Evaluation of the plasma parameters in COMPASS tokamak divertor area

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Abstract. We report results of the evaluation of the plasma potential, the electron temperature and the electron density during the current shots in the COMPASS tokamak, (IPP.CR, Prague, Czech Republic). The comparisons with results from model calculations based on an extended formula for the electron probe current show a satisfactory agreement.

The results presented demonstrate that the procedure proposed allows one to acquire additional plasma parameters using the electron part of the current-voltage Langmuire probe (LP) characteristics in tokamak edge plasma probe measurements.

1. Introduction

Among the contact methods of plasma diagnostics, the electric probes are the most reliable diagnostic tools allowing one to measure edge plasma parameters with a sufficiently high temporal and spatial resolution. In non-magnetized low-density plasmas, LPs allow local measurements of the plasma potential, the charged particles density and the electron energy distribution functions, \( f(\varepsilon) \), (EEDF) [1]-[7].

In magnetized plasma, the interpretation of the electron part of the current-voltage (IV) characteristics above the floating potential, \( U_f \), still remains difficult [8] because the electron part of the IV characteristics is distorted due to the influence of the magnetic field. For this reason, in the strongly magnetized tokamak plasmas, the ion saturation branch of the IV and the part around the floating potential are usually used when retrieving the plasma parameters [9]. The precise evaluation of the plasma potential and the real EEDF is of great importance in understanding the underlying physics of the processes occurring at the plasma edge in tokamaks, such as the formation of transport barriers, plasma-wall interactions, edge plasma turbulence, etc.

In this paper we report results of the evaluation of the plasma potential, the electron temperatures and the electron density during the current shot in the new COMPASS tokamak, (Prague, IPP.CR).

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The results obtained from the data measured by divertor probes confirmed the applicability of the technique proposed.

2. First derivative Langmuir probe method

The first-derivative probe method for evaluating the plasma parameters in tokamak edge plasma was published and discussed in detail in [8,10]. The theory for magnetized plasmas was developed for LPs in a non-local approach when the electrons reach the probe in a diffusion regime [11]. The electron current flowing to a cylindrical probe negatively biased by potential $U$ is given by:

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

(1)

where $W$ is the electron energy; $e$, $m$ and $n$ are the electron charge, mass and density; $S$ is the probe area; $\psi(W)$ is the diffusion parameter; $U$ is the probe potential with respect to the plasma potential $U_{pl}$ ($U = U_p - U_{pl}$). The geometric factor $\gamma = \gamma(R/\lambda)$ assumes values in the range $0.71 \leq \gamma \leq 4/3$ ($R$ being the probe radius) [11].

Here $f(W)$ is the isotropic EEDF normalized by:

$$\frac{4\pi \sqrt{2}}{m^{1/2}} \int_0^{\infty} f(W)\sqrt{W}dW = \int_0^{\infty} f(\varepsilon)\sqrt{\varepsilon}d\varepsilon = n.$$  

(2)

As it was shown in [8,10] for probes oriented parallel to the magnetic field, the diffusion parameter is:

$$\psi_W(W) = \frac{\lambda L' W^{1/2}}{644\gamma_0 R_L(W,B)}.$$  

(3)

Here $L'$ and $R_L(W,B)$ are the characteristic length of the turbulences and the electron Larmor radius.

It was shown in [8] that at strong magnetic fields, i.e., for high values of the diffusion parameter $\psi(W) = \psi_0/\sqrt{W} \gg 1$, the minimum of the first derivative of the IV characteristics is shifted negatively by a value between $T_e$ and $1.5T_e$ in volts with respect to the plasma potential. In this case, and in order to evaluate $U_{pl}$ accurately, we propose the following procedure: the electron temperature is evaluated from the slope in logarithmic scale of the first derivative of the non-distorted part of the experimental IV characteristics. Using this temperature, a model curve of the first derivative (derivative of equation (1)) is calculated. Then the best fit with the experimental first derivative provides the value of the plasma potential.

As it was shown in [8], the EEDF is not represented by the second derivative of the electron probe current (Druyvesteyn formula), but rather by its first derivative. Taking into account equation (3) for the EEDF measured by a cylindrical probe parallel to the magnetic field, we obtain:

$$f(\varepsilon) = -\frac{3\pi \sqrt{2mL}}{128e^2S\lambda^2(\varepsilon, B)U} \frac{dI}{dU}.$$  

(4)

3. Langmuir probe measurements in COMPASS divertor area

The divertor probe system on COMPASS consists of 39 single graphite Langmuir probes embedded parallel to the magnetic field in the divertor target providing profiles with typical spatial resolution in the poloidal direction down to 5 mm. The probe area exposed parallel to the magnetic field in the plasma is $S = 112.5 \times 10^6$ m$^2$ (figure 1 (a) and (b)).

Using the main shot parameters and the probe data during the experiment, we found that the plasma is moving in a poloidal (figure 1 (c)) direction. Until the end of COMPASS operation in the middle of October 2010, a regime with stable position of the plasma column could not be achieved – plasma was
moving in radial and poloidal directions. The signal varied in time so that we did not observe any quasi-stationary phase. Commissioning of the fast feedback for plasma position is presently ongoing. Full performance is planned to be achieved, including elongated diverted plasma, maximum plasma current and H-mode discharges.

Figure 1. (a) Poloidal cross-section of Compass with the position of the divertor probe system; (b) toroidal cross-section through the divertor target showing a Langmuir probe; (c) circular plasma moves to the divertor.

Figure 2. a) Probe bias $U_p$ and b) probe current $I(U_p)$ as a function of the time $t$ during shot 1654 for probe #38.

Figure 2 presents the record of the sweeping probe bias $U_p$ (a) and the probe current $I$ (b) during shot 1654 in probe 38.

To demonstrate the procedure of evaluating $U_{pl}$, $f(\varepsilon)$ and $n$, we will analyze a single IV characteristic, shot 1654 for probe #38, IV5 working gas H$_2$.

Figure 3 presents the first derivative of the smoothed IV curve and the fit with the model curve (first derivative of equation (1)). Using this comparison one can evaluate the plasma potential $U_{pl} = 39$ V. One can also observe there a more or less pronounced bend in the experimental curve. In practice, even a small increment of $I(U)$ at a probe potential $U$ positive with respect to plasma potential leads to $I(U)$ deviating from zero at $U_{pl}$. Additional reasons for this effect are the plasma potential fluctuations due to the plasma turbulence and the smoothing of the experimental IV characteristics.
Figure 3. First derivative of the smoothed experimental IV curve (dots), shot 1654 for probe #38, IV5. Model curve – solid line.

Figure 4 presents the EEDF obtained by parallel probe #38, shot 1654, by using equation (4) (dots). The EEDF may be approximated by a Maxwellian with electron temperature \( T = 6.5 \) eV (solid line). The electron density is calculated by using equation (2) and the estimated value is \( n_e = (8 \pm 2) \times 10^{17} \) m\(^{-3}\).

Finally, using the values obtained by the first derivative probe method, we performed model calculations for the IV characteristics (eq. (1)). Examples of the comparison with the experimental IV curves are presented in figure 5. As one can see, the agreement is satisfactory.

The uncertainties in the values are calculated by regression analysis and the electron temperature was evaluated with accuracy of 7%. The best fit for plasma potential evaluation was sought with an accuracy of about 15%.

Conclusions
The first derivative probe method was used for precise evaluation of the plasma potential, the EEDF (or, respectively, the electron temperature) and the electron density during the current shots in the COMPASS tokamak, (IPP.CR, Prague, Czech Republic). The results obtained after processing the data measured by divertor probes in H\(_2\) are reported. The good agreement between the model and experimental IV curves can be seen.

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