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Density profiles and particle confinement in the modified RFX Reversed Field Pinch

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1. Introduction

This paper presents the behavior of the plasma density in the first experimental campaigns of the modified RFX (RFX-mod) experiment and the comparison with the behavior of density on similar discharges in RFX. With respect to the previous machine, RFX-mod has a thinner and more closely fitting shell (with a time constant of 50 ms) that allows a better equilibrium control and hence a well centered plasma through the whole pulse with a lower bias vertical magnetic field. This condition facilitates the breakdown giving more operational flexibility. RFX-mod has also a new first wall. The graphite tiles fully covering the inside of the vacuum vessel have been redesigned [1] in order to reduce the highly localized plasma wall interaction on the tiles edges, with beneficial effects on density control and plasma performances in particular at high current regimes. So far, the explored operating conditions of RFX-mod have been plasma current from 200 to 600 kA and density from $8 \cdot 10^{18}$ to $5 \cdot 10^{19}$ m^{-3}. With the aim of favoring the spontaneous rotation of the magnetic modes, plasma density was kept at the lowest compatible value at each current and the 200 kA regime (only shortly probed in RFX) was explored but no spontaneous rotation was observed. The rotation, conversely, was successfully induced by mean of a rotating perturbation of the magnetic field. Density profiles have been measured with an 8-chords MIR interferometer, with maximum normalized impact parameter of 0.74 [2]. Neither edge interferometer chords nor other measurements of edge density are yet available, hence only preliminary results about density profiles are shown.

2. Density behavior

As already observed in RFX [3], the electron density at the stationary phase of the discharge is sustained by the hydrogen flux due to recycling processes at the graphite wall that acts as a hydrogen reservoir. The load level of the wall hence determines the value of density. In the case of too high density, performing some discharges with a low gas filling is effective in emptying the wall, even without resorting to active wall conditioning techniques such as Glow Discharge Cleaning (GDC). Figure 1 shows an example of wall emptying for RFX-mod. After a high density pulse (solid line in the figure) gas filling was reduced to about 35% (from $15.8 \cdot 10^{19}$ to $5.6 \cdot 10^{19}$ H_2 molecules) and then kept constant till density progressively decreased to about half the original value in ten shots. The wall emptying proved to be easier for RFX-mod than for RFX that took about twice the shots to reduce density. This is due to the flexibility of the new machine in terms of gas filling thanks to the already mentioned easier breakdown that allows to start the discharge in an extended range of filling pressures. Conversely, after a GDC some shots (of the order of five) are required to load the wall and thus to sustain density, with increasing global performances as far as density increases.

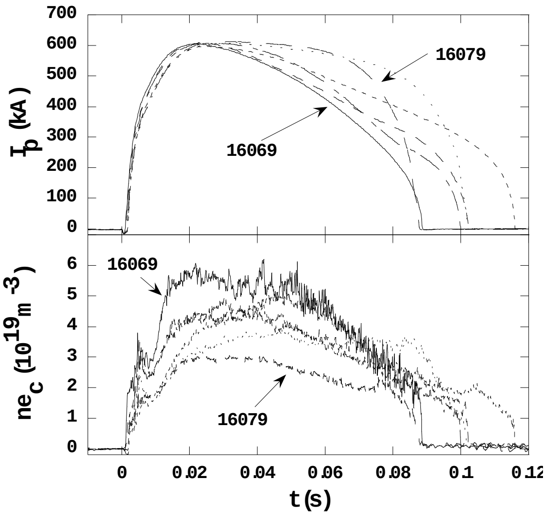

Figure 1: *Plasma current and central density for shots 16069 (solid line, filling 15.8·10^{19} H_2 molecules), 16071, 16072, 16076, 16078, 16079 (dashed lines, filling 5.6·10^{19} H_2 molecules)*

With the aim of inducing modes rotation, several experimental campaigns at plasma current I_p = 600 kA with the application of a rotating m=0 n=1 perturbation of the magnetic field have been performed. The application of the perturbation proved to be lightly detrimental for the discharges at 600 kA, resulting on shorter and worse sustained discharges, the worst when the perturbation does not succeed in rotating the modes (figure 2). The reason of the deterioration even in the case of modes rotation is still under investigation, as well as the actual effect of the perturbation on the plasma column. However the technique has been widely explored, as it will be necessarily applied when RFX-mod will be operated at higher current. Our experience with the previous machine showed, in fact, that at $I_p \geq$ 1MA a locking of the modes to the wall causes enhanced plasma-wall interactions that strongly affect the discharge. In that conditions we expect that the deterioration caused by the perturbation will be negligible in comparison to the beneficial effect of non-wall-locked modes.

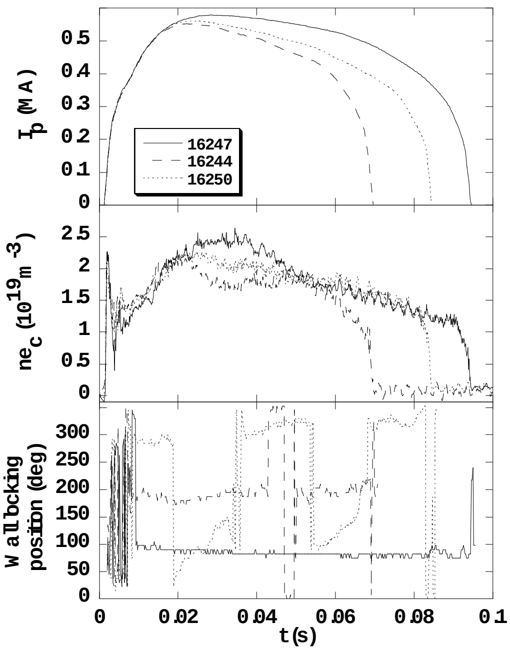

Figure2: *Example of m=0 n=1 perturbation of magnetic field. Solid line (#16247) no perturbation; dashed line (#16244) perturbation applied but no rotation induced; dotted line (#16250) perturbation applied with success.*

3. Density profiles behavior and particle confinement

The behavior of density profiles in standard (i.e. without magnetic field perturbation) RFX-mod and similar RFX discharges is compared. A set of good RFX discharges with I_p<650 kA and central density $ne_c<5.6\cdot10^{19}$ m^{-3} has been selected and data have been averaged over 4 ms centered at the maximum of I_p both for RFX and for RFX-mod. The trend observed in RFX [4] for the profiles shape with I/N (I being plasma current and N line density) is found to be valid also for RFX-mod. The shape is represented by the Peaking Factor (P_F), defined as ratio ne_c/ne_e, where ne_c and ne_e are respectively the average densities measured by the two central chords of the interferometer (normalized impact parameters +0.11 and -0.11 where minus stands for inner side) and the two edge chords (impact parameters +0.66 and -0.74). As shown in figure 3 the profile changes from hollow to peaked when I/N increases. Another characterizing parameter for the profile is the value of the gradient at the edge, estimated by assuming a linear profile in the region from the most external chord available for both the machines (i.e. the chord at impact parameter -0.74) and the plasma edge. The gradient (normalized to ne_c) depends on density in the same way both for RFX and for RFX-mod, as illustrated in figure 4. The apparent saturation of the gradient at ne > $2.5\cdot10^{19}$ m^{-3} is partly due to the fact that as far as density and its gradient grow the assumption of a linear profile in the region from 0.74 and 1 is less valid. It has been already shown on RFX and confirmed on TPE-RX, another RFP experiment operating at very low density values ($2\text{-}5\cdot10^{18}m^{-3}$), that the dependence of the gradient on density is due to the particle transport mechanism at the edge, with a diffusion coefficient that strongly increases when density decreases [4,5].

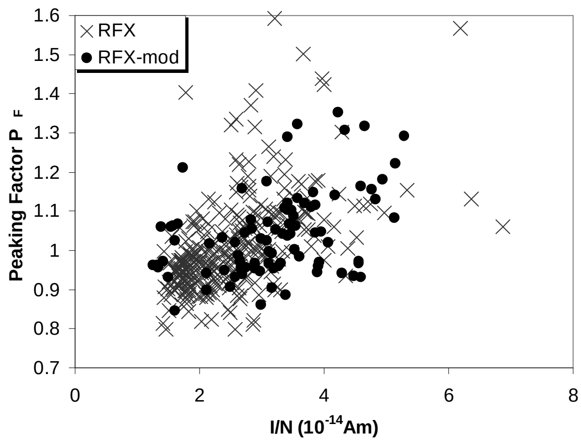

Figure 3: *Peaking factor P_F as function of I/N for RFX and RFX-mod*

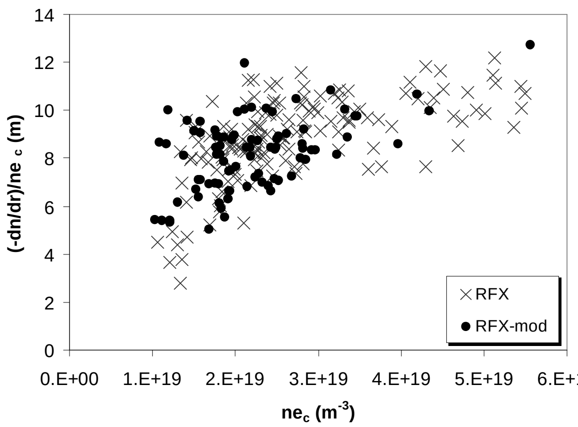

Figure 4: *Dependence of the density gradient at the edge (normalized to ne_c) on density*

Hydrogen influx Γ from the wall has been evaluated from measurements of H_α radiation in the equatorial plane, both in the outer side and in the inner side of the torus [6]. Γ in the outer side is of the order of $7 \cdot 10^{21}$ $m^{-2}s^{-1}$ at I_p = 600 kA and ne < $4 \cdot 10^{19}$ m^{-3}, with slightly higher values at the same current and higher density and slightly lower at I_p ~ 400 kA. In the inner side Γ is about 2.5 times lower. We used these values to estimate the particle confinement time τ_p for 6 average shots at different currents and densities, obtained by averaging plasma quantities over similar shots. Figure 5 shows τ_p for the representative shots: it is found to increase with plasma current and density, ranging from 1 to 2 ms. These values are in agreement with the typical τ_p found on RFX at the same I_p and ne [7, 8].

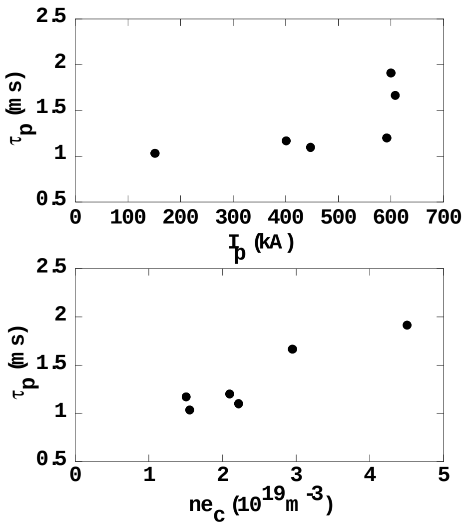

Figure 5: *τ_p for the average shots of RFX-mod*

4. Conclusions

Both density and density profiles show a similar behavior in RFX and RFX-mod. However RFX-mod proved to be more flexible allowing a better density control. The modification of the first wall gave poor advantage in the operational range explored so far. We expect it will affect much more the performances at high current regimes, when the new design of the tiles will allow a better control of plasma wall interaction and hence of gas influxes from the wall. A more detailed comparison of density profiles will be only possible when edge density measurements are available and the analysis of inverted profiles could show a small difference between RFX and RFX-mod even in the operational regimes illustrated in this paper. Larger differences are expected when the active control of the magnetic modes (available on RFX-mod thanks to the thinner shell and an improved set of coils) will be fully operational, since it could affect magnetic chaos and particle transport mechanisms of RFX-mod plasma.

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