Density control in RFX-mod Reversed Field Pinch device

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1. Introduction. RFX-mod is a large size Reversed Field Pinch (RFP) device, with major/minor radius 2/0.459 m, designed to operate at plasma current up to 2 MA [1]. The RFP configuration is characterized by the phase locking of several m=1 resonant magnetic modes, giving a macroscopic helical deformation of the plasma column that causes strong plasma wall interactions (PWI) and thermal power deposition on the wall that can locally reach values of the order of tens MW/m^2 [2]. To mitigate the effect of the PWI, in RFX-mod magnetic modes are induced to rotate by means of active control of the magnetic boundary. Moreover, to bear the thermal load, the wall is entirely covered by graphite tiles whose shape is studied in order to reduce the deposited power density [2]. The disadvantage of a graphite first wall is that it is a reservoir of H_2 particles and during the discharges density can be entirely sustained by particle fluxes coming from the wall, in particular when the H_2 content of the wall, the wall load, is high. The control of density behaviour in RFX-mod, in the sense of the capability to operate the discharge at a desired plasma density, is the subject of this paper.

2. Experimental set-up. In RFX-mod gas fuelling is made by means of two sets of 8 equal piezo valves installed at 4 toroidal sections at 90° each other. The two sets can be used and controlled independently, both to increase the reliability of the system and, in case, to allow experiments of puffing or fuelling with a gas different from H_2, typically He. The total H_2 flow of each set of 8 valves is ~2000 mbar·l/s [3]. The other way to fuel the discharge in RFX-mod is the injection of frozen H_2 pellets. Up to eight pellets with nominal masses in the range $1.5 \div 5 \cdot 10^{20}$ particles and launch velocities from 400 and 1500 m/s can be injected at every discharge. In order to allow a precise fuelling and a better density control during operations, a new diagnostic system, named DESO (DESOrption diagnostic), has been recently implemented on RFX-mod. On the one side, by means of a series of dummy openings before each RFX-mod shot, the system keeps the piezo valves in a working state in order to assure reproducibility by 10% of their flow. On the other side, by processing the time evolution of the in vessel pressure, DESO computes the Desorption factor Des%, the per cent ratio between the fuelled particles and those extracted from the chamber after the end of the

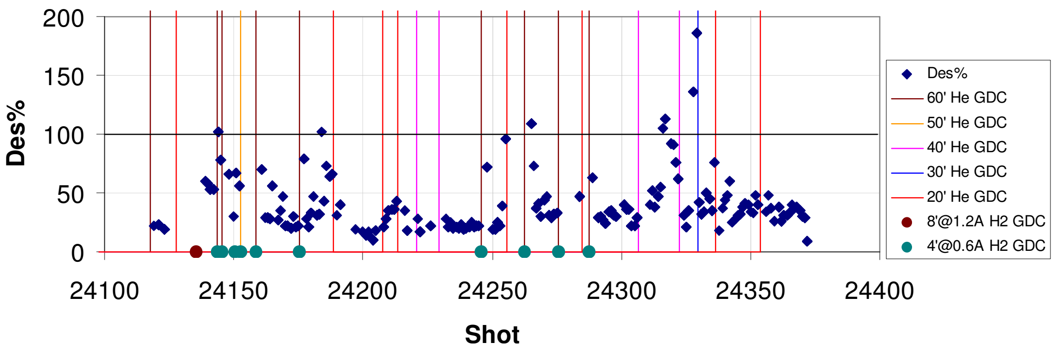

***Figure 1**: Evolution of desorption factor Des%. Vertical coloured lines correspond to He GDCs, coloured spots on the x-axis to H_2 GDCs*

pulse. Des% can be interpreted as an indicator of the state of the wall: a value below 100% corresponds to the capability of the wall to behave as a particle absorber, and hence a not saturated state of the wall, whereas a 100% value corresponds to saturated graphite that at the end of the discharge gives back all the fuelled particles.

3. Evolution of wall loading during experimental campaigns and effect on density. DESO started to work just after a wall conditioning session (30 hours of baking at 170°). Since then it allows to follow the evolution of the loading of the graphite first wall of RFX-mod, both on daily and on long term base. Figure 1 shows the factor Des% estimated up to present days: coloured vertical lines correspond to different He GDCs typically carried out in the morning, before the experimental session, to unload the wall. In many cases the conditioning He GDC was followed by a pre-loading H_2 GDC whose effectiveness as a reproducible way to operate at a desiderate density is under test. The figure shows that after the baking treatment the average wall saturation level was about 30% with extreme values as low as 10%, the points over 50% all corresponding to the pre-loaded cases. As far as the machine was operated, the average Des% kept raising and after about 250 shots a minimum value of Des% of the order of 25% is obtained after the daily He GDC, but during the experimental day the load rises and the saturation of the graphite is sometimes reached. The correspondence between the state of the wall and the plasma density n obtained at the flat top of the discharge is clear in Figure 2, where the n/n_G parameter (n_G is Greenwald density) is plotted versus Des%. Ignoring by now the cases with wall pre-loading, the figure shows the presence of

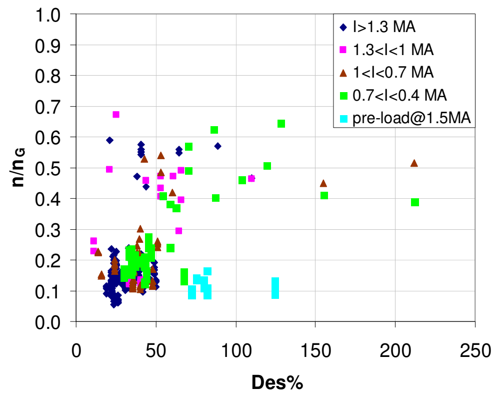

***Figure 2:** Flat top density normalised to Greenwald density n/n_G versus desorption factor Des% for different plasma currents I*

three regimes: when Des% is below 50% a wide range of densities is accessible (n/n_G = 0.05÷0.7), in particular the low ones, at Des% between 50 and 100% density grows with wall load whereas over saturation density is forced at the value $n/n_G = 0.5$, likely corresponding to the maximum sustainable density for the available input power (cfr also [4]).

4. Density control in RFX-mod. Data show that on RFX-mod the status of the wall dominates the determination of the density level of the discharge when the wall load is in the range Des%>50%. On the other side, at every value of wall load the characteristics of the plasma-wall interaction (PWI) play an important role in the process, since PWI controls the influxes of particles from the wall that sustain the density during the discharge. This is the reason, for example, of the correlation found, in particular when Des%<50% and the influence of the status of the wall on n/n_G is negligible, between the average input power (estimated as the product of loop voltage on the axis V(0) and the plasma current I) and the average flat top density (Figure 3). Other characteristics of the PWI, such as the amplitude of the macroscopic helical deformation of plasma column, its toroidal extension and its rotation speed, could not be statistically investigated in the present dataset, since it is composed of discharges with optimised magnetic boundary and without wall-locking of the helical deformation. In this framework, the control of density on RFX-mod passes mainly through the control of wall loading and PWI, but other factors that can influence it have been analysed. In the first place the modulation of the filling pressure of the vessel before the shot, that proved to be ineffective since no correlation has been found with flat top density. Filling has to be dosed in order to allow the breakdown and the feeding of the discharge in the setting up phase of the magnetic configuration but, since the particle confinement time is of the order of some ms (and is even much lower during the setting up of the magnetic configuration) the discharge forget it. If an excess of particles is filled, the only effect is to accelerate the achievement of the saturation of the wall. On the other side, with the injection of H_2 pellet density can be transiently raised, but the side effect is a fast wall loading. Flat top gas puffing is the other way to raise density, but on RFX-mod the method proved to be inefficient. Moreover, its impact on the wall loading process is still to be evaluated. Wall pre-loading by means of H_2 GDC is under test as a reproducible method to obtain a discharge with desired flat top density. The technique had been originally developed

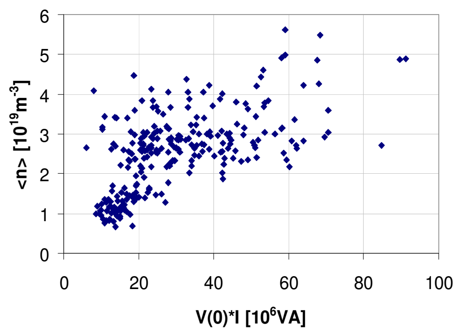

Figure 3: *Average plasma density <n> vs input power V(0)*I (shots with Des%<50)*

as a way to condition the wall after heavy treatments like boronisation, that cause a depletion of graphite and hence difficulties in obtaining a stable discharge. Typically one was forced to operate with very high filling pressures at startup with the only aim to allow the setting up the magnetic configuration, and this proved to reduce the duration of the wall treatment. Conversely, the storage on the wall of a controlled number of particles was found to assure a prompt start of experimental activity. Recently the same technique has been tentatively applied after the morning He GDC. In this case the advantage proved to be the reproducible correspondence between the number of implanted particles, dependent on the current and duration of the loading H_2 glow discharge [5], and the obtained plasma density, even if the relation between the two was found to depend on the plasma current and on the status of the wall. As shown in figure 2, the discharges with optimized wall pre-load are characterized by a low density ($n/n_G \sim 0.1$, the current and duration of the H_2 GDC having been set up to reach this target value; other n/n_G are obtainable with different settings) despite an high value of the Des% parameter that comes from the fact that the implanted particles are easily extracted from the wall after the discharge. In fact at the maximum explored plasma currents I~1.5 MA (the points on figure 2) the effect of pre-load lasts for only one shot, after which the wall behaves like a post He GDC one, but at I<1MA several shots (of the order of 10) with controlled density have been achieved even if they are not included in the data set because DESO was not available. The influence on the duration of the pre-load treatment of the voltage applied to the GDC anodes [6], that determines the energy and hence the depth of the particles implanted in the wall during the H_2 GDC, and of the implant fluence [6], that influences the depth profile, is under test.

5. Conclusions. In RFX-mod the role of the graphite wall on density control during experiments is under investigation. It has been found that when the graphite is sufficiently loaded with H_2 particles n/n_G is determined by the wall and settles at a value of ~0.5 when graphite saturation is reached. At low wall loading a wider range of densities is achievable, the value depending on the strength and uniformity of plasma wall interaction. Wall pre-loading by means of H_2 GDC is proposed as a way to obtain a plasma with desired density even if for a limited number of shots.

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