Edge electron temperature and density measurements in RFX by a thermal helium beam

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1.Introduction

In this paper the first results from the edge diagnostic based on a thermal helium beam recently installed on the RFP device RFX are presented. The injection of an atomic beam into the plasma in combination with the observation of its optical emission is a well known technique to obtain time and space resolved measurements of electron density and temperature [1]. The experimental method consists in the observation of the intensity ratios of selected emission lines : in fact, when the atoms enter the plasma, they are excited by particle collisions with a rate depending on the local plasma parameters n_e and T_e. The measurement of the intensity ratio of selected couples of lines characterised by different n_e and T_e dependence allows the evaluation of the local density and temperature.Actually, this method has been applied on several fusion devices using both thermal [1,2] and supersonic helium beams [3,4] . On RFP's the edge parameters have been up to now measured by probe diagnostics [5]. These are however limited by the allowed power loads (and therefore are not suitable for plasma currents higher than ~0.5 MA) and are anyway a perturbative technique. The installation on RFP's of atomic beams is therefore a very promising diagnostic tool, especially to extend the edge n_e and T_e measurements to high current plasma discharges.

2. Experimental set-up

The injection system is quite similar to that developed for TEXTOR [1]: the helium gas is filled into a reservoir at a pressure of 1 bar and the gas flux is regulated by a piezo-electric

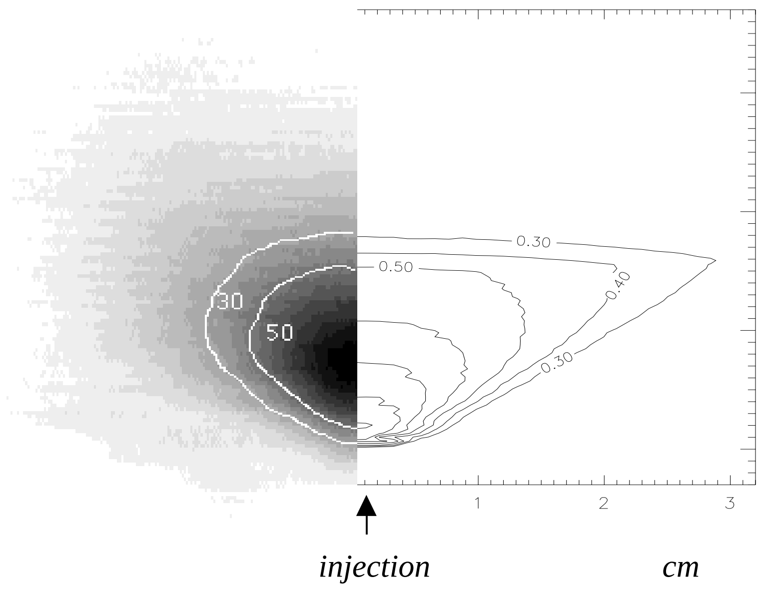

Fig.1: Simulated equi-emissivity surfaces of the helium cloud (right) compared with the CCD image (left) on the equatorial plane.The vertical axis represents the radial coordinate, the horizontal one the toroidal direction.

valve. In order to limit the beam divergence the atoms pass through a single 30 mm long microtube 150 μm in diameter and then through a diaphragm (200 μm in diameter) placed at about 300 μm from the tube end. The resulting full angle of the flux density is found to be of ~ 80^0. The helium flux is ~10^{17}atoms/s, corresponding to a density of ~10^{17}particles/m^3at the microtube outlet, much lower than the local plasma density. The beam is injected radially at the outboard side of the torus, on the equatorial plane, and the lines of sight along which the beam is observed make an angle of 72^0 with the injection direction, thus limiting the radial resolution, that is reduced to about 1 cm. The detection system consists of 4 beam splitters that deviate the light respectively to: - 3 interference filters coupled with array cameras for the observation of the helium lines; - a CCD camera allowing the simultaneous observation of the beam; - a laser diode for alignment purpose. The optical chains beam splitters + interference filter + array camera are absolutely calibrated against an integrating sphere. The measured line ratioes are compared with a look-up table derived from the atomic model discussed in [6], from which the final $T_{e,edge}$ and $n_{e,edge}$ values are interpolated. The signal detected in discharges where the helium valve was closed has been found to be comparable with the array dark current, as detected after the end of the discharge. The possible contribution of the injected helium recycled at the wall has been evaluated from the signal detected by some pixels of the arrays viewing directly the plasma, without intercepting the helium cloud: also in this case values of the same order of the detector noise have been found. In the data analysis the background noise is subtracted to the plasma signal. The error on the signal is then calculated as the rms of the mean value and propagated to the intensity ratioes and to the interpolated T_e and n_e. If the error on T_e and/or n_e is greater than 30%, the data are not considered. A Monte Carlo code, originally developped to simulate the impurity behaviour at the edge [7], has been adapted to compute the helium spatial distribution in the plasma close to the injection tube. A number of helium neutrals (typically 60,000) with a maxwellian velocity distribution peaked around the thermal energy (~0.025eV) are randomly placed within the tube,where they move along straight lines to enter the plasma, and are elastically rebounded when they collide with the wall.

Once entered the plasma, the particles are ionised; after each ionisation, they can be ionised again (from He II to He III) or can re-capture an electron by recombination or charge-exchange processes. An example of the result of this simulation is shown in fig.1, where a bottom view with an inclination of 72^0 (reproducing the experimental situation) is drawn and compared with the helium cloud as observed by a CCD camera.

3. Results and discussion

Fig. 2 shows an example of the time evolution of $T_{e,edge}$ and $n_{e,edge}$ as measured during a 1 MA discharge, with the core electron density and temperature also shown for comparison. The data nrefer to two different lines of sight, each corresponding to a radial average of ~1cm; the axis of the two

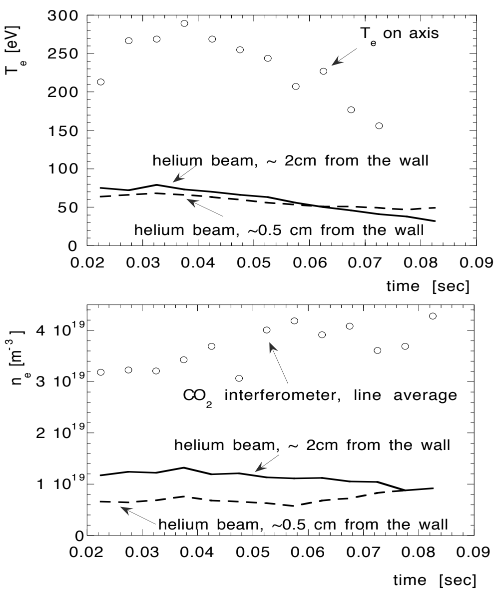

Fig.2:Time evolution of Te_edge and ne_edge

lines of sight differ by ~1.5 cm. The electron temperature is about constant between 60-80 eV and does not change significantly with the line of sight, suggesting a nearly flat profile in the last 3 cm of the radius. The electron density measured on the external chord is lower than that associated to the inner one, corresponding to a density gradient of the order of 0.5 10^{21} m^{-4}.
Moreover, coupling the experimental data to the Monte Carlo code the profiles of temperature and density at the edge have been studied, partially overcoming the low radial resolution of the setup. The edge density gradient has been found to increase with the core density, as shown for example in fig.3, confirming the behaviour deduced from interferometric measurements [8].The behaviour of $T_{e,edge}$ as a function of $n_{e,edge}$ is shown in fig. 4 (the values correspond to a radial average over the last 2 cm of the radius). The temperature decreases with density and edge temperatures as high as ~ 100 eV are observed at densities ≤ 0.5 10^{19} m^{-3}, while for $n_{e,edge} \geq 4$ 10^{19} m^{-3} the temperature decreases to about 20 eV. The edge electron temperature increases with the I/N parameter with a nearly linear scaling, as shown in fig.5 (that corresponds to plasma currents ranging from 0.6 MA to 1.2 MA), while $n_{e,edge}$ shows an opposite behaviour. A linear correlation between $T_{e,edge}$ and I/N has been assumed in order to calculate the hydrogen and impurity influxes, associating the

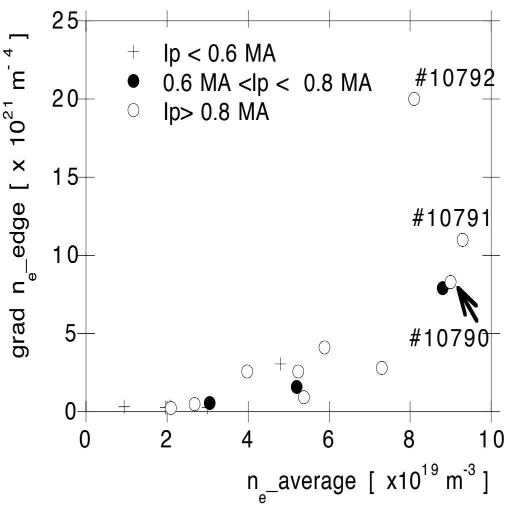

Fig.3: Edge density gradient as a function of the average electron density

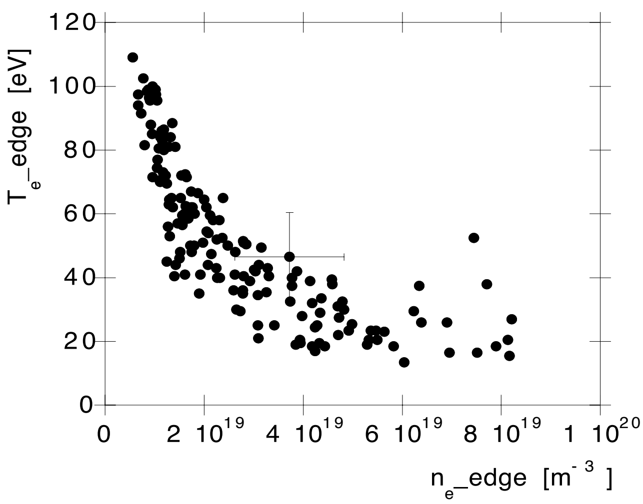

Fig.4: Edge electron temperature as a function of edge electron density. I_p=0.8-1 MA

proper effective emission coefficients to the corresponding line intensities in each plasma condition. In RFX, despite the large input power of tens of MW, the plasma effective charge is found to be within acceptable levels (Zeff≤ 3.5 in well-conditioned discharges), independently on the plasma current. This has been associated to the experimental scaling of the edge temperature with plasma current and interpreted in terms of impurity screening by means of the simulation of the carbon behaviour at the edge of RFX by a Monte Carlo model [7]. In particular, the impact of the edge T_e and n_e profiles on the carbon penetration efficiency ξ (defined as the fraction of carbon atoms produced at the wall that enter the plasma by 4.5 cm, corresponding to several Larmor radii for CII in a variety of plasma situations) has been studied. Three different 1MA discharges have been simulated, corresponding to different values of the plasma average density. The diffusion coefficient assumed for the simulations was 10 m^2/s; a radial electric field of -3kV/m (inward directed) at r=a reversing its direction at r=a-3cm has been assumed, consistently with the experimental findings. The resulting C II and C IV ion population profiles are shown in fig. 6: the example at low density is characterized by a broader profile than the case at medium density and at high density. The corresponding penetration efficiency ξ decreases from 18% to 14.5% and 6.5% respectively, depending on density more than on the temperature. These levels of ξ justify the relatively low plasma contamination, despite the very strong plasma-wall interaction: the minimum Zeff values range from ~2 at n_e= 3 10 ^{19} m^{-3} to ~1.5 at n_e= 8 10 ^{19} m^{-3} with plasma currents ≥ 0.8 MA.

4. Summary

The electron temperature and density at the edge have been measured on RFX observing the line intensity ratio of selected He I lines emitted by a thermal helium beam. This technique has allowed the extension of the $T_{e,edge}$ and $n_{e,edge}$ measurements to high plasma current discharges (up to 1 MA). The experimental $T_{e,edge}$ has been correlated with the parameter I/N, allowing a more reliable evaluation of the impurity influxes. A dependence of the impurity penetration efficiency on $n_{e,edge}$ has been found: a low edge density of ~ 10^{19} m^{-3} corresponds to a relatively high (~ 18%) penetration efficiency, that decreases to ~ 7% at high density.

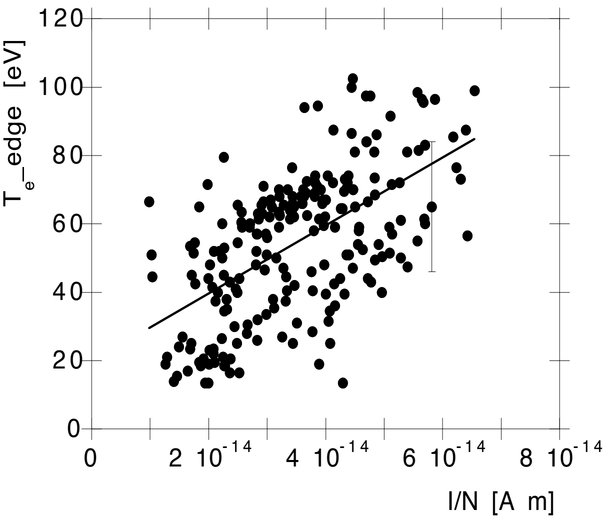

Fig.5: Correlation between $T_{e,edge}$ and I/N

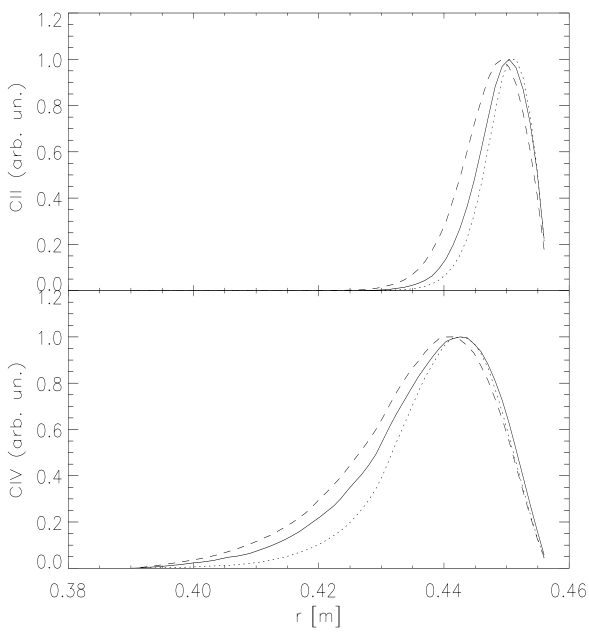

Fig.6:C II and C IV ion population in in three different plasma conditions.
Solid line: Te(a)=60 eV,ne(a)= 2 10^{19} m^{-3}
Dotted line: Te(a)=20 eV,ne(a)= 6$10^{19}$ m^{-3}
Dashed line :Te(a)=100 eV,ne(a)= 10^{19} m^{-}

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