

Determination of the plasma potential and the EEDF by Langmuir probes in the divertor region of COMPASS tokamak

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Abstract. This paper reports experimental data obtained on the COMPASS tokamak by an array of Langmuir probes embedded in the divertor tiles. The measured current-voltage probe characteristics were processed by the recently published first-derivative probe technique for precise determination of the plasma potential and the electron energy distribution function (EEDF). The measurements were performed during L-mode hydrogen and deuterium plasma with a toroidal magnetic field $B_T = 1.15$ T, plasma current $I_p = 180$ kA and average electron density $n_e = 8 \times 10^{19} \text{ m}^{-3}$. The spatial profile of the electron temperatures shows that in the vicinity of the inner and outer strike points in hydrogen plasma the EEDF can be approximated by a bi-Maxwellian distribution, with a dominating low-energy electron population (4 - 7 eV) and a minority of electrons with higher energies (12 - 18 eV). In the private flux region between the two strike points, the EEDF is found to be Maxwellian with temperatures in the range of 7 - 9 eV. In the case of deuterium plasma under similar discharge conditions, the EEDFs in the vicinity of the inner and outer strike points, as well as in the private flux region between the two strike points, are found to be bi-Maxwellian.

1. Introduction

Langmuir probes (LPs) are relatively simple, inexpensive and robust diagnostic tools that are compatible with the tokamak scrape-off layer (SOL) conditions. They are readily deployable in large arrays built into the edge structures, such as limiters and divertor tiles. Because of their simplicity and the ability to perform local measurements of the electron energy distribution function (EEDF) and the plasma potential, LPs are frequently used in magnetized plasmas to characterize the edge plasma parameters [1]. Nevertheless, the interpretation of the electron part of the current-voltage (I/V) characteristics above the floating potential remains a challenging subject in tokamaks because of the strong magnetic field effects.

This paper reports experimental data obtained on the COMPASS tokamak by Langmuir probes embedded in the divertor tiles [2]. The measured current-voltage probe characteristics were processed by means of the recently published [3,4] first-derivative probe technique (FDPT) for the precise



determination of the plasma potential and the real EEDF, which can deviate from Maxwellian. The measurements were performed during L-mode hydrogen and deuterium plasma and the results are analyzed and discussed in the following sections.

2. The first-derivative Langmuir probe technique for evaluating the EEDF in tokamak edge plasma

The FDPT for evaluating the plasma parameters in tokamak edge plasma was published and discussed in detail in [3,4]. It was shown there that the electron current flowing to a cylindrical probe negatively biased by a potential U is given by:

$$I_e(U) = -\frac{8\pi e S}{3m^2} \int_{eU}^{\infty} \frac{(W - eU)f(W)dW}{\gamma(W) \left[1 + \frac{(W - eU)}{W} \psi(W) \right]} \quad (1)$$

Here $f(\varepsilon)$ is the isotropic EEDF normalized by $\int_0^{\infty} f(\varepsilon)\sqrt{\varepsilon}d\varepsilon = \frac{4\pi\sqrt{2}}{m^{3/2}} \int_0^{\infty} f(W)\sqrt{W}dW = n_e$, where ε is

the electron energy; e , m and n_e are the electron charge, mass and density; S is the probe area; U is the probe potential U_p with respect to the plasma potential U_{pl} ($U = U_p - U_{pl}$). The geometric factor γ assumes values in the range $0.71 \leq \gamma \leq 4/3$.

As was shown in [3] for probes oriented parallel to the magnetic field, the diffusion parameter is:

$$\psi^{\parallel}(W) = \frac{\pi L'}{64\gamma R_L(W, B)} \quad (2)$$

Here L' and $R_L(W, B)$ are the characteristic length of the turbulences and the electron Larmor radius. Taking into account (2) for the EEDF measured by a cylindrical probe parallel to the magnetic field, we obtain:

$$f(\varepsilon) = -\frac{3\pi\sqrt{2m}L'}{128e^3SR_L(\varepsilon, B)U} \frac{dI}{dU}. \quad (3)$$

3. Langmuir probe measurements in the COMPASS divertor area

The evaluation of the plasma potential and EEDF was performed in a series of reproducible ohmic discharges in hydrogen and deuterium plasma. The results presented in this section are from typical COMPASS discharges labeled shot # 3908 (hydrogen plasma) and # 6036 (deuterium plasma) where the toroidal magnetic field was $B_T = 1.15$ T, the plasma current $I_p = 180$ kA and the average electron density $n_e = 8 \times 10^{19} \text{ m}^{-3}$. The divertor probe system in COMPASS consists of 39 single graphite Langmuir probes poloidally embedded in the divertor tiles; they are oriented parallel to the magnetic field and provide profiles with a spatial resolution in the poloidal direction down to 5 mm [5]. Each probe has an area of $S = 5.6 \times 10^{-7} \text{ m}^2$. These probes were electrically biased with respect to the tokamak chamber walls by means of triangular signal with a frequency of 1 kHz [6].

Results of the evaluation of the poloidal distribution of the plasma potential during hydrogen (# 3908) and deuterium (# 6036) discharges are presented in the figures 1a and 1b. The positions of the strike points are indicated by the vertical dashed lines: inner (Langmuir probe (LP) #7 at radial position $R = 0.419$ m) and outer (LP #24, $R = 0.501$ m) strike points for shot # 3908, and (LP #10, $R = 0.431$ m) and (LP#19, $R = 0.477$ m), respectively, for shot # 6036. During discharge # 6036 in deuterium, the X-point was closer to the divertor and, thus, strike points were closer to each other. It is seen that the plasma potential values in both shots decrease monotonically from the high-field side to the outer strike point and then increase (more pronounced for discharge # 6036).

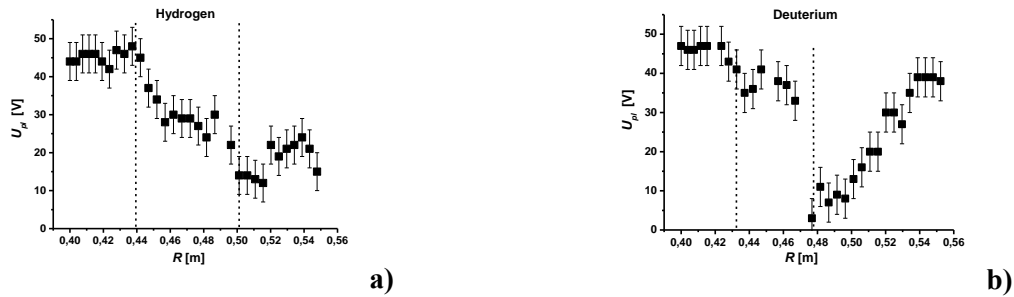


Figure 1. Poloidal profiles of the plasma potential obtained by the FDPT:

a) shot # 3908 in hydrogen and **b)** shot #6036 in deuterium.

The poloidal profile of electron temperatures in figure 2a shows that in hydrogen plasma in the vicinity of the inner and outer strike points the EEDF can be approximated by a bi-Maxwellian energy distribution. The low temperature (4 - 7 eV) population is dominant with presence of a small high energy (12 - 18 eV) electrons group. In the private flux region between the two strike points, the electron energy distribution function is found to be Maxwellian with temperatures in the range of 7 - 9 eV [3]. The corresponding densities are presented in figure 2b with the same symbols. We should point out that further theoretical and experimental investigations are needed to clarify the origin of the low-energy fraction in the bi-Maxwellian EEDF [7,8]. It should be noted that a bi-Maxwellian EEDF was also recently observed in the liquid lithium divertor area of National Spherical Torus Experiment (NSTX) at Princeton Plasma Physics Laboratory [9]. In these articles [7,8,9] a hypothesis accounting for the inelastic collision effects (i.e. excitation and ionization of neutral hydrogen or deuterium) is proposed to explain this EEDF feature.

The poloidal profile of the electron temperatures and densities corresponding to shot # 6036 in deuterium plasma are shown in figures 2c and 2d. The EEDF is bi-Maxwellian in the entire divertor region of this deuterium plasma.

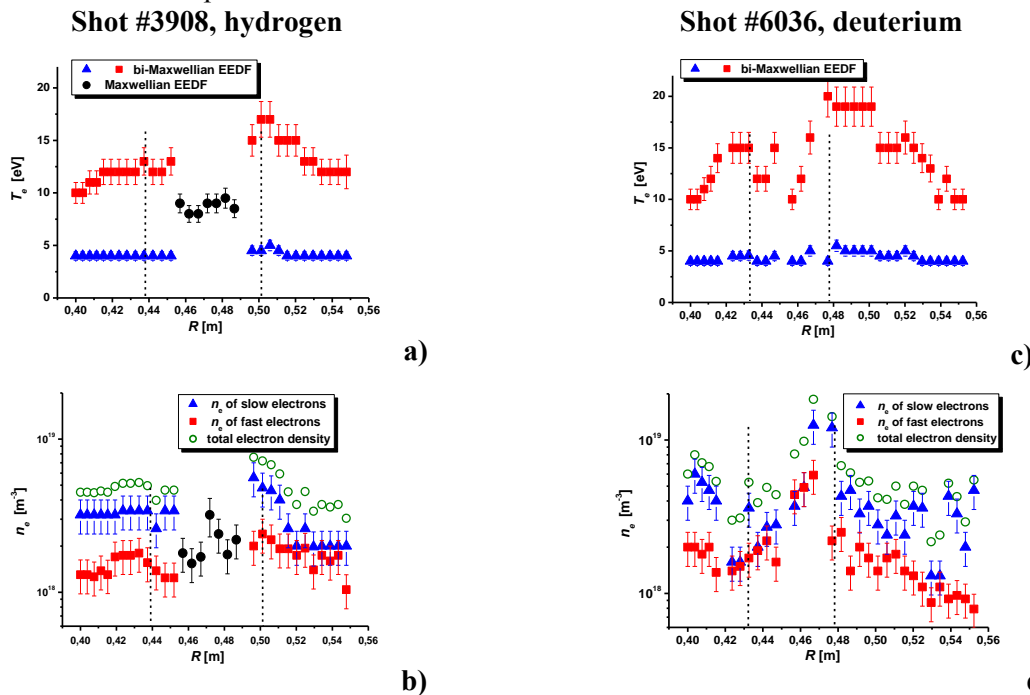


Figure 2. Poloidal profiles of the electron temperatures and densities obtained by the FDPT for shot # 3908 (a and b) and # 6036 (c and d). The solid squares and triangles indicate the high and low temperatures and densities; the open circles are the temperatures and densities of the Maxwellian EEDF.

In the hydrogen discharge, the electron densities of the low and high energy fractions differ in the high field side (HFS) by a factor of ~ 3 , and on the low field side (LFS), by a factor of ~ 1.5 . In deuterium, the difference on HFS is ~ 4 , around the outer strike point, ~ 2 , and after radial position 0.52 m ~ 5 .

4. Conclusions

This paper reports experimental data obtained on the COMPASS tokamak by Langmuir probes embedded in the divertor tiles. The first-derivative probe method was used for precise evaluation of the poloidal distribution of the plasma potential and the EEDF (respectively, the electron temperatures and the electron densities) during the current shots in hydrogen and deuterium ohmic L-mode plasma.

The spatial profile of the electron temperatures shows that in hydrogen plasma in the vicinity of the inner and outer strike points the EEDF can be approximated by a bi-Maxwellian distribution, with a dominating low-energy electron population and a minority of electrons with higher energies. In the private flux region between the two strike points, the electron energy distribution function is found to be Maxwellian.

In the case of deuterium plasma at similar conditions of the discharge, the EEDFs in the vicinity of the inner and outer strike points, as well as in the private flux region between the two strike points, are found to be bi-Maxwellian.

Acknowledgements

This research has been supported by the European Community under the contract of Association between EURATOM/IPP.CZ and EURATOM/INRNE.BG; by Bulgarian National Science Fund through the Association EURATOM-INRNE and by DNTS 01-10/28.11.2011, International Atomic Energy Agency (IAEA) Research Contract No 17125/R0, R1 as a part of the IAEA CRP F13014 on "Utilisation of a Network of Small Magnetic Confinement Fusion Devices for Mainstream Fusion Research" and 5th and 6th IAEA Joint Experiment, by the JOINT RESEARCH PROJECT between Institute of Plasma Physics v.v.i., AS CR and Institute of Electronics BAS BG, the grant project GA CR P205/11/2341, by MSM Project # LM2011021 and project BG051PO001-3.3.05-0001 "Science and business".

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