A novel approach to direct measurement of the plasma potential

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A novel probe and approach to the direct measurements of the plasma potential in a strong magnetic field is suggested. The principle of this method is to reduce the electron saturation current to the same magnitude as that of the ion saturation current. In this case, the floating potential of the probe becomes identical to the plasma potential. This goal is attained by a shield, which screens off an adjustable part of the electron current from the probe collector due to the much smaller gyro–radius of the electrons. First systematic measurements have been performed in the CASTOR tokamak.

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1 Introduction

Up to now, emissive probes [1] and heavy ion beam probes [2] have been used for the determination of the plasma potential in tokamaks. However, use of these technique is hampered by various technical problems and peculiarities in measured data interpretation. In practice single Langmuir probes are used to measure the floating potential V_{fl} and the plasma potential Φ is deduced from the simple formula:

$$V_{\mathrm{fl}} = \Phi - T_{\mathrm{e}} \ln(R) \tag{1}$$

where T_e is the electron temperature in eV. The quantity $R = I^-_{sat}/I^+_{sat}$ represents the ratio of the electron and ion saturation currents, respectively. The theoretical value of $\ln(R)$ in hydrogen plasma is about 3.

The value of the plasma potential deduced from equation (1) is correct only if the electron temperature T_e and ratio R are known. The electron temperature can be estimated from the I–V characteristics of a Langmuir probe with a sufficient precision, but the value of R can not be experimentally obtained. The basic idea of the direct plasma potential measurement, which is proposed in this contribution, is to adjust R to be equal to one. If this is achieved, the floating potential of the probe V_{fl} is equal to the plasma potential Φ, as evident from equation (1).

2 Direct plasma potential measurements with a novel probe

2.1 The probe head

The probe head, which allows a modification of R is shown in Fig. 1. Its orientation with respect to the magnetic field is also indicated. The probe consists of a conically shaped collector, which is shielded by an isolating tube made of boron nitride. The collector is movable inside the tube on a shot–to–shot basis. It is either completely shielded or partially exposed to the plasma. In the ideal case, when the collector is hidden inside the tube, as shown in Fig. 1, only ions with sufficiently large Larmor radii can reach the collector surface and the collecting area for electrons is negligible ($R << 1$). When the collector is shifted toward the plasma, the electron current as well as the R increase. At a certain collector position, the electron and ion current are expected to be balanced (i.e., $R = 1$), in which case $V_{fl} = \Phi$.

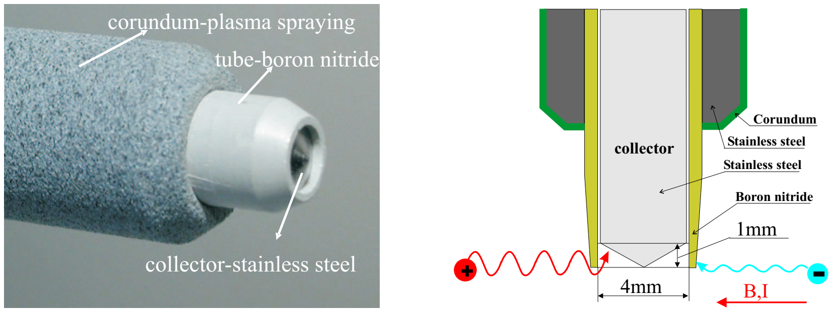

Fig. 1. Left hand side – photograph of the probe probe. Right hand side – positioning of the probe head with respect to the toroidal magnetic field lines.

2.2 Experimental results

The test measurements have been performed at the CASTOR tokamak (major radius = 40 cm, minor radius = 8.5 cm, $B_T = 1.3$ T, $I_P = 10$ kA). At the plasma edge, the electron and ion temperature are in the range of 10 eV. The corresponding Larmor radii are $\rho_{\mathrm{i}} \approx 0.5$ mm and $\rho_{\mathrm{e}} \approx 0.01$ mm. The edge plasma density is $\approx 10^{18}\ \mathrm{m}^{-3}$. The probe was inserted into the edge plasma and biased by a sweeping voltage ($f = 1$ kHz, $\pm$ 100 V). Examples of I–V characteristics are plotted in Fig. 2 – left hand side for two different positions of the collector. The probe current is normalized to its ion saturation value I^{+}_{sat}. The electron temperature, the ion saturation current and the floating potential are obtained by fitting the ion branch of the I–V characteristic ($V_{\mathrm{p}} \leq V_{\mathrm{fl}}$). The R value is given by the saturation of the electron branch of the I–V characteristic, see Fig. 2 – left hand side. It is seen from the figure that R and V_{fl} strongly depend on the collector position. The magnitudes of the electron and ion saturation currents, I^{-}_{sat} and I^{+}_{sat}, are almost balanced, when the collector is 1 mm inside the shielding tube ($h = -1$ mm).

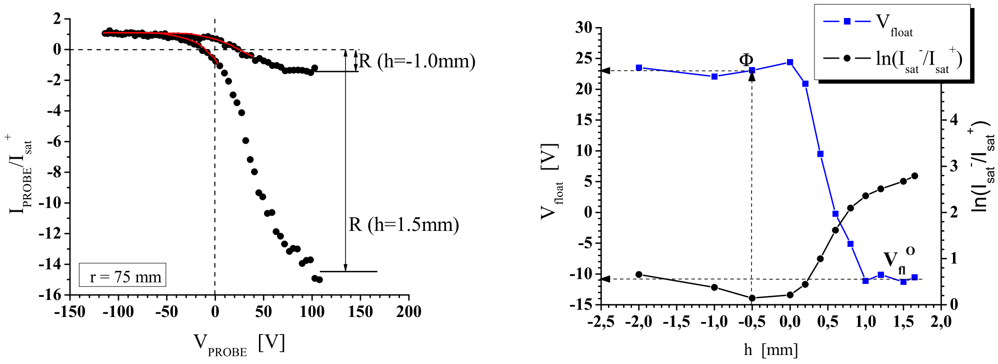

Fig. 2. Left hand side – example of an I–V characteristics for two different collector positions. The h value is negative for collector position hidden inside the shielding tube. Right hand side – variation of the floating potential V_{fl} and $\ln(R)$ with respect to the collector position. The position of the probe head is at a minor radius of 75 mm.

The results of systematic measurements of the floating potential V_{fl} and the ratio R as a function of the collector position are plotted in Fig. 2 – right hand side. It is evident from the figure that $\ln(R)$ is always positive for any collector position. This indicates that electrons are present even in the shadow of the shielding tube, and the electron current is always higher than the ion current. This is in contrast to the simple model based on the electron and ion gyro–motion along the magnetic field lines, which is described in the previous section. The reason for this discrepancy might lie in a certain $\mathbf{E} \times \mathbf{B}$ drift of the particles into the shadow region of the probe. Nevertheless, $\ln(R)$ attains a minimum (i.e., $\ln(R) = 0.1$), when the tip of the collector is slightly inside the shielding tube ($h = -0.5$ mm). In this situation the probe potential is close to the plasma potential. According equation (1), the difference between plasma and probe potential is in the order of volts in this case ($T_{\mathrm{e}} \cong 10$ eV).

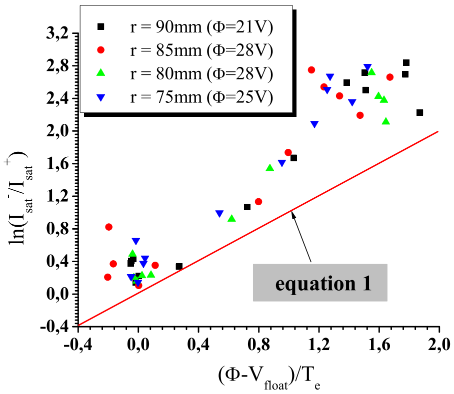

Fig. 3. Experimental relation between the logarithm of R and the difference between plasma (Φ) and floating potential (V_{fl}) normalized to the electron temperature T_{e}.

It is seen from the figure that the value of the probe potential significantly decreases when the collector is more and more exposed to the plasma. When the collector is fully outside the shielding tube ($h \cong 1.5$ mm), the probe operates as a conventional single Langmuir probe and measures the floating potential V_{fl}^{O}. It is interesting to note, that the probe potential is approximately constant and equal to the plasma potential Φ, when the collector is hidden inside the tube. The reason for this behaviour is not clear. However, it has practical importance for direct plasma potential measurements by this probe, because the collector could be hidden inside the shielding tube deeper than in previous case ($h = -0.5$ mm) and protected from high energy flux.

Fig. 3 summarizes measurements at several radial positions of the probe head. We plot here $\ln(R)$ versus the difference of the plasma (Φ) and the floating potential (V_{fl}) normalized to the electron temperature. As seen from the figure the relation between these two quantities appears to be linear. The linearity is in good agreement with the equation (1), but the expression of the linear fit ($y = 1.36\,x + 0.31$) is not exactly confirmation of the simple model given by equation (1). The possible reason can be accuracy of estimation of the electron temperature and ratio R or the simple model is not fully correct for these plasma conditions.

Radial profiles of the plasma and the floating potential in standard ohmic discharges are plotted in Fig. 4 – left hand side. In this case the collector is not biased and only its floating potential is measured. For each radial position of the probe head, the collector is either hidden inside the shielding tube ($h = -1$ mm) or sufficiently exposed in plasma ($h = 1.5$ mm). From the figure is seen a comparison with the radial profile of the floating potential measured by the radial array of sixteenth Langmuir probes located at different toroidal position, which is used as a routine technique for the estimation of the electric field at the edge plasma at CASTOR tokamak. Such an arrangement allows the measurement of the radial profile of the fluctuations, which are plotted in rms values in Fig. 4 – right. It is evident that the

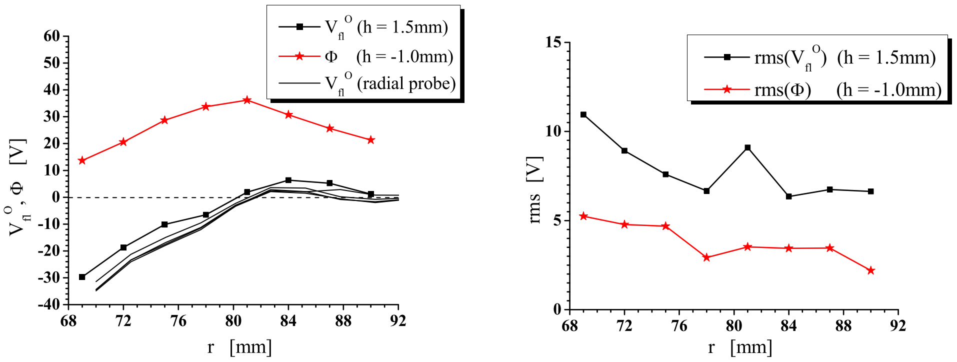

Fig. 4. Left hand side – radial profile of plasma potential (red stars) and floating potential (black squares) measured by the novel probe compared with the floating potential of a radial array of Langmuir probes (black single lines). Right hand side – radial profile of rms values of the floating potential (black squares) and plasma potential (red stars).

level of the fluctuations of the plasma potential is lower than that of the floating potential by a factor 2.

3 Summary and conclusions

The novel probe designed for the direct plasma potential measurement has been tested at CASTOR tokamak. First systematic measurements have shown that the probe allows a modification of its collected electron and ion currents (R). At a certain collector position, $\ln(R)$ attains a minimum (i.e., $\ln(R) = 0.1$) and the probe potential is close to the plasma potential. The difference between plasma and probe potential is on the order of volts in this case ($T_e \cong 10$ eV). The equation (1) deduced from the simple Langmuir probe theory has been experimentally tested and confirmed within the precision limits of the experiment.

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References

[1] R. Schrittwieser, J. Adámek, P. Balan, M. Hron, C. Ionită, K. Jakubka, L. Kryška, E. Martines, J. Stöckel, M. Tichý, G. Van Oost: Plasma Phys. and Control. Fusion **44** (2002) 567.

[2] A. V. Melnikov, L. G. Eliseev: Czech. J. Phys. **49** Suppl. 3 (1999) 35.

[3] J. P. Gunn: Phys. Plasma **8** (2001) 1040.

[4] N. Ezumi: Contrib. Plasma Phys. **41** (2001) 488.