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Direct Measurements of the Electron Temperature by a Ball-pen/Langmuir probe

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1. Introduction

Among the various diagnostic tools to measure the electron temperature T_e in a plasma, probes are the least expensive, simplest and most versatile. Probes can be used in most types of plasma, even in the plasma of medium-size tokamaks, and they allow localised measurements with good spatial resolution. The usual and best known method to determine T_e with a cold probe is to register the current-voltage characteristic and to evaluate the exponential increase of the electron current in the retarding field region. A disadvantage of this method is its low temporal resolution which naturally is limited by the frequency with which the characteristic can be scanned. This is usually not more than about 1 kHz.

In principle also the difference between the floating potential V_{fl} and the plasma potential Φ_{pl} contains the information of the electron temperature. From simple probe theory we obtain the relation:

$$T_e = \frac{\Phi_{pl} - V_{fl}}{\alpha}, \qquad (1)$$

with $\alpha = \ln\left|I_{sat}^{-} / I_{sat}^{+}\right|$ being the logarithm of the ratio between the electron and ion saturation currents to a cold probe, respectively. In a hydrogen plasma α is around 3 [1]. Although in principle the current-voltage characteristic of a cold probe in a Maxwellian plasma without electron drift contains both values, Φ_{pl} and V_{fl}, this method is subject to the same temporal restrictions as described above since we need to know and evaluate the entire characteristic. If, however, we use a method to determine Φ_{pl} and V_{fl} simultaneously, Eq. (1) could be used to determine T_e very quickly, with the temporal resolution depending only on the limitation of the data acquisition system. To apply this method we introduce the so-called ball-pen probe [2], by which a direct determination of the plasma potential is possible and which, in combination with a standard Langmuir probe, serves to measure T_e in CASTOR tokamak.

The measurement of the plasma potential Φ_{pl} by means of the ball-pen probe utilises the difference between the electron and ion gyroradii in a magnetised plasma. Since the former are on the average much smaller, they are easily screened off by the BN tube, when the collector is withdrawn inside (the position *h* being negative), while ions can still reach the probe collector. This principle was also used by Katsumata and Okazaki for measuring the perpendicular ion energy distribution in a magnetic field [3,4]. However, in contrast to this earlier method, where the electrons were screened off completely, in our case, by shifting the collector inside the BN tube, the effective collection area in particular of the electrons $A_p^e(h)$ can be adjusted very easily. The position of the collector is indicated by *h*, with *h* = 0 meaning that the collector tip is exactly in the plane of the mouth of the tube. Therefore, the electron current reaching the collector can be adjusted almost to the same absolute value as that of the ion current. In this case the quantity α becomes:

$$\alpha = \ln\left(\left|\frac{I_{sat}^{-}}{I_{sat}^{+}}\right|\right) = \ln\left[\left|\frac{A_p^e(h) j_e}{A_p^i(h) j_i}\right|\right], \tag{2}$$

and the argument of the logarithm can be adjusted to one, in which case in a Maxwellian plasma the floating potential of the collector is equal to the plasma potential [2].

2. Experimental setup

Figure 1 shows a drawing and a photo of the combination of ball-pen and a standard Langmuir probe.

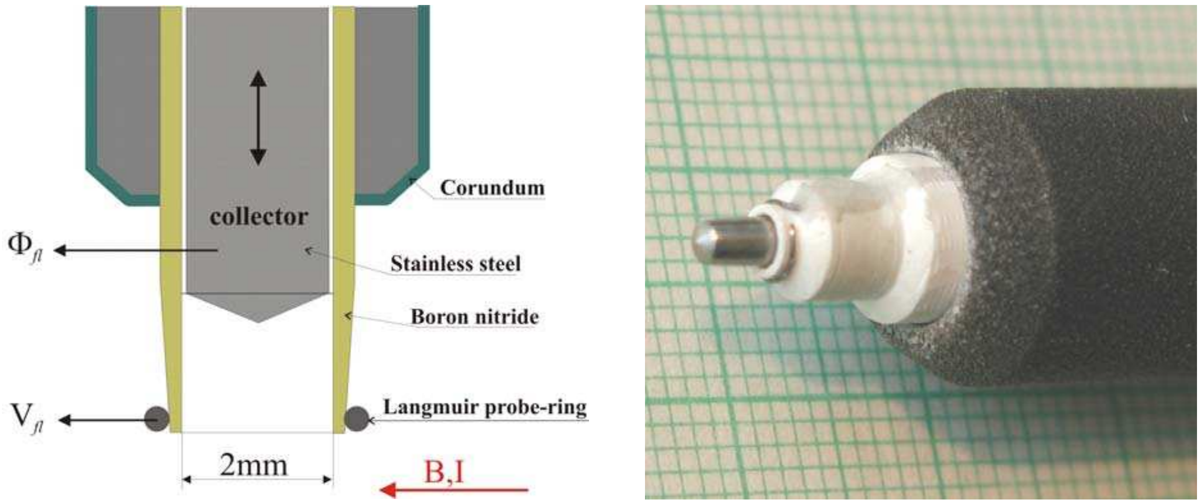

Fig. 1. Left panel: Schematic of the ball-pen/standard Langmuir probe combination. The conical collector can be shifted inside the boron nitride (BN) screening tube that acts as a shield for electrons, with h indicating the position of the collector inside the tube. The Langmuir probe is made of 0.2 mm diameter tungsten wire. Right panel: Photo of the ball pen probe. In this case the ball-pen collector is fully exposed to the plasma.

The Langmuir probe-ring that is attached around the BN tube (see Fig. 1) is fully exposed to the normal flux of electrons and ions from the plasma. Therefore its floating potential corresponds to the conventional value. Thus the difference between the floating potentials of the correctly adjusted ball-pen probe (for $h \cong -1$ mm where $R(h) = 1$) and of the Langmuir probe-ring can be used for calculating T_e according to Eq. (1).

With this probe combination the electron temperature in the CASTOR edge region ($R = 40$ cm, $a = 8.5$ cm, $B_T = 1.3$ T, $I_P \cong 10$ kA) was measured. In addition, the measured values are compared to the electron temperatures obtained from the *I-V* characteristics of the probe-ring and the exposed collector, where it acts as standard Langmuir probe.

3. Experimental results and discussion

Figure 2 shows in the left panel an example of the *I-V* characteristic of the swept Langmuir probe at radial position $r = 66$mm. The probe current is normalized to the ion saturation current. The ratio of electron and ion saturation currents reaches a value approximately –17. The systematic measurements of the quantity α for different radial positions are plotted in the right panel. The mean value of α is 2.89±0.15 which is in correspondence with the theoretical value 3 [1].

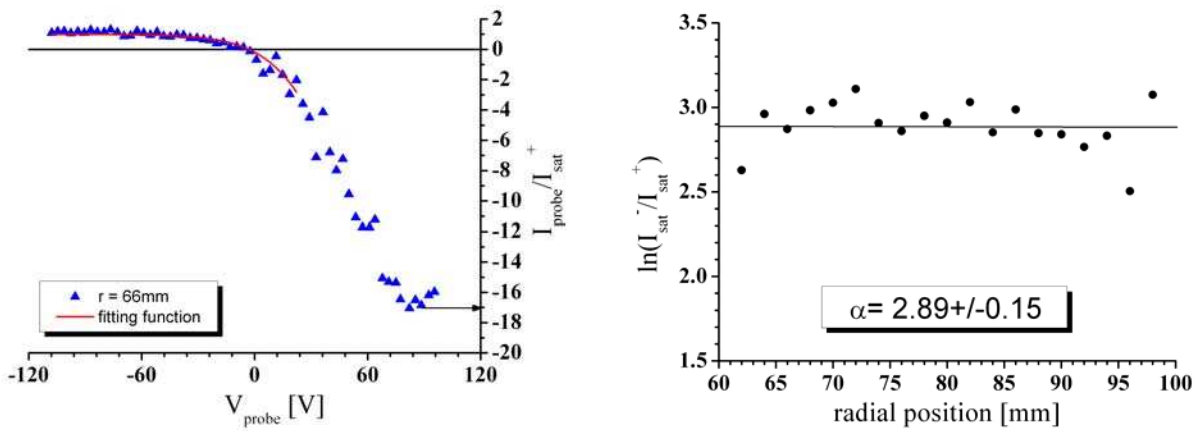

Fig. 2. Left panel: Example of the I-V characteristic of the swept Langmuir probe. The current is normalized to ion saturation current. The radial position is r = 66mm. Right panel: The dependence of the ratio α on the radial position.

Figure 3 shows in the left panel radial profiles of the plasma potential Φ_{pl} (red squares) as measured by the ball-pen probe with retracted collector and of the floating potential V_{fl} of the Langmuir probe-ring (black triangles). This gives us the possibility to calculate the electron temperature T_e from Eq. (1) using the experimental value of the quantity α.

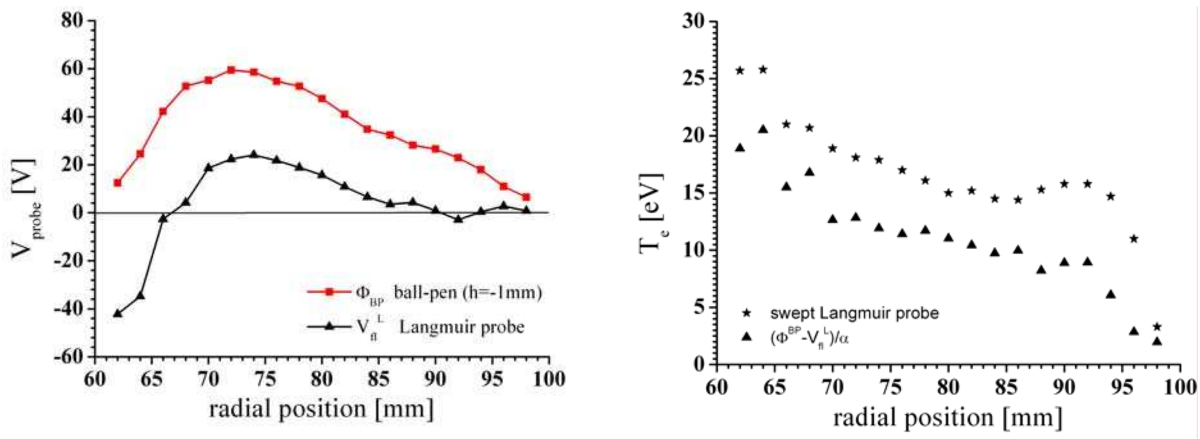

Fig. 3. Left panel: The radial profile of the of the plasma potential Φ_{pl} (red squares) as measured by the ball-pen probe with retracted collector and of the floating potential V_{fl} of the Langmuir probe-ring (black triangles). Right panel: Radial profile of the electron temperature calculated using Eq. (1) with α=2.89 (black triangles) and determined from swept Langmuir probe (black stars).

The right panel of figure 3 shows the electron temperature determined from Eq. (1) with $\alpha = 2.89$ (black triangles) and from the *I-V* characteristics of the Langmuir probe-ring when this was swept with a frequency of 1 kHz between –150 V and +50 V (black stars). The latter results show systematically higher values. We consider the results from Eq. (1) to be more reliable since it is known that electron temperature measurements from Langmuir probe current-voltage characteristics in hot plasmas tend to deliver higher results [5].

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References:

[1] J. Adamek et al., Czech. J. Phys , 54 (2004), C95.

[2] J. Adamek et al., *31st EPS Conf. Plasma Phys.* (London, Great Britain, 2004), *Europhys. Conf. Abst.* 28G (2004), p. 5.120.

[3] I. Katsumata and M. Okazaki, *Japan J. Appl. Phys.* 6 (1967), 123.

[4] I. Katsumata, *Contrib. Plasma Phys.* 36 (1996), 73.

[5] J.P. Gunn, Rev. Sci. Instr. 75 (2004) 4328.