Modification of plasma density profile during PPCD experiments in EXTRAP T2R

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1. Introduction

Pulsed poloidal current drive (PPCD) experiments have been conducted in the resistive shell EXTRAP T2R reversed-field pinch experiment [1]. The experimental results [2] showed that the PPCD phase of discharges is characterised by an improved energy and particle confinement. The central electron temperature increases up to 380 eV, and the estimated energy confinement time doubles, reaching $380\ \mu s$.

In this paper we analyze the modification of density profiles induced by the PPCD. The evolution of the plasma density profiles has been modelled by a one-dimensional transport code that allows the estimation of the time evolution of the particle diffusion coefficient D. The results indicate a clear improvement of particle confinement in the central part of the plasma.

2. Experimental results

The electron density in EXTRAP T2R is measured by a four-chord CO_2 interferometer. The central chord has an impact parameter equal to 0, two symmetrical chords, with normalized impact parameter equal to -0.41 (inboard side) and 0.41 (outboard side), give information on the middle region of plasma. The edge chord has a normalized impact parameter equal to -0.82 (inboard side). However, only a single detector is available and therefore simultaneous measurement of the line-integrated density at different radial positions is not possible for the same discharge. Nevertheless a radial line integrated density profile can be obtained on a set of similar discharges, due to the high reproducibility of pulses.

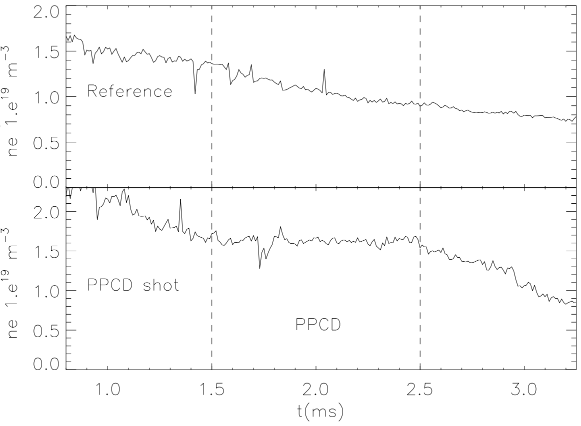

Figure 1: *Central density in the reference and PPCD discharge. The vertical lines indicate the start and the end of PPCD*

The density profile $n_e(r)$ has been modelled according to the following formula:

$$n_e(r) = [n_e(0) - n_e(a)]\left[1 - \left(\frac{r}{a-\Delta}\right)^{\alpha}\right]^{\gamma} + n_e(a) \tag{1}$$

where $n_e(0)$ and $n_e(a)$ are respectively the central and edge electron density and Δ is the Shafranov shift. Equation 1 is used to calculate the line integrated electron density along the four chords and by χ^2 minimisation the best-fit parameters to the measured ones are obtained. The effect of PPCD is most evident on the central chord: the electron density, which usually decreases throughout the discharge, remains constant during the PPCD phase, as it is shown in the figure 1. However the electron density measured by the other chords decreases with time, indicating that the density profile is changing. As a result the profile peaks instead of decreasing as it does in the reference discharge. Figure 2 shows the density profiles as calculated by the interferometer measurements at the PPCD beginning (t=1.5 ms) and after 0.5 ms, still before PPCD termination, when the central electron temperature has reached its highest value.

4. Description of the transport code

A one-dimensional particle transport code has been used to study the time evolution of electron density profiles. This code has been already used in two RFP experiments, RFX [4] and TPE [3], to study the plasma confinement properties in standard conditions and in discharges where the PPCD has been applied. The code assumes different particle transport mechanism at the edge and in the core of the plasma. At the edge the transport is driven by electrostatic fluctuations, while in the core by magnetic fluctuations related to the RFP intrinsic stochastic nature of the internal magnetic field. The effect of electrostatic fluctuations on transport is parametrised assuming a particle diffusion coefficient $D_E(r,t)$ that has its maximum at the plasma surface and vanishes in the region of the toroidal magnetic field reversal $(r/a \approx 0.8)$.

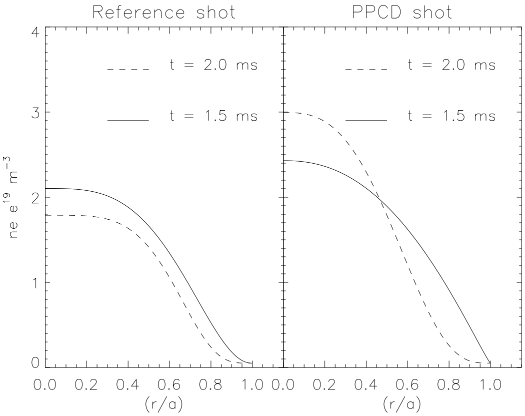

Figure 2: *Density profile in the reference and PPCD discharge*

Particle transport in a stochastic magnetic field [5] is described in terms of a particle diffusion coefficient $D_{ST}(r,t)$ and a convective velocity $V_{ST}(r,t)$ proportional to magnetic fluctuation amplitude. In standard conditions the profile of D_{ST} has its maximum in the plasma core and decreases along the plasma radius vanishing at the edge. The D_{ST} profile used to simulate the density profile evolution of the reference discharge is shown in figure 3. The total particle diffusion coefficient $D(r,t)$ is the sum of $D_{ST}(r,t)$ and $D_E(r,t)$. The pinch term $V(r,t)$ is the sum of a classic drift term $V_{E\times B}(r,t)$ and of the stochastic one $V_{ST}(r,t) = -0.5 D_{ST}(r,t)\nabla T(r,t)/T(r,t)$. $T(r,t)$ is the electron temperature The particle diffusion coefficient and convective velocity are obtained via the continuity equation. The contribution of neutral particles to the electron flux is estimated using a Monte Carlo code to evaluate the neutral particle radial profile. The Monte Carlo code is based on the code described in [6] with the addition of the modeling of hydrogen recycling based on the TRIM databases [7]. The neutral particle density profile is then normalised to yield the experimentally measured edge particle confinement time, which is approximately $200\ \mu s$ [8].

6. Simulation results

Figure 3 shows the D profiles before and during PPCD, used to simulate the density evolution of the reference and PPCD discharge. In discharges without PPCD the measurements of interferometer chords are well reproduced by keeping the D_{ST} profile constant in time, with a value equal to $20\ m^{-2}s^{-1}$ in the core, while $D_E(a)$ must be increased from its initial value of about $100\ m^{-2}s^{-1}$ to $150\ m^{-2}s^{-1}$.

This is mainly due to the decrease of the electron density at the edge. The results of the simulation are presented in figure 4. The profile of D_{ST} obtained in the reference discharge is used as the initial profile for PPCD discharges.

The influx is assumed to decrease as a consequence of PPCD from its initial value of $5 \times 10^{21}\ m^{-2}s^{-1}$ to about $3 \times 10^{21}\ m^{-2}s^{-1}$ during the first 0.5 ms of simulation, as described in [2]. In this case the measurements of the edge chord require a lower value of $D_E(a)$, as it can be easily seen by the shape of the inverted density profile which is initially less depleted at the edge than in the case of the reference discharge.

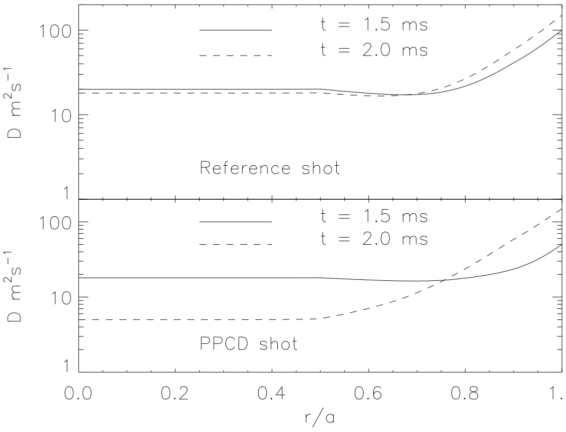

Figure 3: *Total D ($D_{ST} + D_E$) time evolution for reference and PPCD discharge*

An interpretative analysis carried out on the density profile evolution indicates that the PPCD causes a reduction of D_{ST} value, and its largest effect is in the plasma core.

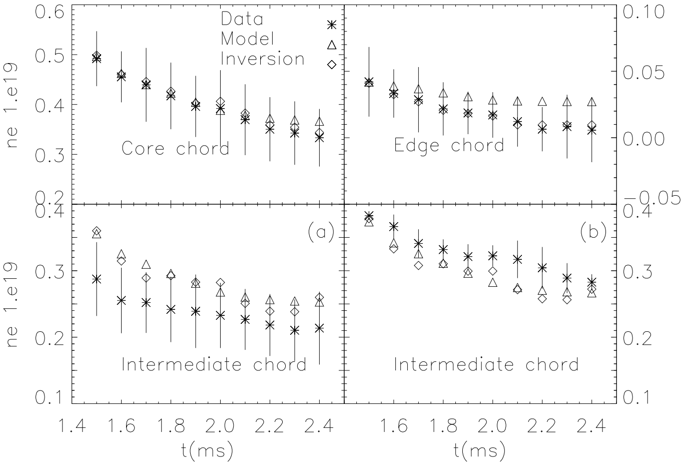

Figure 4: *Comparison between interferometer measurements and simulation result for the reference discharge. The graphs (a) and (b) show the results for the intermediate chords respectively on the inboard and outboard side*

The results of the predictive simulation are shown in figure 5. The measurements of the interferometer central chord are well reproduced using a $D_{ST}(r,t)$ profile which is lower by a factor four than before the PPCD application up to $r/a < 0.5$, as shown in figure 3. The effect of PPCD is progressively reduced in the more external region of the plasma, for $0.5 < r/a < 0.7$. However the value of $D_E(a)$ must be increased with time up to values comparable to those used to simulate the reference shot. As a consequence the $D(r,t)$ profile in the external region of plasma, where $r/a > 0.7$ is higher than the pre-PPCD phase and reaches the same values of the reference discharge. This seems to indicate that the PPCD does not improve the edge confinement, even though the low reliability of the edge measurements does not completely rule out the possibility that a positive effect could be hidden within experimental errors. The simulation has been performed again assuming that the neutral influx does not decrease. In this case the D_{ST} reduction of a factor two up to $r/a < 0.5$ is still required to obtain results similar to those presented in figure 5 for the central chord.

4. Conclusions

A 1D transport code has been used to study the evolution of density profile in reference and PPCD discharges.

The simulation results indicate that a reduction of stochastic D_{ST} during PPCD is required in the central region of plasma ($r/a < 0.5$), to reproduce the behaviour of the electron densiy as measured along four different chords, and in particular the central one. This reduction is of a factor four if the neutral influx is supposed to halve during the PPCD. Otherwise, if the flux is kept constant, the improvement is about of a factor two. The ratio between the pre-PPCD and the PPCD D_{ST} reduces going towards the edge, and the two coincide when $r/a \approx 0.7$.

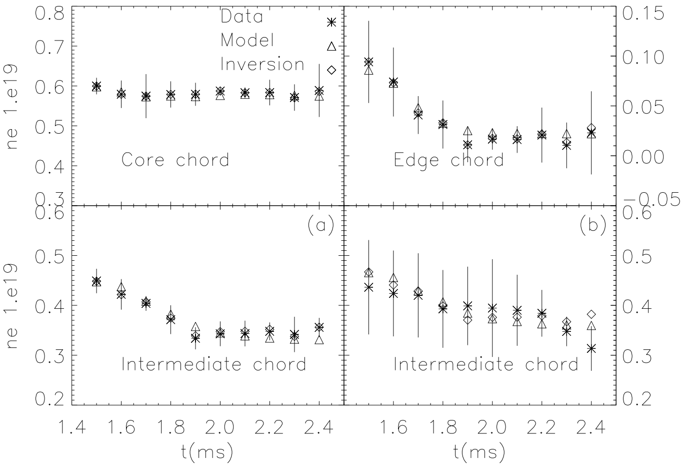

Figure 5: *Comparison between interferometer measurements and simulation result for the PPCD discharge. The graphs (a) and (b) show the results for the intermediate chords respectively on the inboard and outboard side*

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