Electron Density and Transport in EXTRAP T2R

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Introduction

The electron density profile has been measured in the EXTRAP T2R reversed field pinch (RFP) experiment. The electron density profiles, both in discharges with and without gas fuelling, are interpreted using a particle diffusion code with a stochastic diffusion coefficient and a classical inward pinch velocity. A Monte Carlo code is used to calculate the neutral particles density profile. EXTRAP T2R is characterised by full-metal first wall protected by a set of mushroom-shaped molybdenum limiters and by a high aspect ratio R/a = 6.8 where R = 1.24 m and a = 18.3 cm. EXTRAP T2R is typically operated with plasma current from 75 to 120 kA. The plasma is characterised by electron densities in the range of $0.5 - 2 \times 10^{19}$ m^{-3}, central electron and ion temperatures between 100 and 200 eV and I/N between 5 and 20×10^{14} Am. Due to the metal wall, the recycling coefficient is less than unity and electron density decreases during the discharge causing I/N to become extremely large. Density control is achieved by a gas puff system. Using the puff I/N can be lowered down to 5×10^{14} Am even at the lowest currents. In combination with gas fuelling, low and intermediate current discharges have been studied. The current time trace for the low current scenario is shown in figure 1. Intermediate current discharges have peak currents up to 100 kA.

Electron and neutral density profiles

The average electron density profile is reconstructed by measuring the line integrated electron density with a single-chord single-colour CO_2 interferometer by repeated measurements along four different chords. The measurements have good reproducibility thanks to the full metal first wall and the absence of locked modes. The profile is modelled according to the relation $n_e(r) = n_e(a) + [n_e(0) - n_e(a)] [1-(r/(a-\Delta))^\alpha]^\gamma$ where $n_e(0)$ and $n_e(a)$ are the central and edge electron density, Δ the plasma radial displacement and α and γ the profile parameters. The edge electron density and the plasma displacements are measured by Langmuir probes and by standard magnetic diagnostics respectively. The unknown $n_e(0)$, α and γ are then obtained by χ^2 minimisation fitting procedure. The estimated central electron density is in good agreement with estimates of $n_e(0)$ obtained by a single-shot, single-point

Thomson scattering system as shown in figure 2. The Thomson measurement provides only a relative estimated of $n_e(0)$. This estimate is normalised to the interferometric estimate at $t = 2$ ms. The Thomson estimates at later times are obtained with the same normalising factor. An example of the electron density profile for discharges at intermediate current and with gas fuelling is shown in figure 3. The profile is peaked and does not change in shape throughout the discharge. The central electron density decays more slowly than in discharges without gas fuelling. A comparison of the electron density profile for discharges with and without gas fuelling is shown in figure 4. It can be observed that in addition to the difference in the central electron density, the profile in the gas fuelling discharges is more peaked than in discharges without it. This is a consequence of a deeper penetration of neutral hydrogen atoms from the wall into the plasma centre. In order to verify this a Monte Carlo code, based on a simplified version of the code described in [1], has been used to calculate the neutral density profile n_n corresponding to the electron density profiles shown in figure 4. The code includes Franck-Condon neutrals launched from the wall, charge-exchange and electron-impact ionisation processes as well as a model for the hydrogen recycling from a stainless steel wall [2]. The neutral particles influx from the edge, used to normalise the simulated profile, is obtained by measurements of the neutral fluxes obtained with a neutral particle energy analyser based on time of flight technique [3]. The results are shown in figure 5. The corresponding electron source term is shown in figure 6. As expected the neutral density and the source term are larger with gas fuelling than without it. Both with and without gas fuelling the penetration of neutrals right into the plasma centre is quite large compared to that of RFX and quite similar to that of TPE-RX [4], two other RFP experiments of similar size ($a = 0.46$ m, $R = 2$ m and $a = 0.45$, $R = 1.7$ m respectively). RFX has central densities and temperatures of the order of $4 - 5 \times 10^{19}$ m^{-3} and $250 - 400$ eV [5]. In TPE-RX the electron temperature spans a similar range as in RFX while the density is in the range $0.2 - 0.8 \times 10^{19}$ m^{-3} (without gas puff) [4]. T2R is characterised by similar electron densities as TPE-RX and by lower electron temperatures. The differences in neutral penetration can be explained in terms of the different electron densities: devices with higher density have lower neutral penetration [5]. Electron temperature, in these ranges, plays a minor role in the neutral penetration.

Particle transport

Particle transport is studied using the continuity equation $\partial n_e/\partial t = -1/r \partial(r\Gamma)/\partial r + \langle\sigma v\rangle_{ion} n_e n_n$ and neglecting the recombination term. The particle flux is expressed as $\Gamma = - D \partial n_e/\partial r + V n_e$ where D is the diffusion coefficient and V is the pinch velocity given by the $\boldsymbol{E} \times \boldsymbol{B}$ drift. The pinch velocity is calculated from the measured resistive loop voltage and the estimated poloidal magnetic field (PFM model [6]). The pinch velocity for the two cases here discussed is shown in figure 7. Integration of the continuity equation provides the particle flux Γ. Inserting the electron density profile, the pinch velocity and the particle flux in the expression for the particle flux provides an estimate for the diffusion coefficient. The result for the two cases is shown in figure 8. The obtained values for the diffusion coefficient are compatible with the parallel Rechester-Rosenbluth diffusion along stochastic magnetic fields in the plasma centre that is characterised by a diffusion coefficient $D_{ST} = (\delta B/B)^2 L v_{th,i}$ where $\delta B/B$ is the magnetic fluctuation level, L the fluctuation correlation length ($L \approx a$) and $v_{th,i}$ the ion thermal velocity [7]. In EXTRAP-T2R D_{ST} is in the range $10 - 30$ m^{2}s^{-1}. Towards the edge the calculated diffusion coefficients increase mimicking transport driven by electrostatic fluctuations. Inclusion of an outwardly directed anti-pinch term driven by temperature gradient does not modify qualitatively the above picture.

Acknowledgements

References

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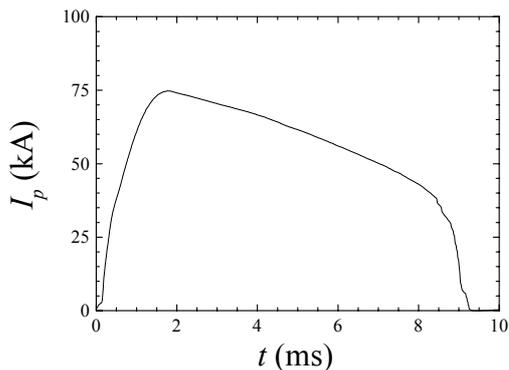[7]   Rechester A B and Rosenbluth M N, *Phys. Rev. Lett.*, **40**, 38, 1978
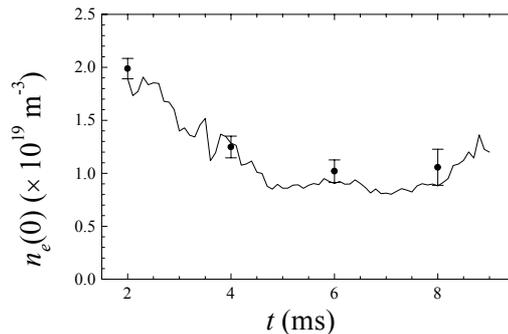
Fig. 1 Plasma current.

Fig. 2 Central density evolution: interferometer (—) and Thomson scattering (●).
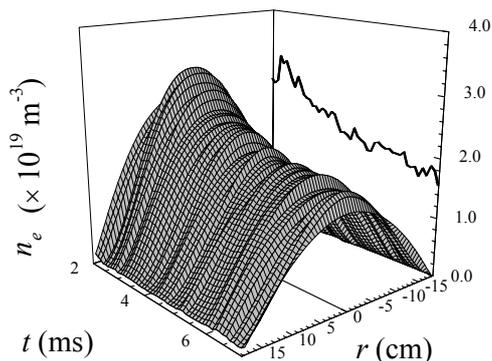
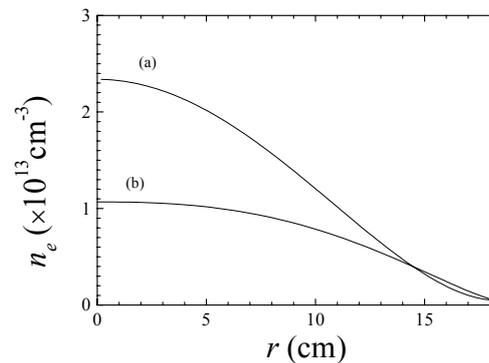**Fig. 3** Electron density profile evolution with gas fuelling.

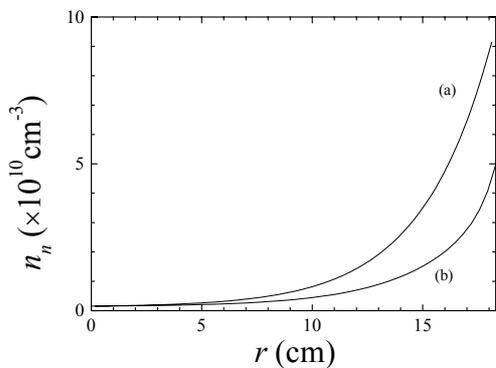**Fig. 4** Electron density radial profiles: (a) with gas puff, (b) without gas puff.

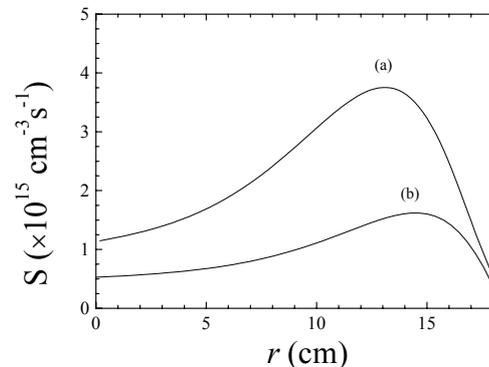**Fig. 5** Neutral density radial profiles: (a) gas puff, (b) without gas puff.

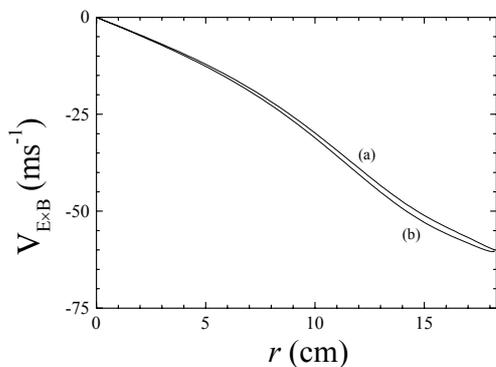**Fig. 6** Ionization source term radial profiles: (a) gas puff, (b) without gas puff.

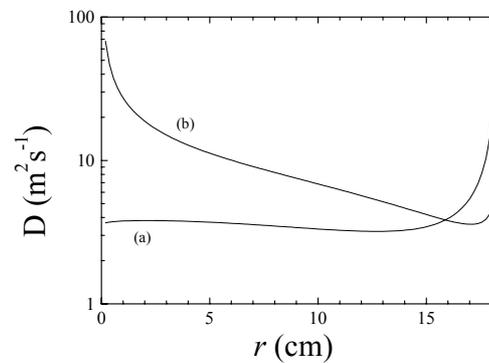**Fig. 7** Pinch velocity radial profiles: (a) gas puff, (b) without gas puff.

Fig. 8 Diffusion coefficient radial profile: (a) gas puff, (b) without gas puff.