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EEDF Measurements in the CASTOR Tokamak Using the First Derivative Langmuir Probe Method

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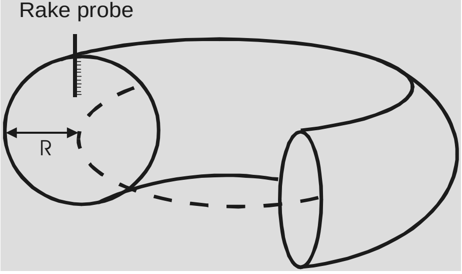
Introduction

Langmuir probes (LP) are widely used in plasma physics to provide local measurements of important plasma parameters, like the plasma potential, the density of the charged particles or the electron energy distribution function, $f(\varepsilon)$ (EEDF),. The accuracy the LP under adverse conditions, such as the presence of magnetic fields or high plasma temperature, is still being questioned. The applicability of the first-derivative method for processing the electron part of the current-voltage (I-V) characteristics measured in tokamak edge plasmas to acquire the EEDF was discussed and published in [1].

In this paper we report results of the time dependance of the plasma potential, electron temperature and densities during a typical discharge in the CASTOR tokamak, [2]. In the confined plasma we find the EEDF to be bi-Maxwellian. The results obtained are in good agreement with the Stangeby method [3] usually used for LP data processing.

Results from different methods of differentiating the I-V characteristics are also discussed.

Langmuir probe measurements in the CASTOR tokamak edge plasma.



Major radius	400 mm
Minor radius R	100 mm
Toroidal magnetic field	0.5-1.5 T
Plasma current	5-20 kA
Pulse length	< 50 ms
Working gas	30-40 mPa hydrogen

Figure 1: Schematic representation of the CASTOR tokamak experimental set-up and list of the main parameters.

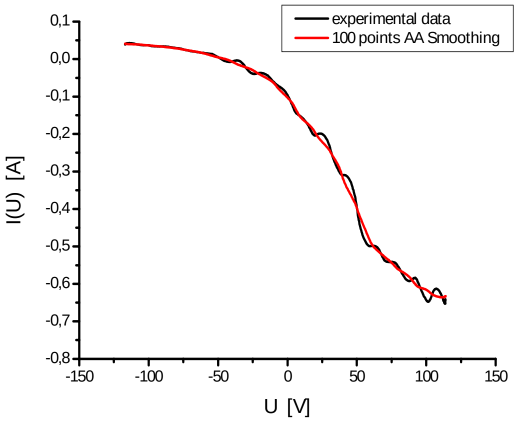


Figure 2: A single I-V characteristic from the shot #26402, pin #1 (r = 56 mm) of the Rake probe.

The I-V characteristics measurements in the CASTOR tokamak edge plasma were carried out by using an array of 16 single Langmuir probes, the Rake probe oriented perpendicular to the magnetic field lines (Fig. 1). Each cylindrical probe tip has a length of L=2 mm and a radius of R=0.35 mm. The probes are spaced by 2.5 mm in the radial direction. All probe tips are biased simultaneously by a triangular voltage $U(t)$ with respect to tokamak chamber, which serves as a reference electrode. The time necessary to measure a single I-V characteristic (Fig. 2) is typically ~ 1 ms.

The procedure for evaluating the EEDF from I-V characteristics using the first derivative probe method is described in [1]. The connection between the first derivative of the probe current, *dI(U)/dU* and the EEDF for probes oriented perpendicular to the magnetic field is:

$$\frac{dI(U)}{dU} = -const\frac{eU}{\psi(\varepsilon)}f(\varepsilon) \tag{1}$$

where e is the electron charge, U is probe potential with respect to the plasma potential and $\psi(\varepsilon)$ is the diffusion parameter [4]. To calculate the diffusion parameter, we take into account the fact that, although the local diffusion near the probe is classical, the global transport is anomalous (Bohm diffusion) due to the turbulence [4,5]. The EEDF is thus described by:

$$f(\varepsilon) = -\frac{3\sqrt{2m}R\ln\left(\frac{\pi L'}{4R}\right)}{32e^3SR_LU}\frac{dI(U)}{dU} \tag{2}$$

where m is the electron mass, S is the probe area and R_L is the Larmor radius. We normalize the EEDF by the electron density, n : $\int_0^\infty f(\varepsilon)\sqrt{\varepsilon}d\varepsilon = n$.

An example of the EEDF for the radial position r = 56 mm in the middle of the current impulse of the shot #26402 is shown in Figure 3. The green line is a sum of the red one and the blue one. It is clearly seen that the EEDF is bi-Maxwellian develop.

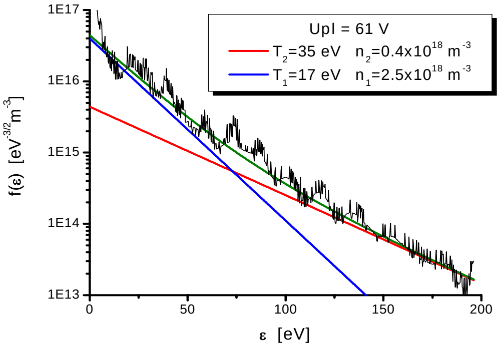


Figure 3.

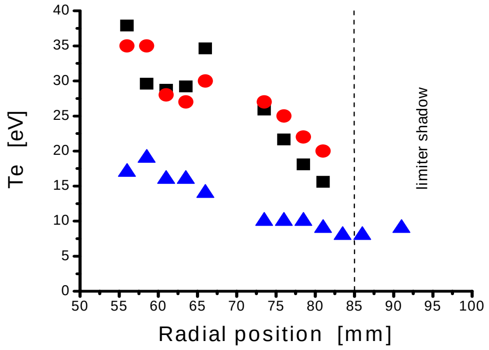


Figure 4.

In Fig. 4 the two electron temperatures at different radial position are presented. The fit with the experimental EEDF was obtained with an accuracy of 5%. It has to be noted that in the limiter shadow, $r > 85$ mm, the EEDF is mono-Maxwellian with a temperature about 8 eV.

In the same figure the results obtained by Stangeby method [3] (squares) are also presented. We must point out that the Stangeby method assumes a Maxwellian EDF of the electrons. Only the temperature of the high energetic fraction of electrons dominates [6,7] and can be evaluated. On the other hand the density of the hot population of electrons is about 10% of the total electron density. In the figure 5 the total electron densities at different radial positions are presented.

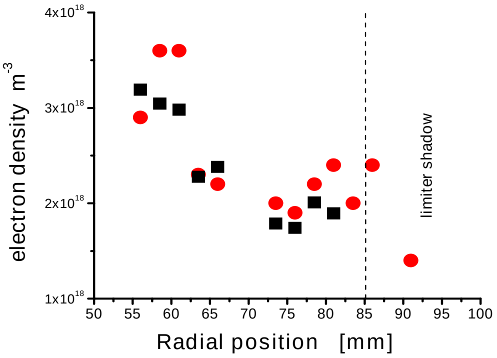


Figure 5.

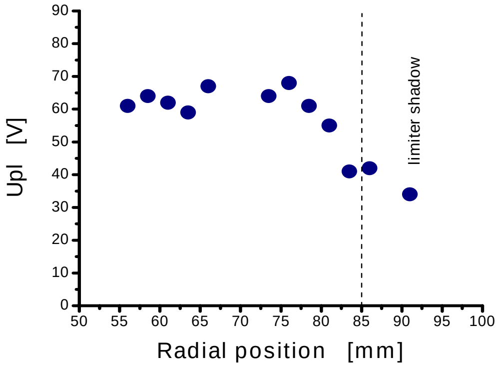


Figure 6.

We compare the first derivative probe method results (dots) with the Stangeby method (squares). The uncertainty in the first derivative method values evaluated does not exceed ± 30%. The two methods show good agreement. However, the first derivative method allows one to obtain in addition the "real" EEDF and the plasma potential values as well (Figure 6).

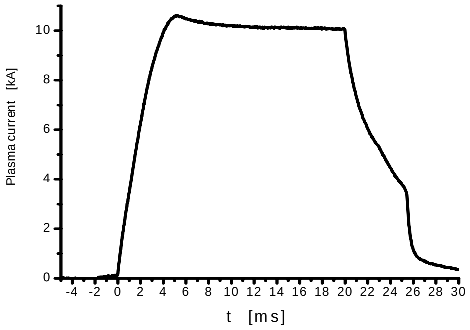


Figure 7.

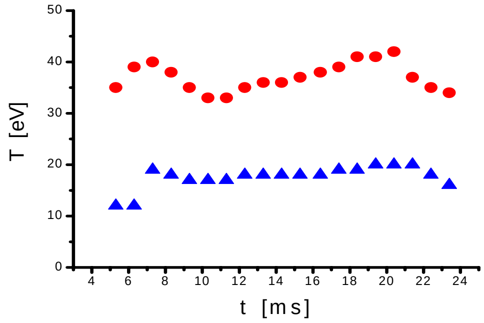


Figure 8.

In the Figure 7 the current impulse of the shot #26402 is presented. Figure 8 presents the time evolution of the two temperatures of the high and low energy electrons at r = 56 mm. The data presented in Fig. 8 in general follow the behavior of the current impulse.

The experimental data presented in figures 2-9 was processed using the Origin Lab 6.1 software. In figure 10 the same data is processed using an advanced method based on an adaptive choice of the filtering and differentiating instrument functions (see P5.080 in this conference), and which additionally provides error evaluation as well as the period and amplitude values of the fluctuations. The plasma parameters achieved in this way are practically the same as those presented here, and we foresee that the advanced method will be useful for identifying the main modes of plasma turbulence.

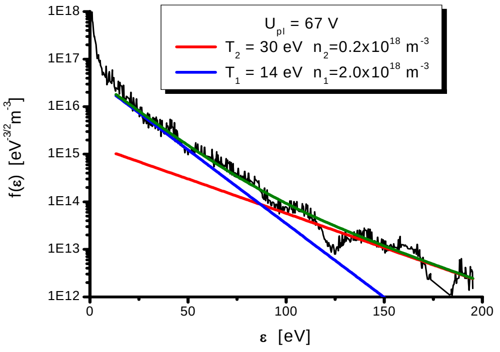


Figure 9: EEDF for the shot #26402, pin #5 (*r* = 66 mm), processed by using the Origin Lab 6.1 software.

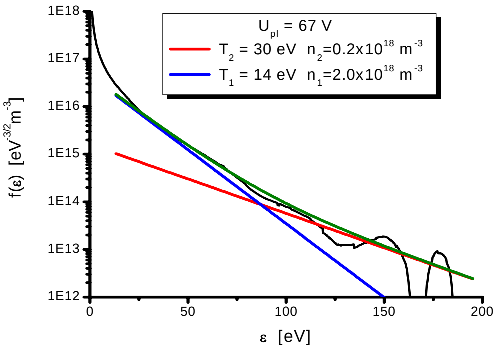


Figure 10: EEDF for the shot #26402, pin #5 (*r* = 66 mm), processed by using an advance method for smoothing the experimental curves.

Conclusion.

Results of EEDFs for tokamak plasma at different radial positions in the edge plasma are acquired and the values of the plasma potential, electron temperature and electron densities are evaluated.

- It is shown that in the confined plasma the EEDF is bi-Maxwellian.
- In the limiter shadow, $r > 85$ mm, the EEDF is mono-Maxwellian with a temperature about $T\sim$ 8-9 eV.
- The results obtained are in good agreement with the Stangeby method usually used for LP data processing.

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