GAS PUFFING EXPERIMENTS IN THE RFX REVERSED FIELD PINCH

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1. Introduction

Some gas puffing experiments have been performed on the RFX reversed field pinch during the current sustainment phase. The goals of the experiments were mainly two. First of all, as already done for stationary RFX discharges [1], to analyse the electron density behaviour and to obtain information on the transport mechanism during the perturbed phase. Moreover, since the RFX graphite first wall can be heated up to 300°C and this is believed to ensure lower recycling and higher plasma purity, we have done puffing in cold and hot first wall conditions to investigate the wall behaviour at different temperatures.

The puffing experiments have been performed using two different types of valves: piezo-electric (PZE) valves, which have been used to induce a moderate influx perturbation, and (EM) valves, allowing a larger influx perturbation.

Three different types of experiments have been analysed. In the first experiment (pulse 8981, Ip=360kA) the first wall was kept at room temperature and the PZE valves were driven for 20ms at 300V. Taking into account the opening delay of the PZE valves, this corresponds to an effective influx of $1.2\cdot10^{21}m^{-2}s^{-1}$ between 47ms and 67ms.

In the second experiment (pulse 9812, Ip=900kA) the first wall was at a temperature of 240°C and the PZE valves were opened for 40ms at 300V. As before, this corresponds to an influx of $1.2\cdot10^{21}m^{-2}s^{-1}$ between 62ms and 102ms.

In the third experiment (pulse 9685, Ip=650kA) the first wall temperature was 270°C and a large density perturbation was applied by driving 8 electromagnetic valves (EM) for 18ms at the maximum allowed voltage of 18V. Taking into account the opening delay and assuming the throughput increases and, after the voltage pulse, decreases with a triangular and symmetric waveform, we have an effective puffing between 37ms and 47ms with a maximum influx of $5\cdot10^{21}m^{-2}s^{-1}$ at 42ms.

The paper presents the results of the experiments and the information obtained analysing the plasma response to the applied density perturbation both with a 0-dimensional and a 1-dimensional model.

2. 0-Dimensional analysis

As a first approach, the three discharges described above have been analysed by means of a 0-dimensional two-reservoir model. The aim of this analysis was to investigate the dependence of the first wall behaviour on temperature. The equations of the model are [2]:

$$\frac{\partial N_p}{\partial t} = -(1-R)\frac{N_p}{\tau_p} + \frac{N_w}{\tau_w} + \gamma_E \Phi_E \qquad \frac{\partial N_w}{\partial t} = (1-R)\frac{N_p}{\tau_p} - \frac{N_w}{\tau_w} + (1-\gamma_E)\Phi_E$$

where N_p is the total plasma particle content; N_w is the wall inventory; τ_p is the plasma particle confinement time; τ_w is a time characterising the adsorbing and desorbing properties of the wall (it should be noted that, given the variety and the complexity of the involved phenomena, no simple physical meaning can be associated with τ_w); R is a reflection coefficient, i.e. the probability that a particle bounces on the wall without being adsorbed; Φ_E is the incremental flux associated with the gas puffing and γ_E is the fuelling efficiency of the puffing.

As for the input parameters of the model the following assumptions have been made:

- N_w has to be estimated from considerations on the quantity of hydrogen adsorbed on the graphite. We have assumed that N_w is in any case limited by the saturation level of hydrogen on graphite which, at room temperature, is 0.42 times the graphite density. A typical value for this quantity is 10^{29}atoms/m^3; if we assume an implantation range of 4nm [3] we obtain a total number of about $6\cdot10^{21}$particles in the RFX first wall surface (36m^2). Furthermore, on the basis of the link between operating density and wall saturation condition observed in RFX [1], we have

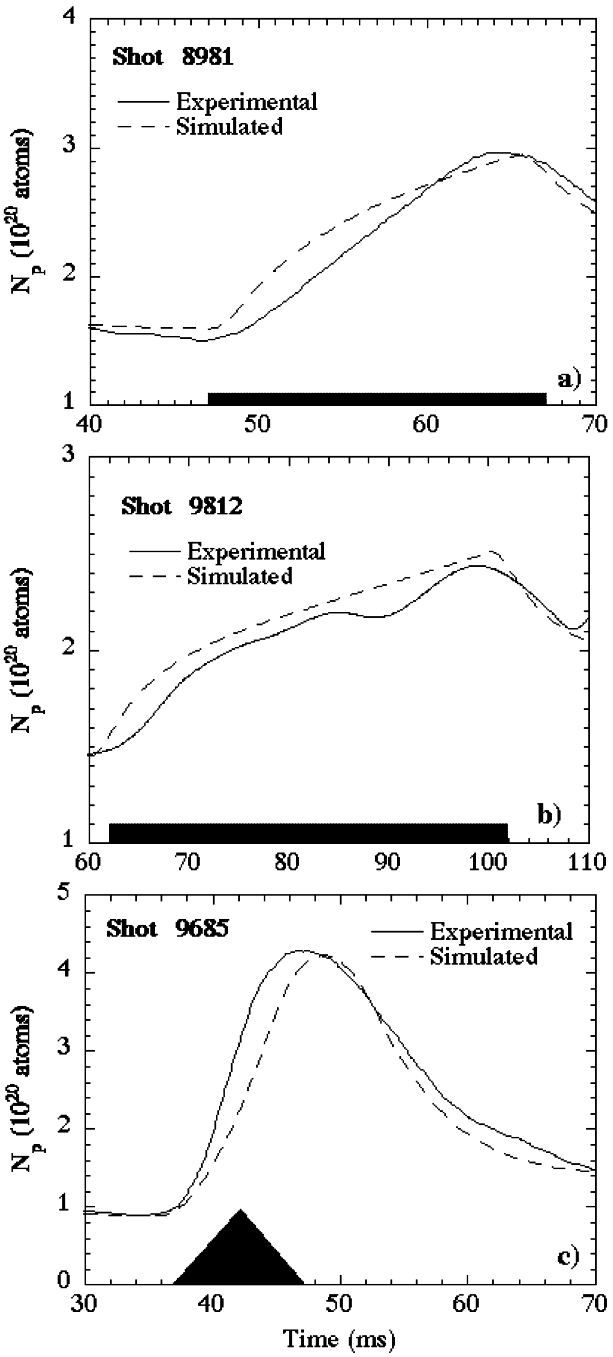

Figure 1: *0-dimensional simulations of three RFX discharges perturbed by gas puffing. The additional influxes are indicated by the shadowed areas.*

- ***a)*** *moderate gas puffing by piezo-electric valves; first wall at room temperature;*
- ***b)*** *moderated gas puffing by piezo-electric valves; first wall at 240°C;*
- ***c)*** *strong gas puffing by electromagnetic valves, first wall at 270°C.*

assumed that the lower ($1\div2\cdot10^{19}m^{-3}$) and upper ($6\div7\cdot10^{19}m^{-3}$) limits of the RFX operating density range correspond respectively to conditions of 40÷50% saturated wall (which is the typical level after a glow discharge cleaning session, when the lowest densities are achievable) and completely saturated wall. The transition is assumed to take place in a linear way.

- τ_w is adjusted in order to simulate the equilibrium pre puffing phase at different densities. Since it is not possible to simulate all the density regimes with the same value of τ_w, we have assumed a dependence of τ_w on N_w. This is justified by the fact that one can expect that the desorbing properties of the wall depends on the saturation level of the graphite [4]. The two values that permit to simulate the equilibrium at lower and upper density limit have been linearly interpolated to give the following scaling:

$\tau_w(sec)=0.17-2\cdot10^{-3}\,N_w$ (10^{20} particles).

It should be noted that τ_w can also depend on the ohmic power dissipated in the plasma [5], but this is not taken into account in our model.

- N_p is measured and results from the integration of the electron density profiles.
- R is assumed equal to 0.5 [6].
- the values and the scaling with density of τ_p are obtained from the analysis of stationary discharges [1]. Typical values for RFX range from 1ms at low density to 3ms at high density.
- Φ_E is known and γ_E is adapted to simulate correctly the density rise during the gas puffing.

Figure 1 shows the results of the simulations for the three cases considered and the agreement between experiment and simulation is satisfactory.

For the case of room temperature first wall (pulse 8981), the displayed result has been obtained with γ_E=45% and R=0.5.

Afterwards, we have simulated the cases of hot first wall without modifying the values of γ_E and R (because it is reasonable that they do not depend dramatically on first wall temperature). To reproduce the behaviour of the discharges considered we had to decrease the term N_w/τ_w by 30÷40%. This indicates that desorption from the first wall is reduced. This is probably due to a reduction of the saturation level of the hydrogen deposited on the graphite at higher first wall temperature.

3. 1-Dimensional analysis

A 1-dimensional transport analysis has been performed to compare and validate the results obtained in a previous work [1] which focused on the current flat-top phase of a database with pulses at different densities. The study has been done using a transport code which simulates the evolution of the ion and neutral density profiles given the evolution of the temperature profile and is described in detail in [1].

To describe the particle source we have distinguished fuelling from recycling.

Recycled plasma ions incident on the graphite wall can be backscattered as neutrals with energies comparable to the ions or trapped in the wall and later desorbed as wall-temperature hydrogen atoms or molecules. These recycled particles are represented by means of a monoenergetic group of atoms entering the plasma with an energy ε of about 7eV which is a weighted average among the various reflection and desorption processes.

Fuelled particles via gas puffing enter the discharge as wall-temperature hydrogen molecules. These molecules undergo principally two processes creating hydrogen atoms and ions [7, 8]:

- molecule ionisation ($H_2+e^- \rightarrow H_2^+ + 2e^-$), followed by ion dissociative excitation ($H_2^+ + e^- \rightarrow H^+ + H^0 + e^-$);
- molecule dissociative excitation: ($H_2 + e^- \rightarrow 2H^0 + e^-$).

Both atoms (≥75%) and ions (≤25%) are created within about one centimetre from the wall with velocities isotropic in space and with energy spectrum which extends approximately from 2 to 12eV [9]. Given the isotropy in the velocity distribution we have chosen to represent the fuelled particles by means of two equal neutral monoenergetic populations: one (ε=5eV) representing the atoms that enter directly the plasma and another (ε=1eV) representing the atoms directed toward the wall and completely recycled back to the plasma.

The spatial distribution of both the fuelling and the recycling source has been calculated in agreement with the model described in [1] and [10]. For the fuelling term we have introduced also a time dependence reproducing the opening and closing characteristics of the valves, scaled in agreement with the intensity of the puffing.

The core ($r/a \leq 0.9$) transport coefficients are modelled in agreement with the theory of stochastic diffusion [11, 12]. This theory predicts a diffusion coefficient and an outward directed velocity given by the relations:

$$D_S = (\delta B/B)^2 \, L_{//} \, v_{th}; \qquad V_S = -\frac{D_S}{2T}\frac{dT}{dr}$$

where δB/B is the relative magnetic perturbation level (1÷2% in RFX), $L_{//}$ is a connection length of the order of the minor radius and v_{th} is the ion thermal velocity, T is the ion temperature and has been assumed equal to the electron temperature. The total convective velocity V is the sum of V_S and the classical $\mathbf{E}\times\mathbf{B}$ velocity and is given by:

$$V = V_S + V_{\mathbf{E}\times\mathbf{B}} = V_S + \frac{\mathbf{E}\times\mathbf{B}}{B^2}$$

In the edge ($r/a \geq 0.9$) region, where the diffusion is believed to be non stochastic and driven mainly by electrostatic fluctuations, we have introduced an anomalous diffusion coefficient $D_E(r)$ [1]. The analytic expression used to perform numerical calculations is:

$$D_E(r) = D_{E0}\, e^{\left(\frac{r-a}{\lambda}\right)^2}$$

and the width λ is typically a/10.

The results of the 1-dimensional analysis are displayed in figure 2 for the three cases considered. The discharges perturbed with moderate puffing ($\Delta\Gamma/\Gamma \approx 0.2$ where $\Delta\Gamma$ is the additional influx and Γ is the pre-puffing influx, derived from H_α emission measurements) can be simulated with the same core transport parameters before and during the puffing, while the diffusion in the external region has to change according to the particle confinement time which increases with density. The typical values of the diffusion coefficients used in the simulations are: $D_S(0) \approx 20 m^2/s$, corresponding to a level of magnetic fluctuations δB/B of approximately 1.5%, a total outward velocity V≈20m/s and an edge anomalous diffusion coefficient D_{E0} varying

from 2 to 10m^2/s. This indicates also, as one may expect, that the plasma diffusion properties do not depend on wall temperature.

On the other hand the strongly perturbed discharge (EM puffing) presents a different behaviour before and during the puffing. In particular, the simulations show the occurrence of a faster inward diffusion of the injected gas than in moderately perturbed discharges. This phenomenology cannot be simulated with the same parameters as the pre puffing phase and indicates that something has changed in the transport characteristics of the plasma. A possible candidate to explain this behaviour is the perturbation of the temperature profiles (reduction of ∇T) due the large cooling of the outer region, ultimately resulting in a temporary reduction of the outward convective velocity, V_S. Further investigation is in progress to understand this point.

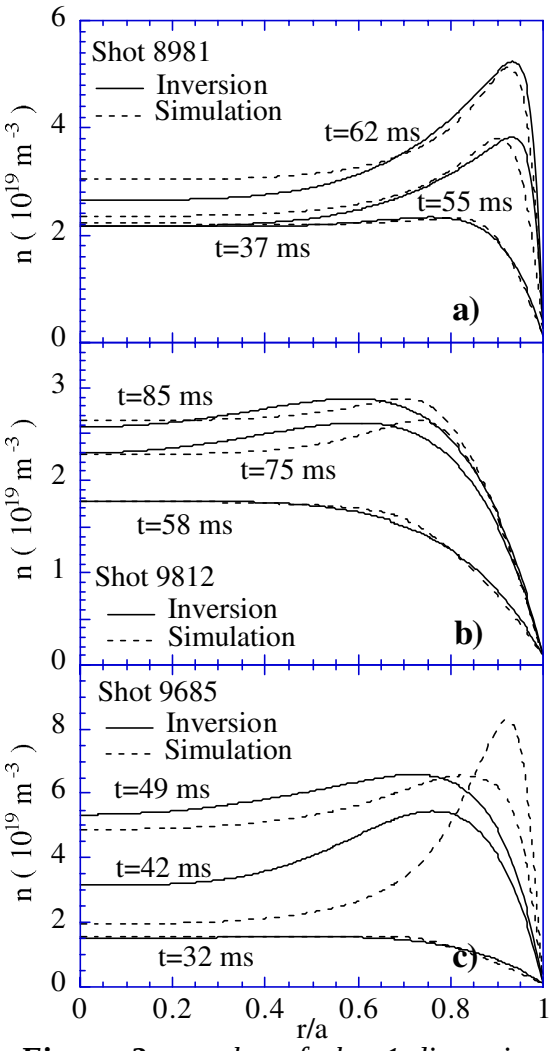

Figure 2: *results of the 1-dimensional simulation.*
a) *moderate puffing, first wall at room temperature;*
b) *moderate puffing, first wall at 240°C;*
c) *intense puffing, first wall at 270°C.*

4. Conclusions

Gas puffing experiments have been performed on RFX. They have been modelled using a simple 0-dimensional two-reservoir model and a more complex 1-dimensional transport model. The 0-dimensional analysis has permitted to establish that the puffing fuelling efficiency was 45% in all the cases analysed and that the desorption from graphite had to be reduced in hot first wall condition to simulate the experimental density waveforms. As to the 1-dimensional analysis, the most important result is that in moderate puffing conditions the same diffusion coefficients used in the stationary phase of the discharge permit to simulate also the perturbed phase, whereas in case of stronger perturbation, something changes in the transport mechanism which appears as a temporary suppression of the outward convective velocity, leading to a fast filling in of the hollow profile created by the puffing.

References

[1] Gregoratto D., Garzotti L., Innocente P., Martini S., Canton A.: "Behaviour of Electron Density Profiles and Particle Transport Analysis in the RFX Reversed Field Pinch", *to be published in* Nucl. Fusion.
[2] Lachambre J.L. et al.: Plasma Phys. Control. Fusion, **38** (1997) 1943.
[3] Larsson D., Bergsåker H.: in Controlled Fusion and Plasma Physics (*Proc. 24th Eur. Conf.* Berchtesgaden, 1997), Vol. 21A, Part III, European Physical Society, Geneva (1997) 1233.
[4] Möller W.: J. Nucl. Mat., **162** & **164** (1989) 138.
[5] Pitcher C.S.: Fusion Eng. Des., **12** (1990) 63.
[6] Ehrenberg J.K.: *in:* Physical Processes of the Interaction of Fusion Plasmas with Solids. Hofer W. O. and Roth J. eds., Academic Press, San Diego (1996).
[7] Howe H.C. jr.: J. Nucl. Mat., **111** & **112** (1982) 424.
[8] Jones E.M.: Culham Report CLM-R 175 (1977).
[9] Barnett C.F. et al.: Oak Ridge Report ORNL-5207 (1977).
[10] Düchs D.F., Post D.E., Rutherford P.H.: Nucl. Fusion, **17** (1977) 565.
[11] Rechester A.B., Rosenbluth M.N.: Phys. Rev. Lett., **40** (1978) 38.
[12] Harvey R.W., McCoy M.G., Hsu J.Y., Mirin A.A.: Phys Rev. Lett., **47** (1981) 102.