

Electron energy distribution function in the divertor region of the COMPASS tokamak

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Abstract. The plasma parameters during an L-mode hydrogen discharge in the COMPASS tokamak with a toroidal magnetic field $B_T=1.15$ T, line-averaged electron density $n_e = 6 \times 10^{19} \text{ m}^{-3}$ and a plasma current variation from 209 kA to 100 kA were studied in the divertor region. The electron energy distribution function for 209 kA at the high-field side and the private region is Maxwellian with a temperature in the range of 5 – 9 eV, while around the outer strike point and the low-field side it is bi-Maxwellian with a low-energy electron group (4 – 5 eV) and higher energy electrons (10 – 20 eV). As the plasma current decreases, the appearance of the bi-Maxwellian EEDF is shifted towards the low-field side; at plasma current of 100 kA, the EEDF is Maxwellian in the whole divertor region.

1. Introduction

The experimental knowledge of the electron energy distribution function (EEDF) is of great importance in understanding the underlying physical processes that occur at the edge of tokamak plasmas, such as the interaction of the plasma with the tokamak wall, turbulence and the formation of the edge transport barrier.

The plasma parameters during an L-mode hydrogen discharge in the COMPASS tokamak [1] with a toroidal magnetic field $B_T=1.15$ T and a line-averaged electron density $n_e = 6 \times 10^{19} \text{ m}^{-3}$ with a variation of the plasma current from 209 kA to 100 kA were studied in the divertor region by means of 39 Langmuir probes embedded in the divertor tiles. For precise determination of the plasma potential and evaluation of the real EEDF, the current-voltage (IV) characteristics measured were processed using the recently published [2-5] first-derivative probe technique (FDPT).

2. Langmuir probe measurements in the divertor region of the COMPASS tokamak

The probe measurements were performed during L-mode hydrogen plasmas (discharge # 9009 and #9008) with a toroidal magnetic field $B_T=1.15$ T and a line-averaged electron density $n_e = 6 \times 10^{19} \text{ m}^{-3}$.

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Figure 1 presents the temporal profile of the plasma current during the discharge. The time points, (respectively plasma currents) when the plasma parameters were evaluated are marked by different colors.

The divertor probe system in the COMPASS tokamak consists of 39 single graphite Langmuir probes poloidally embedded in the divertor tiles providing data with a 5 mm spatial resolution [3]. The probes are biased with respect to the tokamak chamber wall by a triangular voltage $U_p(t)$ swept at a frequency of 1 kHz supplied by a KEPCO 100-4M power supply. The ramp-up/ramp-down phases last 0.5 ms, so that the plasma current can be assumed constant during each sweep cycle. The probe potential and the probe current versus time are recorded by the tokamak DAQ [6]. The IV probe characteristics are constructed using the data recorded at different moments during the discharge.

Figure 2 a) presents the radial profile of the ion saturation current density, J_{sat} . The different colors (the same as in figure 1) correspond to the different plasma current values. The radial positions of the maximums at different discharge currents J_{sat} correspond to the positions of the outer strike points provided by the Equilibrium FITing code (EFIT) reconstructions. The EFIT reconstructions of the magnetic field surfaces with accuracy of about 5 mm (figure 2 b)) show that as the plasma current decreases, the position of the outer strike point changes within a few millimetres. That is why the outer strike point positions are presented as a region here and below. In contrast, the position of the inner strike point is shifted towards the high-field side by about 5 cm.

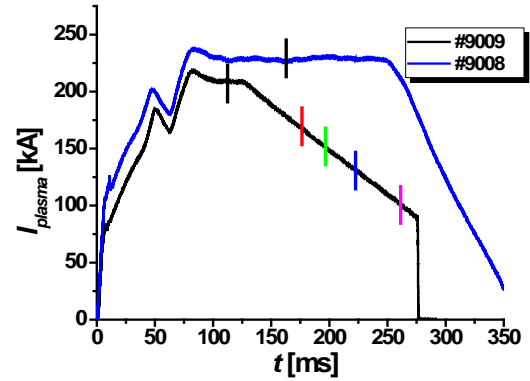


Figure 1. Temporal profiles of the plasma current for discharge #9009 and #9008.

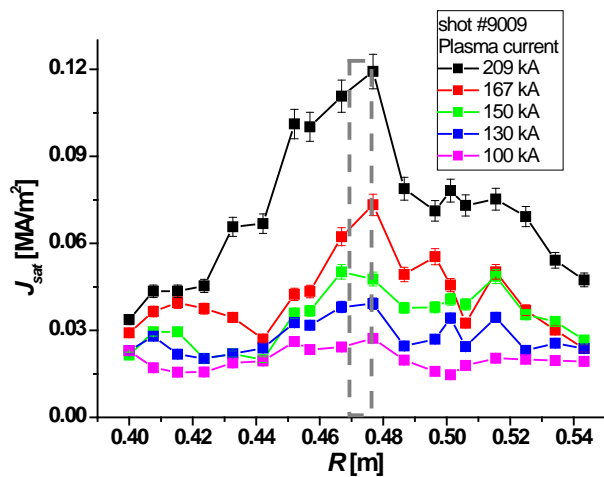


Figure 2 a). Spatial distribution of the ion saturation current density.

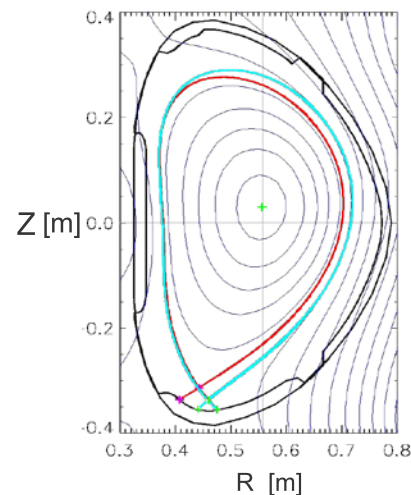


Figure 2 b). The EFIT reconstructions of the magnetic field surfaces - separatrix at 209 kA (blue) and 150 kA (red curve).

Further, the FDPT was applied to process the IV characteristics in order to obtain the plasma potential and the EEDF (respectively, the electron temperatures and densities) [2-5]. For example, figure 3 a) shows the electron energy probability function (EEDF) on probe #12 (at radial position $R = 0.4421$ m) when the plasma current is $I_{pl} = 210$ kA for shot #9009.

The EEDF has the same information about the electron gas as EEDF and is frequently used to represent measured probe data. The EEDF, presented in a semi-log scale, allows a quick visualization

of a departure of the measured EEPF from the Maxwellian distribution, which is a straight line in this representation [7]. The EEPF on the high-field side (HFS) is Maxwellian. Using the slope of the EEPF in a logarithmic scale, one can evaluate the electron temperature at $(8.5 \pm 0.8 \text{ eV})$.

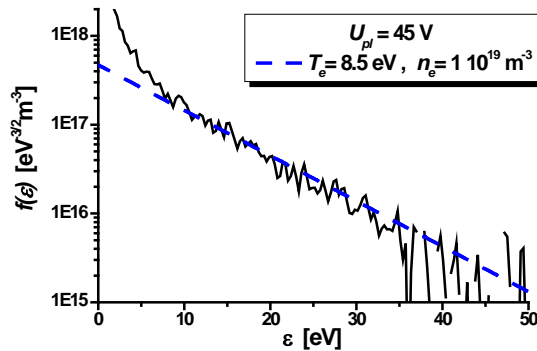


Figure 3 a). Experimental EEPF (black line) and the Maxwell model line (dashed) for LP#12, $R = 0.4421 \text{ m}$.

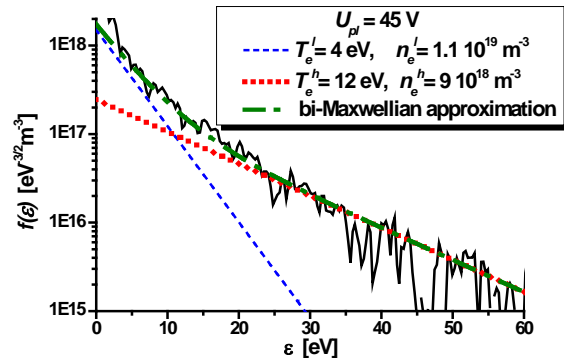


Figure 3 b). Experimental EEPF (black line) and the sum of the model ones for two electron temperatures (dashed dotted line) for LP#15, $R = 0.4569 \text{ m}$.

The electron density is calculated using the expression for normalization of the EEDF; in this case $n_e = 1 \times 10^{19} \text{ m}^{-3}$. Around the outer strike point, the EEPF is found to be non-Maxwellian but can be approximated by a bi-Maxwellian one – i.e., by a sum of two Maxwellian EEPFs with two different temperatures. An example of a bi-Maxwellian EEPF measured by probe #15 ($R = 0.4569 \text{ m}$) is presented in figure 3 b). The low-temperature electron group (blue line, $T_e^l = 4 \pm 0.4 \text{ eV}$) has a density higher than that of the high-temperature one (red line, $T_e^h = 12 \pm 0.1 \text{ eV}$). The influence of the two-temperature EEDF on the parallel heat flux density, as well as a discussion on the origins of the two temperatures, is presented in detail in our recent publication [4].

3. Results and discussion

We present below the main plasma parameters for discharge #9009 using the IV characteristics. The results of the evaluation of the poloidal distribution of the floating potential and the plasma potential during L-mode hydrogen discharges are presented in figures 4 a) and 4 b). The colors correspond to the different plasma current values. The position of the outer strike points (presented as a region as was mentioned above) from the reconstruction of the magnetic surfaces by the Equilibrium FITing code (EFIT) is also shown in the figures. It is seen that at higher plasma currents the values of the

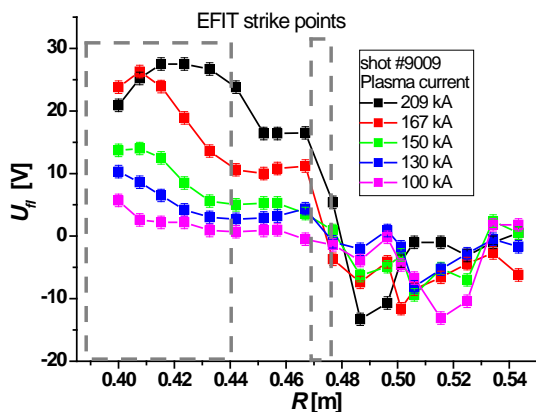


Figure 4 a). Poloidal distribution of the floating potential at different plasma currents.

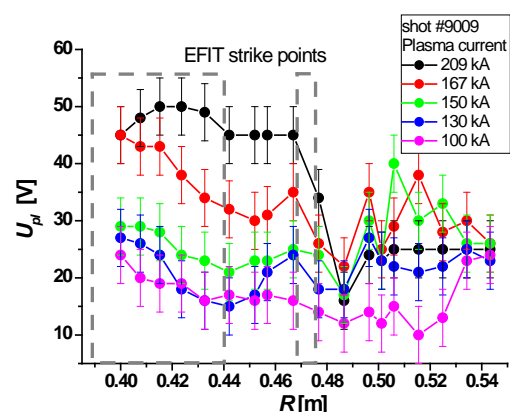


Figure 4 b). Poloidal distribution of the plasma potential at different plasma currents.

potentials are increasing, which is noticeable on the HFS and in the private flux region. Thus, for a difference of 100 kA, the plasma potential value rises by a factor of two, from 20 V to 50 V. However, on the low-field side (LFS), the effect of the plasma current is less obvious, because the plasma is much more turbulent, so that similar values of about 30 V are evaluated.

Figure 5 shows the poloidal distribution of the electron temperature. The dots correspond to the Maxwellian EEDFs. The triangles and squares indicate the low and high temperatures of the bi-Maxwellian EEDFs, respectively.

The position of the two strike points from the EFIT are indicated by colored dashed lines. It is seen that, at plasma current of 210 kA, the EEDF changes to bi-Maxwellian at 2 cm from the outer strike point in the private flux region. When the plasma current decreases, the appearance of the bi-Maxwellian EEDF is shifted to the LFS direction. At 100 kA, the EEDF is Maxwellian in the whole divertor region with temperatures of 5–9 eV.

Using the EEDF, the electron densities are determined for both electron groups. In figure 6 a), an example is given for the poloidal profile of the electron densities at 210 kA represented (here and below) by the same symbols as used in figure 5. Both electron groups exhibit similar values of the densities. In figure 6 b), the dependence is presented of the total electron densities on the plasma current.

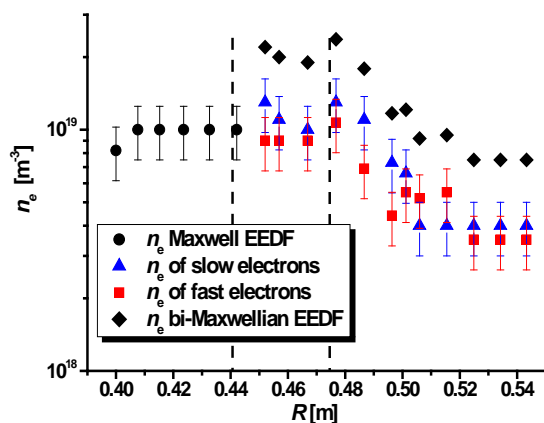


Figure 6 a). Poloidal distribution of the electron densities n_e at discharge current of 210 kA for shot #9009.

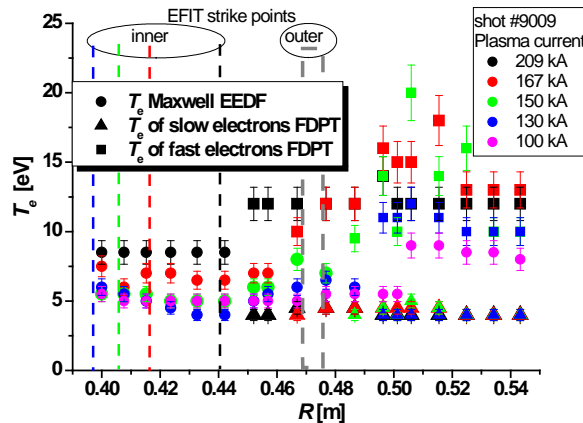


Figure 5. Poloidal distribution of the electron temperature T_e for different discharge currents for shot #9009.

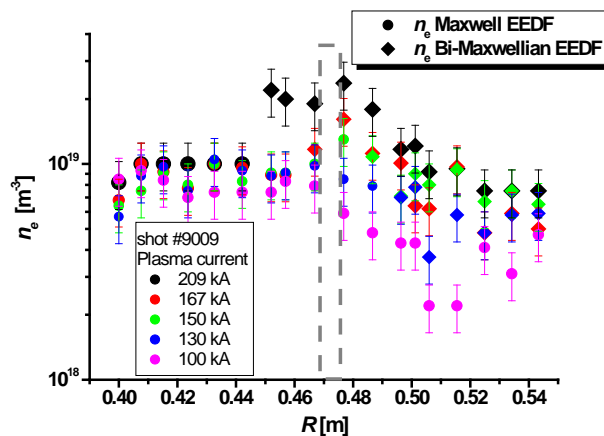


Figure 6 b). Poloidal distribution of the total electron densities n_e for different discharge currents for shot #9009.

For a comparison, we present below (figure 7) results from shot #9008 with a constant discharge current of 230 kA and a line average density of $5 \times 10^{19} \text{ m}^{-3}$ during the steady-state phase of the discharge. The data refer to time 162 ms.

The EEDF in the private flux region is Maxwellian, while in the LFS and HFS outside of the strike points it is bi-Maxwellian. The distance between the strike points is ~ 5 cm. This is in agreement with our previous studies [3,8].

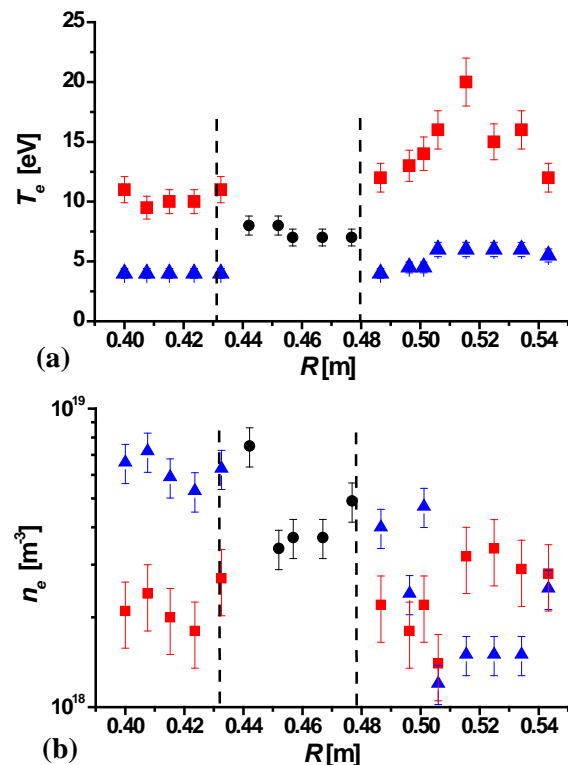


Figure 7. Poloidal distribution of (a) the electron temperature T_e and (b) the electron densities n_e during discharge #9008.

4. Conclusions

This paper reports the electron energy distribution function (EEDF) in the divertor of the COMPASS tokamak as determined by the first-derivative probe technique. The current-voltage probe characteristics measured were processed by this technique, which gives information about the plasma parameters. The effect of the plasma current on the plasma parameters was studied.

The poloidal profile of the electron temperatures show that at a plasma current of 100 kA the EEDF is Maxwellian with temperatures in the range of 5 – 9 eV. As the plasma current increases, the behavior of the EEDF changes. It was found that in hydrogen plasmas in the vicinity of the strike points the EEDF can be approximated by a bi-Maxwellian distribution, with a low-energy electron group (4 – 5 eV) and higher energy electrons (10 – 20 eV). The dependence of the strike point position when the bi-Maxwellian distribution appears was also studied. When the plasma current decreases, the appearance of the bi-Maxwellian EEDF is shifted to the LFS direction.

Acknowledgements

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