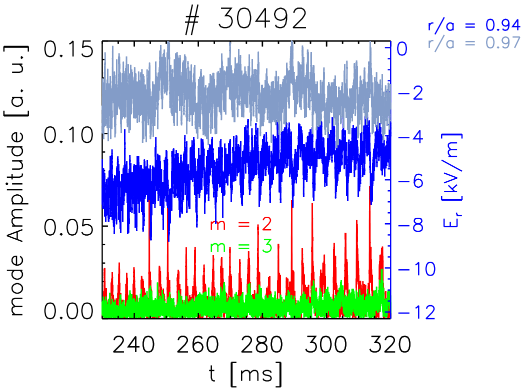

Fig. 6 Time behaviour of (m=2, n=1) mode during the q=2 phase of discharge, compared with the corresponding time series of the radial electric field measured at r/a=0.94 and r/a =0.97.

Summarizing a first characterization of 3D flow edge radial profiles obtained on RFX-mod, operated as a tokamak, was carried out. By exploring different plasma equilibria, it was found that the presence of m=2 mode affects the flow topology around a limited radial region at edge.

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