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Plasma potential measurements in the edge plasma region of a small tokamak by means of electron emissive probes

Codrina Avram,[1,2] Petru C. Balan,[2] José A. Cabral,[3] Fernando H. Figueiredo,[3] Valentin Pohoata,[2] Roman Schrittwieser,[1] Carlos Varandas[3]

[1]*Institute for Ion Physics, University of Innsbruck, A-6020 Innsbruck, Austria*
[2]*Faculty of Physics, University "Al. I. Cuza", RO-6600 Iasi, Romania*
[3]*Centro de Fusão Nuclear, Instituto Superior Técnico, P-1049-001 Lisboa codex,Portugal*

Abstract

In this contribution an arrangement of three electron emissive probes for measurements in the edge plasma region of the ISTTOK (**I**nstituto **S**uperior **T**écnico **Tok**amak) at Lisbon is presented. Each probe consists of a little loop of tungsten wire which can be heated externally. The probes are mounted in such a way that the tips of the loops are situated on the same poloidal meridian. Their lengths have been adjusted so that the tips are on different minor radii in the scrape-off layer of the ISTTOK. With this arrangement, the plasma potential has been measured in the edge region of the ISTTOK, and first results are presented here.

1. Introduction

A reliable and exact determination of the plasma potential and its fluctuations is decisive in many plasma devices. The stability of fusion plasmas and the radial transport across the **s**crape-**o**ff **l**ayer (SOL) is determined by the radial potential profile of the SOL and by the turbulent fluctuations present there (**e**dge-**l**ocalised **m**odes – ELMs). The question about the actual mechanism of the turbulent transport through the SOL is still pending. There is a lot of evidence that the radial potential profile is controlled by self-organised criticality (SOC), since the spectrum of the fluctuations shows so-called $1/f$ noise [1].

In magnetised fusion plasmas, sheared poloidal flows have a stabilising effect for turbulent transport. One explanation is the generation of poloidal flows by plasma fluctuations via the Reynolds stress [2,3,4,5]. Turbulent Reynolds stress plays a linking role between turbulence and averaged flows. It has been argued theoretically that sheared poloidal flows can be generated in the presence of a radially varying Reynolds stress R in fusion plasmas [6]. A measurement of the Reynolds stress requires a precise knowledge of the fluctuating electric fields (and thus of the plasma potentials), since $R \propto \langle \tilde{v}_r \tilde{v}_\vartheta \rangle \propto \langle \tilde{E}_r \tilde{E}_\vartheta \rangle$, where $\tilde{v}_r$ and $\tilde{v}_\vartheta$ are the radial and poloidal particle velocities, respectively, and $\tilde{E}_r$ and $\tilde{E}_\vartheta$, the radial and poloidal components of the electric field fluctuations, respectively.

2. Drawbacks of cold probes

Electric probes are very helpful for a quick determination of three important plasma parameters: the electron density n_e, the electron temperature T_e and the plasma potential Φ_{pl}. Also density and potential fluctuations can in principle be observed with probes. The most accurate measure of Φ_{pl} is taken from the "knee" of the current-voltage characteristic of the probe.

It is well known, however, that a comprehensive theory of probes is either very complicated, or a number of compromises have to be made for an easy evaluation of the probe signals. Thus the above mentioned plasma parameters can be subject to severe systematic errors. One of the gravest errors concerns the determination of the plasma potential, since for the sake of simplicity it is usually assumed that the floating potential Φ_{fl} is a sufficiently good measure for the plasma potential. Indeed the two values are proportional to each other through the relation

$$\Phi_{fl} = \Phi_{pl} - \mu T_e, \tag{1}$$

where μ is a proportionality factor, which contains $\ln(m_i/m_e)$ (with $m_{i,e}$ being the ion and electron mass, respectively). Since often not the absolute values but just the relative values of Φ_{pl} (or potential fluctuations $\tilde{\Phi}_{pl}$, respectively) are of interest, it suffices to measure the fluctuations $\tilde{\Phi}_{fl}$ of the floating potential of a cold probe.

But Eq. 1 shows that the floating potential is also related to the electron temperature, and only if we suppose that there are no temperature fluctuations during the recording of $\tilde{\Phi}_{fl}$, we can be sure that we get a reliable measure of $\tilde{\Phi}_{pl}$. This is, however, often not the case, especially in the edge plasma region of magnetically confined fusion plasmas.

An additional, often completely neglected fact is the following: Any sufficiently strong electron drift or electron beam (or if the entire electron population is drifting) will distort the entire current-voltage characteristic of a cold probe. In such a case a determination of the plasma potential from the "knee" of the characteristic delivers an erroneous result, and of course, also the floating potential is no longer related to Φ_{pl} through Eq. 1.

In order to estimate the order of magnitude of an electron drift which will distort the characteristic, we recall that for thermal electrons in a one-dimensional plasma the probe electron saturation current density j_{es} is given by:

$$j_{es} = -n_e e \bar{v}_e = -n_e e \sqrt{\frac{8k_B T_e}{\pi m_e}}\,, \tag{2}$$

with e being the elementary charge and k_B the Boltzmann constant.

However, for the case of an electron beam, the probe saturation current $j_{es,b}$ is:

$$j_{es,b} = -n_{eb} e v_b = -n_{eb} e \sqrt{\frac{2eV_b}{m_e}}\,, \tag{3}$$

where n_{eb} is the density of the beam electrons and v_b their velocity. The term eV_b is the kinetic energy of the beam electrons. In such a case, the probe characteristic is shifted to the left by V_b and the "knee" will show an apparently negative value of Φ_{pl}.

If in a plasma there are thermal electrons and drifting electrons or an electron beam, respectively, the characteristic will be distorted if $j_{es,b} \geq j_{es}$, i.e., for

$$n_{eb}\sqrt{2eV_b} \geq n_e \sqrt{\frac{8k_B T_e}{\pi}} \rightarrow n_{eb}^2 V_b \geq n_e^2 \frac{4T_e^*}{\pi}\,, \tag{4}$$

with T_e^* being the kinetic electron temperature.

2. The advantages of electron emissive probes

All these problems can be circumvented when we use a probe, which not only passively registers the electron current (the ion current can be entirely neglected in these considerations), but actively emits an electron current [7,8,9]. An electron emission current will be able to flow from the probe to the plasma as long as the probe bias V_p is below the plasma potential Φ_{pl}, *irrespective* of the flow of plasma electrons. But for $V_p \geq \Phi_{pl}$, the emission current drops and electron collection begins. According to the theory [7], the inflection point of the characteristic is a rather accurate measure of the true value of the plasma potential, but usually simply the emissive probe floating potential is considered as the plasma potential. There are, however, also restrictions of this method when the electron emission becomes too strong [10].

An emissive probe is usually realised by a small loop of tungsten wire, carried by a double-bore ceramic tube, and heated by an external current so that the W-wire becomes emissive. A necessary condition for sufficient electron emission is that the electron emission saturation current $j_{ee} = A^* T_w^2 \exp[-eW_w/(k_B T_w)]$ (with A^* being the Richardson constant, and T_w and W_w the temperature and the work function of the wire, respectively) be at least twice the value of the electron collection current.

3. Emissive probe arrangement for the Instituto Superior Técnico Tokamak (ISTTOK)

As far as we know, up to now, only cold probes have been used for measurements of potential fluctuations in the edge region of fusion plasmas [11]. Although cold probes in hot plasmas can become self-emissive due to the heating by the plasma [12], we believe that it is more reliable to use an emissive probe, which is heated externally in a controllable way from the start of the measurement.

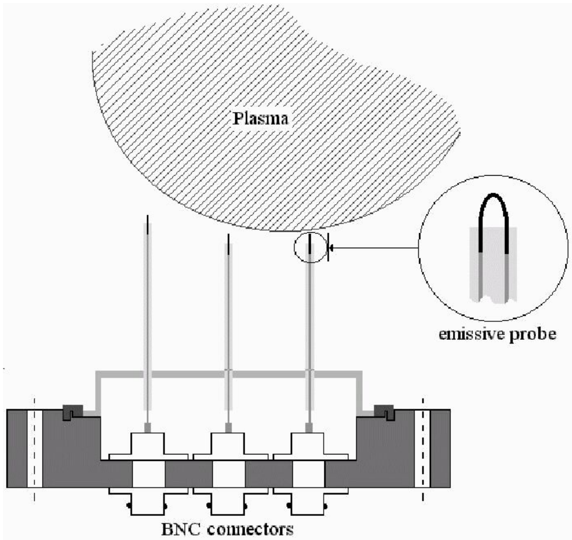

Fig. 1 Schematic of the three emissive probes in the ISTTOK in Lisbon

We have mounted an array of three emissive probes on one flange of the ISTTOK, Lisbon. The probes have a distance of 20 mm from each other, and the tips of the loops of all three probes are situated on the same poloidal meridian, i.e., they have the same toroidal coordinate φ, but different poloidal positions ϑ. Their lengths are such that the probe tips are on different minor radii r_1 = 86,1 mm, r_2 = 87,3 mm and r_3 = 88,1 mm. The minor radius of the plasma ring in the ISTTOK is a = 85 mm, and it is determined by a metallic limiter. Thus all three probes are in the shadow of the limiter, but not directly in the plasma. This could be pernicious for the probes even in this relatively small tokamak. With this arrangement, the plasma potential and its fluctuations can be measured on three radial positions in the edge region of the ISTTOK, and thus an approximate radial potential profile can be determined in the limiter shadow. Fig. 1 shows this arrangement schematically.

4. Preliminary experimental results

Here we present preliminary results of measurements with the centre probe of the array, thus at a distance of 2,3 mm from the edge of the plasma. The probe (together with the entire heating circuit) was simply attached to a high input impedance oscilloscope, and the temporal evolution of the probe floating potential was registered. Each ISTTOK discharge takes about 20 ms. By slowly increasing the heating of the probe from shot to shot, the region of emission was approached. Thus the first measurements have still been done with a cold probe, but with increasing heating, the probe became more and more emissive. It turned out that a current of almost 5 A is necessary to heat the probes to electron emission. In this preliminary stadium, a regulated power supply was used for the heating. In a later stage, a battery-powered heating circuit will be used for each probe, in order to minimise 50 Hz noise.

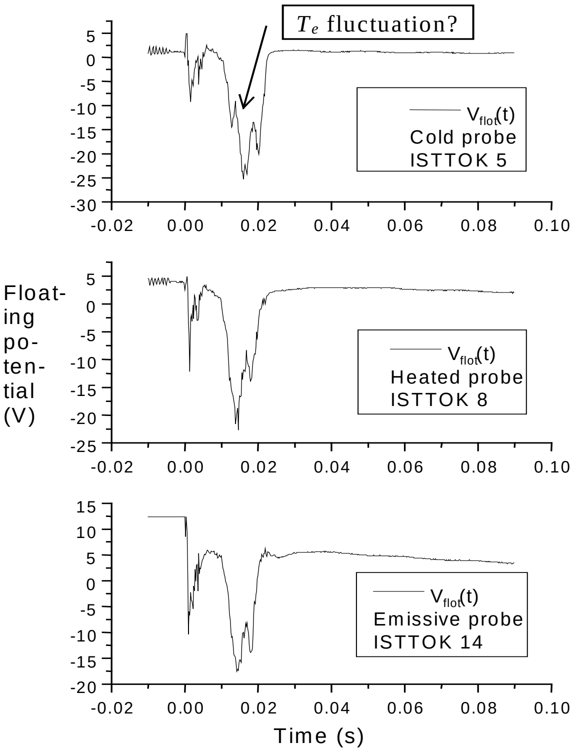

Fig. 2: Temporal evolution of the floating potential of the centre probe during three shots of the ISTTOK. (a) For a cold probe (almost no heating, I_{ph} = 2 A), (b) for a heated but not yet emissive probe (I_{ph} = 4 A), (c) for a strongly heated probe (I_{ph} = 4,75 A).

Fig. 2 shows three temporal evolutions with different heating currents as indicated in the figure caption. Unfortunately, these ISTTOK discharges have not been very stable. But the most essential features of the emissive probe behaviour can still be seen. Especially pregnant is the difference between the topmost and the lowest curve. In the former case, we see just $\Phi_{fl}(t)$ of a cold probe. In the latter case, we see a general rise of the entire curve by about 10 V, which is clear since Φ_{pl} is always more positive than the floating potential of a cold probe. Thus we assume that in this case the probe was indeed emissive enough to ensure that its floating potential was close to Φ_{pl}.

In the topmost curve (for a cold probe) the arrow is indicating a strange peak in the potential curve, which is not seen in the other two curves. This could be a sign of a temperature fluctuation, which would leave a trace only in the cold probe floating potential, but not in the actual plasma potential.

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