Measurements of Plasma Potential Fluctuations in the Edge Region of the ISTTOK Plasma, Using Electron Emissive Probes


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1. Introduction

At the edge of a magnetically confined hot plasma, especially in the scrape-off layer (SOL), there are strong gradients of the charge carrier densities \( n_{e,i} \) of the plasma potential \( \Phi_{pl} \) and of the electron and ion temperatures, \( T_{e,i} \). These gradients can drive a number of instabilities, which are called edge localized modes (ELMs). These ELMs are manifested as fluctuations mainly of \( \Phi_{pl} \) and they lead to an enhanced radial loss of plasma across the SOL. To understand the actual mechanism of the turbulent transport through the SOL, a reliable and precise knowledge of \( \Phi_{pl} \) and its fluctuations is vital for a comparison of the experimental observations with theoretical models and numerical simulations.

In order to measure the plasma potential as precisely and directly as possible, we have used electron emissive probes, the floating potential of which approaches the true value of the plasma potential \( \Phi_{pl} \), when the electron emission current \( I_{em} \) is increased up to a certain value by increasing the heating of the probe \([1,2]\). This follows from the formula for the floating potential of a heated probe (valid, however, only for a Maxwellian plasma and for probe voltages below the plasma potential, i.e., \( V_p < \Phi_{pl} \))

\[
V_{fl} = \Phi_{pl} - \mu T_e = \Phi_{pl} - T_e \ln \left( \frac{I_{es}}{I_{is} + I_{em}} \right).
\]  

(1)

with \( I_{es} \) and \( I_{is} \) being the plasma electron and ion saturation currents, respectively.

Eq. (1) shows that for increasing emission current \( I_{em} \), the floating potential of the emissive probe grows and approaches \( \Phi_{pl} \). For \( I_{em} = I_{es} - I_{is} \), \( V_{fl} \) attains the plasma potential. Indeed, also in a realistic experiment, \( V_{fl} \) is observed to increase with the emission current, however, reaching a clear saturation for \( I_{em} \equiv I_{es} \), i.e., a further increase of \( I_{em} \) will not lead to a further growth of \( V_{fl} \). This saturated value of \( V_{fl} \) is then considered to be a good approximation for \( \Phi_{pl} \). This result can, however, be falsified by a number of effects, among them the formation of a space charge around the emissive probe by the emitted electrons \([2]\).
2. Experimental set-up

ISTTOK has a major radius of 0.46 m and a minor radius of \( a = 0.085 \) m, the latter being determined by a metallic limiter, which can also be biased. The background pressure is smaller than \( 10^{-7} \) mbar. Before each discharge, the chamber is filled with H\(_2\) up to a pressure of around \( 10^{-4} \) mbar. Each shot has a duration of up to 40 ms. The strength of the toroidal magnetic field on the minor axis is usually 0.5 T, the toroidal plasma current is typically 9 kA. The maximum attainable plasma density is \((5 - 10) \times 10^{18} \) m\(^{-3}\) and the electron temperature is in the range 80 - 220 eV. In the SOL the density drops to values around \((5 - 10) \times 10^{16} \) m\(^{-3}\), and \(T_e\) is on the order of 10 eV [3,4].

Into one of the radial flanges of ISTTOK, an array of three emissive probes has been inserted [1]. Each probe consists of an Al\(_2\)O\(_3\) tube of 2.8 mm outer diameter with four bores of 0.5 mm diameter each. Through two opposite bores, a 0.2 mm diameter tungsten wire is inserted so that a loop of about 5 mm length is formed. A current up to 7.2 A is needed to heat each emissive probe sufficiently. The three probes are situated on the same poloidal meridian, but on different poloidal positions. The probe tips have different minor radii \( r_1 = 86 \) mm, \( r_2 = 89 \) mm and \( r_3 = 92 \) mm. Thus all three probes are outside the last closed flux surface. Fig. 1 shows a schematic of this probe arrangement.

3. Results and discussion

In order to make sensible measurements of the plasma potential, an electron emission current of up to about 120 mA has to be produced by each of the probes. Then the floating potentials of the emissive probes shows \( \Phi_{pl}(r,t) \) on the three different radii. We have registered
\( \Phi_{pl}(r_{1-3},t) \) for various conditions and have thereby obtained a rough radial profile of the plasma potential, showing also the temporal evolution during each shot. Fig. 2 shows the temporal evolution of the raw signals of the three probes versus the radius.

![Fig. 2: Raw signal of the floating potential (which here corresponds to the plasma potential) from the three emissive probes (from IST-TOK) without limiter biasing. The probe positions are here given as the distances from the limiter.](image)

The radial profile shows a strong drop of the plasma potential in the SOL. Between \( r_1 = 86 \text{ mm} \) and \( r_2 = 89 \text{ mm} \) the plasma potential decreases from \( \Phi_{pl,1} \equiv 48 \text{ V} \) to \( \Phi_{pl,2} \equiv 18 \text{ V} \). This corresponds to an electric field of \( E_r \equiv 10 \text{ kV/m} \) even without limiter bias. This value is in keeping with similar results of the CASTOR tokamak, but has been achieved there only with a limiter bias of \(+100 \text{ V}\) [2]. The amplitude of the fluctuations also decreases between these two positions. According to the assumptions, these signals show solely the fluctuations of the plasma potential so that possible temperature fluctuations are excluded.

![Fig. 3: In this case the limiter was biased with a 50 Hz ac-voltage of \( V_{lim} = 160 \text{ V}_{\text{rms}} \). The lowermost curve shows the current flowing to the limiter; it is positive (ions) for \( V_{lim} < 0 \) and becomes (much more) negative for positive values of \( V_{lim} \) when electrons are attracted to the limiter.](image)

Fig. 3 shows the probe signals when the limiter is biased with a 50 Hz ac-voltage. As reference, the lowermost curve shows the current flowing to the limiter. For \( V_{lim} > 0 \), this
means a strong electron current, and we observe that $\Phi_{pl,1}$ is increased only slightly during this time. Also the other two probes show a slight increase of their floating potentials $\Phi_{pl,2,3}$, respectively. The fluctuation levels, however, show no considerable change for positive or negative limiter biases. Remarkable is the strong increase of the plasma density for $V_{lim} > 0$.

We have also calculated the power spectrum of the fluctuations in a frequency range of 100 Hz $< f < 60$ kHz. Fig. 4 shows this for the signals of Fig. 2.

In a certain range the spectra are proportional to $f^{-\alpha}$, and the exponent $\alpha$ turns out to be about 1.9. However, for the existence of flicker noise in the edge region, $\alpha$ should be around one. So our results are not conclusive to decide the question whether or not there is self-organised criticality in the SOL. Further measurements with a different set-up will try to shed more light into this subject.

References