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Edge effects of dynamically shaped tokamak configuration in RFX-mod experiment

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The RFX-mod experiment is a fusion oriented device designed as Reversed Field Pinch, 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 allows operating the machine also as a Tokamak, in such a way that a switch from one magnetic configuration to the other one can be rather easily provided and allows the unique possibility of comparing two different configurations, namely the reversed field pinch and the tokamak, in the same device. The new magnetic configuration obtained is basically a circular ohmic tokamak, but recently the dynamical control of the plasma column shift and ellipticity become available within a single discharge. In order to afford the challenge of an effective MHD mode control also in the tokamak configuration and in the perspective of performing operation beyond the circular shape also with single or double-null D-shaped plasmas, a new system for control of plasma position and shape was designed and commissioned [1].

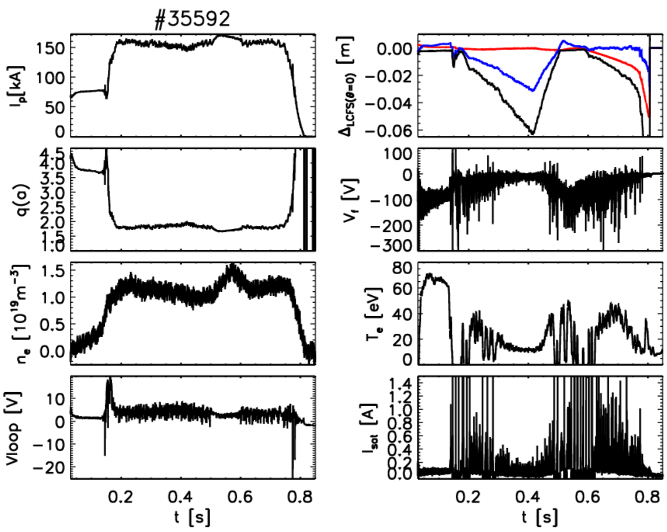

Fig.1 Main plasma and edge (r/a=0.95) parameters time evolution of the representative shot #35592.

The system performance was simulated by a finite element 2D MHD equilibrium code MAXFEA, in order to meet the specification requirements.

Aim of this contribution is to provide a characterization of the edge region in this new operation mode to be used as a starting point for the next tokamak configuration that will be available at the RFX-mod in the next future. Edge measurements are performed by inserting, up to r/a = 0.91, probe heads from the Low Field Side (LFS) combining electrostatic and magnetic measurements. Specifically the data presented here are provided by the probe dubbed U-probe [2], equipped with 2D arrays of both electrostatic pins and 3-axial miniaturized magnetic coils placed in the cross-field plane. The probe insertions on a shot-to-

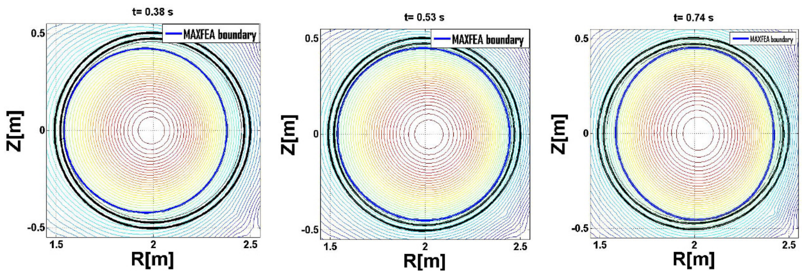

Fig. 2 Boundary equilibrium reconstruction at three time instants of the shot #35592: the LCFS shape and position is evidenced by the blue curve.

shot basis and the modulation of LCFS position, by active control of the plasma shift and ellipticity, can be combined in order to explore the SOL region and the position of the LCFS. The typical time evolution of the main discharge parameters are represented in fig.1: apart from the setting up phase the flattop average plasma current, I_p, is maintained at 150 kA, corresponding to an edge safety factor q(a)~2; the average core density within the considered dataset is in the range 1.2÷1.5 10^{19} m^{-3}. These discharges were used as a basis for the application of a controlled shift waveform; in this case from t=200 ms the plasma column was gradually shifted towards high field side (hfs) up to 3 cm, then centered back at t=500 ms (blue curve); a second phase of plasma column modification was applied starting from 550 ms, this time the plasma ellipticity was modified (see red curve), inducing the LCFS shrinking the plasma column at the equatorial plane, while elongating it vertically. The total displacement of the LCFS from the first wall (r=a), at the equatorial plane θ=0, Δ_{LCFS}, is shown by the black curve in the top right panel of fig.1. The edge consequences of these plasma column modifications were monitored by the insertable probes. In particular the local measurements of some edge plasma parameters are shown in the remaining panels of fig.1. The time evolution of the local (r/a=0.95) plasma parameters such as the floating potential, V_f, the electron temperature, T_e, and the ion saturation current I_{sat}, as representative of the behavior of the plasma density, n_e, are shown. A clear modification of both average values and their respective fluctuations is observed corresponding to the modulation of Δ_{LCFS}; in particular an absolute value reduction on all averaged measured quantities is observed at t=0.4 s, i.e in the close proximity of the larger imposed shift towards the

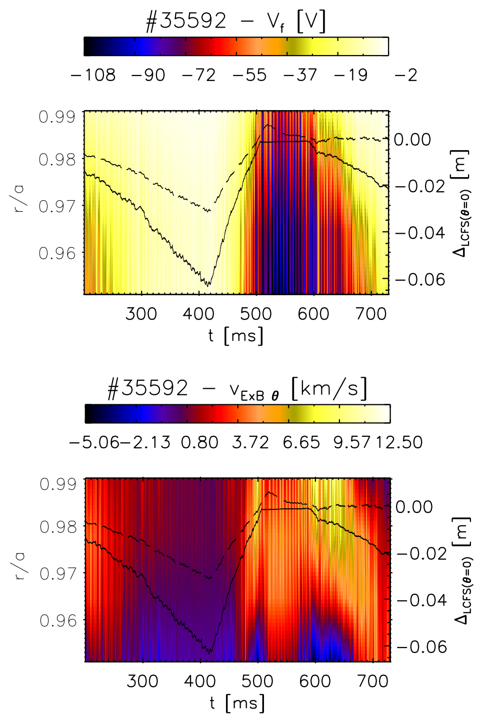

Fig. 3 Time evolution of $V_f(r)$ and $v_{E\times B}(r)$ radial profiles, compared with the corresponding plasma shift (dashed line) and Δ_{LCFS} at the probe insertion.

hfs. Strong peaks (I_{sat}>1.4 A) on the I_{sat} measurement around 0.2 and 0.6 s, are related to the probe electronics self-protection system. In order to provide a better idea of the plasma column modifications applied during the representative shot of fig.1, the real time reconstruction of the flux map on the poloidal section was calculated by the 2D equilibrium code MAXFEA [3].

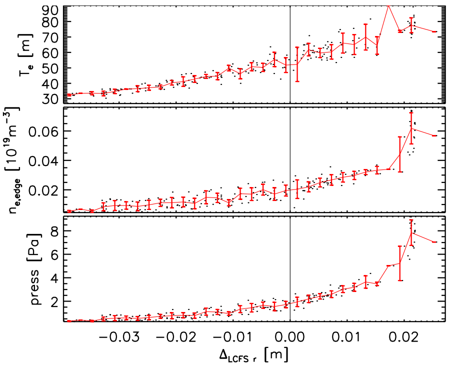

Fig.4 Reconstruction of edge radial profiles vs Δ_{LCFS}

A direct representation of the LCFS shape and position is shown in fig. 2, where its time evolution corresponding to a selection of the most significant time instants is shown. From left to right panels of fig.2 the condition of maximum shift towards the hfs (t=0.38 s), the rest position (t=0.53 s) and the maximum applied ellipticity during the flattop (t=0.74 s). In fig.2 the inner black circle represents the first wall position, r=a, whereas the inner blue curve represents the plasma column boundary. The Δ_{LCFS} at the probe location is then the essential information for the edge measurements interpretation. The investigation of the edge region radial profiles was based on measurements by probe heads inserted from the lfs, and different probe insertions and radial arrays of pins were exploited and combined with the active modification of the plasma column. In fig.3 an example of the time evolution of the radial profile of V_f, as measured by the U-probe is shown. The pins used are 4 in this case and radially spaced by 6 mm, so that the measurements cover a radial region of 18 mm, however the plasma column movements allowed an even larger exploration of the Scrape off Layer (SOL) transition region. A modification of the V_f radial profile during the discharge is evident. The time traces related to the plasma boundary and described in figure 1 are superimposed on the $V_f(r)$ time evolution, thus providing a direct comparison between the two quantities: a clear correlation is then evidenced both during the shift modulation phase and during the applied ellipticity shaping: similar $V_f(r)$ profiles are observed for analogous relative positions of the LCFS with respect to the measurement points. In figure 3 (right) an analogous picture shows the time evolution of the radial profile of poloidal flow, $v_{E\times B}(r)$, confirming that the modulation due to the moving position of the plasma boundary affects also this quantity. As mentioned before, the extent of radial profile accessible by this experiment around the LCFS is much larger that of the available probes array. A further extension is provided by comparing similar discharges with different insertion of the probe head. The average radial profiles of edge parameters can then be obtained throughout the transition from the SOL to the confined edge plasma.

Figure 4 shows the radial profiles of n_e, T_e and electron pressure with respect to Δ_{LCFS}, the radial position of the LCFS at the probe poloidal location, θ=0. The profiles are obtained as average on 10 ms time intervals taken during the plasma current flattop, focusing on the shift-moving phase, and further averaging on several analogous discharges, on corresponding relative position Δ_{LCFS}. The radial profiles of the different plasma parameters exhibit an increasing trend moving from the outside to the inside confined plasma, i.e. towards $\Delta_{LCFS} > 0$, as expected, confirming the reliability of the adopted method. However it is worth noting that some limited variations in the main plasma parameters, such as the core density, can also play a role on the time evolution shape of the radial profiles, so that a larger statistics could help in corroborating these results.

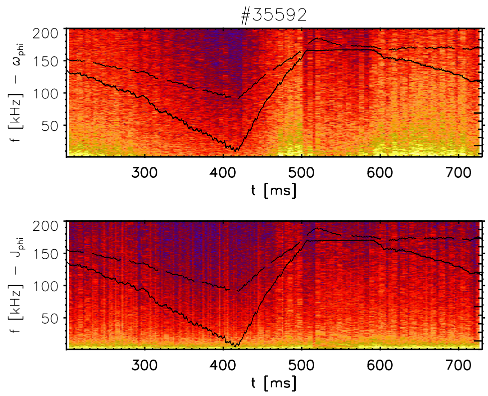

Fig. 5 Spectrograms of parallel vorticity and current density at r/a=0.96, compared with the corresponding plasma shift (dashed line) and Δ_{LCFS} at the probe insertion. Color scale from blue to yellow.

Further information achievable for this experiment regards the fluctuation level of edge parameters as a function of Δ_{LCFS}. An example of the behavior of both electrostatic and magnetic fluctuations is shown figure 5. In particular the availability in the U-probe of the suitable arrays of electrostatic pins and of tri-axial magnetic coils was exploited in order to obtain the local fluctuations of vorticity, $\omega_{phi}=\nabla\times\delta v$, and current density, $J_{phi}=\nabla\times\delta B/\mu_0$, parallel to the main magnetic field [4]. The respective spectrograms are clearly correlated with the time evolution of the plasma column boundary, in particular the strong reduction of the highest frequency, f>50 kHz, is evident around t=400ms, where the probe head is definitely in the SOL, according to the equilibrium reconstruction (see fig. 2).

Summarizing, the edge region features of the new tokamak discharges performed in RFX-mod were characterized in the transition around the separatix and cross checked with the new tool for the active control of the plasma boundary, providing edge features consistent with the magnetic equilibrium reconstruction.

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