ANALYSIS OF THE BEHAVIOUR OF ELECTRON DENSITY IN THE TPE-RX REVERSED FIELD PINCH AND COMPARISON WITH RFX

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1. Introduction

In this paper we analyse the behaviour of plasma density in TPE-RX, a large Reversed Field Pinch (RFP) experiment (a=0.45m, R=1.72m), both in the stationary phase of discharges and during gas puffing experiments. The measurement of the line integrated electron density along two chords is obtained by a recently installed mid infra red double wavelength interferometer. The normalised impact parameters for the chords are 0 (central chord) and +0.69 (edge chord), which allow to get also some information on the density profiles.

The typical operation densities and plasma currents in TPE-RX are in the ranges $2\div 8\cdot 10^{18}$ m^{-3} and 200÷400 kA respectively. In standard discharges, density shows an almost linear dependence on the plasma current, resulting in a nearly constant value of plasma current over line density: I/N ~ $7.5\div 13\cdot 10^{-14}$ Am [1]. The only way to control actively the average density in TPE-RX is by mean of gas puffing, by which it is possible to reduce the I/N ratio up to a factor of five.

Plasma density behaviour in TPE-RX is compared with that of RFX, an RFP experiment of similar size (a=0.46m, R=2m) operating at higher current (I_p = 0.2÷1.2 MA). In RFX plasma density is measured by a 13 chords medium infra red double wavelength interferometer [2]. RFX operates at densities higher than TPE-RX and its data span a range of I/N ~ $1\div 8\cdot 10^{-14}$ Am. The differences in the density and I/N values between the two machines are mainly due to the recycling properties of their first wall, which in RFX is made of a full graphite tiles armour, whereas in TPE-RX of a metal vessel protected by 244 mushroom-shaped molybdenum limiters. In RFX the experimental I/N value depends mainly on the level of loading of the first wall.

The shape of RFX density profiles was studied by a transport code, leading to the understanding of the particles transport mechanisms acting in the plasma [3]. The experimental analysis of TPE-RX data confirms the picture obtained for RFX plasma and establishes that it can be considered characteristic of RFP plasmas.

2. Plasma density behaviour in the stationary phase

The behaviour of plasma density in TPE-RX in the stationary case has been investigated by analysing a data set of discharges at different plasma current values, with I_p ranging from 200 to 350 kA and an average I/N of ~ $8\cdot 10^{-14}$ Am.

The density profiles vary from peaked to nearly flat (see Fig. 1), with a ratio edge/central chord density, n(0.7)/n(0), from ~0.3 to ~0.9, which indicates the presence in TPE of profiles more peaked than a parabola (which corresponds to a ratio ~0.5).

The ratio shows a clear dependence on the pinch parameter θ (Fig. 2). It exhibits also a dependence on plasma current I_p and on the average density measured by the central chord n(0), but, due to the fact that the values of these parameters are correlated in standard TPE–RX discharges, it is impossible to establish from the stationary phase data set which is the leading one.

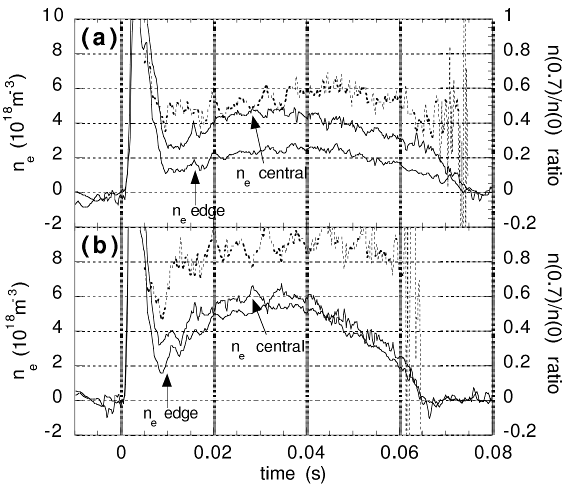

***Figure 1**: Average central and edge density and average n(0.7)/n(0) ratio for two sets of discharges at 260 kA (a) and 370 kA (b).*

The comparison with RFX, however, seems to confirm that the average density could be the better candidate. In RFX density profiles have been studied on a large data set of pulses [3]. The shape of the profiles depends only on the average density $<n_e>$ and changes from peaked to hollow as density increases. A similar trend can be observed in TPE-RX. In Fig. 3 the ratio n(0.7)/n(0) calculated for TPE-RX and low current RFX discharges are plotted versus the central density. The ratio for RFX has been calculated in the same way as in TPE, by considering as central (edge) density the average of the densities measured by the RFX chords at impact parameters +0.12 and -0.12 (+0.67 and -0.73), where the minus sign stands for inner side. In this way it has been averaged the effect of plasma column shift that in RFX can be as large as two centimetres, much higher than in TPE-RX where the shell is shifted with respect to the vessel. The TPE-RX data set in Fig. 3 contains discharges at different θ values that influence the trend versus n(0). However preliminary results show that the scaling with n(0) is confirmed on data sets for which the θ value is nearly constant.

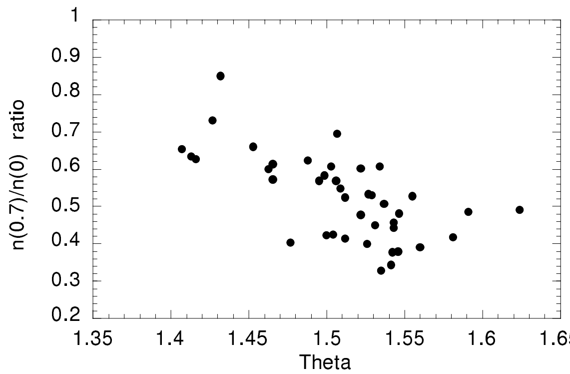

***Figure 2:** n(0.7)/n(0) ratio versus θ at I_p~250 kA and n(0) ~$5\cdot10^{18}$ m^{-3}.*

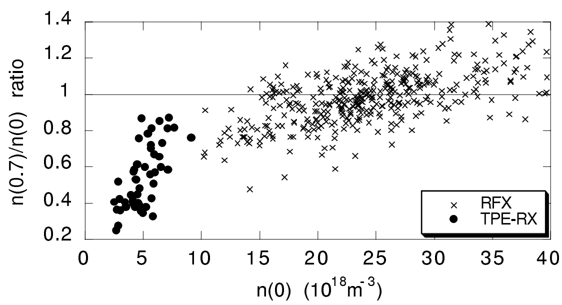

***Figure 3:** Scaling of the ratio n(0.7)/n(0) with the central density for TPE-RX and RFX.*

3. Gas Puffing experiments

In TPE-RX by mean of gas puffing (GP) it is possible to reduce the I/N value up to a factor of 5 at constant I_p and θ, permitting to analyse the dependence of the n(0.7)/n(0) on the density value. Deuterium gas is injected by two fast magnetic valves placed at toroidal positions at 180° each other. The valves are always opened at the same time (20 ms) and for the same duration (2 ms). The total particle input has been changed in the range $1.5 \div 4.5 \cdot 10^{20}$ by varying the gas flow. Plasma current and θ values for all the discharges in this data set were ~250 kA and ~1.45.

The time evolutions of average density and n(0.7)/n(0) ratio are plotted in Fig. 4a and 4b. With the strongest influxes the profile becomes flat, with a ratio increasing to one. The statistical analysis of the data set (Fig. 4c) shows that the actual profiles at the lower densities are comparable to stationary profiles at the same density, and that they can be hollow at higher densities in agreement with the behaviour in RFX.

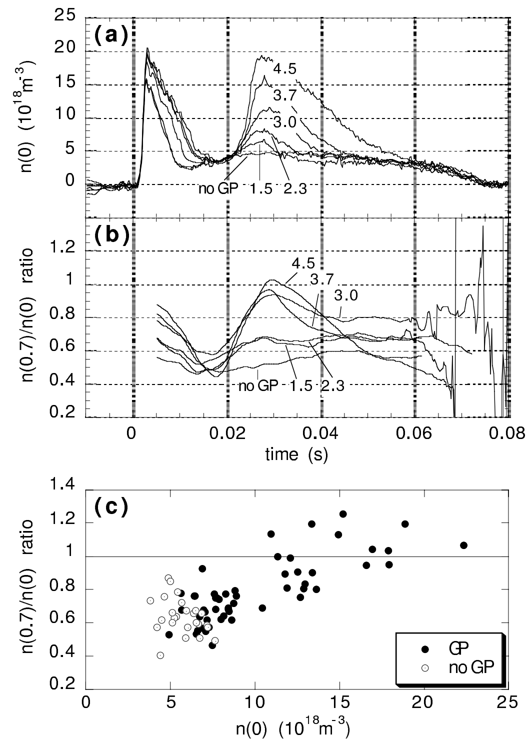

Figure 4: Density (a) and n(0.7)/n(0) ratio (b) averaged over a set of ~5 similar discharges. The numbers in the graphs are the estimated particle inputs ($\cdot 10^{20}$ particles). (c) Statistical distribution of the ratio versus density.

There are experimental evidences that the profile scaling in gas puffing experiments can be extended to stationary conditions TPE-RX plasmas. In fact it has been observed that, in ~70% of the GP discharges, the time evolution of the n(0.7)/n(0) ratio follows quite well the time evolution of the density after it has reached the maximum value. This suggests that when the external gas flux ends, plasma evolves through quasi-equilibrium states. This result is in agreement with the fact that the characteristic time scale of density evolution is up to about ten times the particles confinement time (τ_p).

The particles confinement time has been estimated for a data set of discharges with different gas puffing at I_p~260kA. The source term was estimated from the measurements of D_α emission obtained with a recently implemented toroidal array of 16 detectors evenly distributed around the torus. The particle confinement time results degraded by gas puffing, as shown in Fig. 5. In particular, experimentally its value ranges between ~5 ms on the standard discharges to ~2 ms on the strongest puffing discharges.

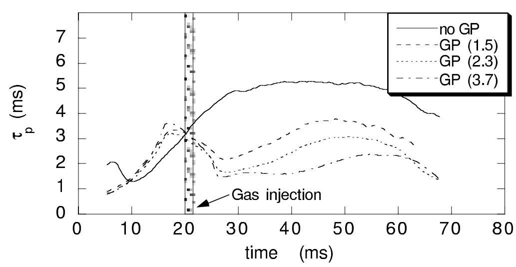

Figure 5: Particle confinement time for discharges with gas puffing at I_p~260 kA. The numbers in the legend are the estimated particles input for each level of puffing ($\cdot 10^{20}$ particles).

4. Discussion

In RFX [3] the measured profiles at the different densities are consistent with a particle transport mainly convective at the centre and diffusive at the edge of the plasma. In the core transport is thought to be driven by parallel transport in a stochastic magnetic field, giving rise to an apparent anti-pinch velocity proportional to the temperature gradient, magnetic fluctuations and ion thermal velocity. At the edge, particle diffusion coefficient D has experimentally been found to be highly dependent on density, decreasing from ~10 to ~1 m^2s^{-1} with density growing from 2 to $8 \cdot 10^{19}$ m^{-3}. Within the same physical picture, TPE-RX density profiles are consistent with a penetration depth for the neutrals much higher than in RFX, as highlighted by the application to TPE data of the code used to simulate RFX profiles. In fact in TPE-RX neutrals are found to penetrate up to the plasma core, whereas in RFX, due to the higher density, the penetration of the neutrals is limited to the plasma outer 10 centimetres, where the particle flux decreases by 1 order of magnitude. In Fig. 6 the profile of neutrals computed for the two machines is compared. The code takes into account neutrals coming from the wall and generated by charge exchange up to the third generation [4]. In the computation the temperature assumed for neutrals at the wall is 5 eV and the electron temperature profile is $T_0(1-r^4)$ (T_0 = 300 eV for RFX [5] and 600 eV for TPE [6]). The electron density profile is $n_0(1-r^{\alpha})$ (α = 10 and n_0= $30 \cdot 10^{18}$ m^{-3} for RFX [3], α = 2 and n_0= $3 \cdot 10^{18}$ m^{-3} for TPE).

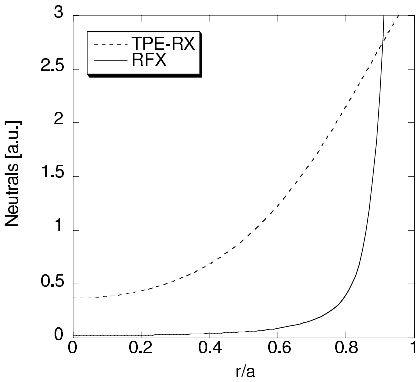

Figure 6: *Comparison of the neutral penetration profiles for TPE-RX and RFX.*

The different penetration depth of neutrals in the two machines can also explain qualitatively the dependence of the density profile on θ in TPE-RX, not observed in RFX. The increase of θ, in fact, corresponds to a global change of the magnetic (and q) profile and a peaking of the current profile, that causes in particular the change of the diffusion profile in the plasma core. In TPE, where neutrals are present in the core, this results in density profiles more peaked than in RFX.

5. Conclusions

Density profiles behaviour has been studied in TPE-RX and the results have been compared with those of RFX. In TPE-RX profiles change from peaked to flat with the average density. Their peaking depends also on the value of the pinch parameter θ. In RFX a similar dependence on n is also well observed whereas no dependence has been observed on the global magnetic configuration linked to θ. The difference between the two experiments has been related to the different neutrals penetration profile, which can be confirmed by simulations performed with the RFX transport code.

6. References

[1] Hirano, Y., et al., in Fusion Energy, Proc. 17th Conf., Yokohama, 1998, Vol. 1 (1999), p. 375.
[2] Innocente, P., et al., Review of Scientific Instruments, Vol. 68 (1997), p. 694.
[3] Gregoratto, D., et al., Nuclear Fusion, Vol. 38 (1998), p.1199.
[4] Düchs, D.F., et al., Nuclear Fusion, Vol. 17 (1997), p. 572.
[5] Carraro, L., et al., in Controlled Fusion and Plamsa physics, Proc. 23rd Eur. Conf., Kiev, 1996, Vol. 20C II (1996), p. 649.
[6] Yagi, Y., et al., in Fusion Energy, Proc. 18th Conf., Sorrento, 2000