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Direct measurements of the plasma potential in ELMy H-mode plasma with ball-pen probes on ASDEX Upgrade tokamak

J. Adamek [a,*], V. Rohde [b], H.W. Müller [b], A. Herrmann [b], C. Ionita [c], R. Schrittwieser [c], F. Mehlmann [c], J. Stöckel [a], J. Horacek [a], J. Brotankova [a], ASDEX Upgrade Team [b]

[a] Institute of Plasma Physics, Association EURATOM/IPP.CR, Prague, Za Slovankou 3, 182 00, Prague 8, Czech Republic
[b] Institute of Plasma Physics, Association EURATOM/IPP, Garching, Germany
[c] Institute for Ion Physics and Applied Physics, University of Innsbruck, Association EURATOM/ÖAW, Austria

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ABSTRACT

Experimental investigations of the plasma potential and electric field were performed for ELMy H-mode plasmas in the vicinity of the limiter shadow of ASDEX Upgrade. A fast reciprocating probe with a probe head containing four ball-pen probes (BPPs) [J. Adamek et al., Czech. J. Phys. 54 (2004) C95 – C99.] was used on the midplane manipulator. Different gradients of the plasma potential were observed during ELMs and in between them. The temporal resolution of the direct plasma potential measurements with BPP was determined by using power-spectra analysis.

1. Introduction

The investigation of the electric field and its fluctuations remains one of the most important tasks in the context of anomalous edge plasma and momentum transport. A precise knowledge of the plasma potential and its fluctuations in the edge plasma region is vital for a better understanding of transport phenomena and is thus also relevant for ITER, in particular for the life time of first wall components. Moreover, direct plasma potential measurements are necessary for understanding SOL physics and the experimental verification of different codes for modelling SOL [1,2].

The ball-pen probe (BPP) [3–6] for direct measurements of the plasma potential was recently developed in the Institute of Plasma Physics AS CR in Prague. Here we report on BPP measurements of the plasma potential in ELMy H-modes of ASDEX Upgrade. Radial profiles of the plasma potential are obtained for the time during an ELM event and in the quiet phase in between ELMs. Furthermore, frequency spectra of potential fluctuations are analyzed.

2. Principle of the ball-pen probe

The principle of the BPP (see Fig. 1) is to make use of the large difference between the gyro-radii of electrons and ions in magnetized plasma, which is based on the concept of the Katsumata probe [7]. The conically shaped collector of a BPP is retracted by a certain depth (h) inside a screening channel of ceramic (usually boron nitride – BN). Thereby a certain part of the electron current density is shielded from the collector, whereas the ions, due to their much larger gyro-radii are less impeded from reaching it. In this way the current-voltage characteristic of the retracted collector can be made almost symmetric, which is indicated by the fact that the magnitudes of the ion and electron saturation currents, $|I^+_{\mathrm{sat}}|$ and $|I^-_{\mathrm{sat}}|$, are almost equal. It can be shown [8] that in this case in Maxwellian plasma the floating potential of the collector V_{fl} become equal to the plasma potential Φ_{pl}:

$$V_{fl} = \Phi_{pl} - T_e \ln(|I^-_{\mathrm{sat}}/I^+_{\mathrm{sat}}|),\ \mathrm{where}|I^-_{\mathrm{sat}}/I^+_{\mathrm{sat}}| \simeq 1 \quad (1)$$

3. Probe construction and experimental set-up

The fast reciprocating probe shaft on the ASDEX Upgrade midplane manipulator was used to insert a probe head containing four BPPs with different retraction depth (h) of its collectors (h = −0.5 mm (BPP0), −1 mm (BPP1), −2 mm (BPP2) and −3 mm (BPP3)) and two Langmuir probes (LP1 and LP2) as shown in Fig. 2. The BPPs are made of stainless steel collectors with diameters of 4 mm, which are fixed inside the ceramic shielding tubes with inner diameters of 6 mm. The shielding tubes are made of one piece of boron nitride. The first Langmuir probe LP1 was used for the floating potential measurements, but it did not provide any signal because of damage during the experiment. The second Langmuir probe LP2 measured the I – V characteristics, but the probe current was in the same level as the signal noise.

The whole probe head is protected by a carbon shield with 50 mm diameter against the high heat flux of the plasma. The

* Corresponding author.
E-mail address: adamek@ipp.cas.cz (J. Adamek).

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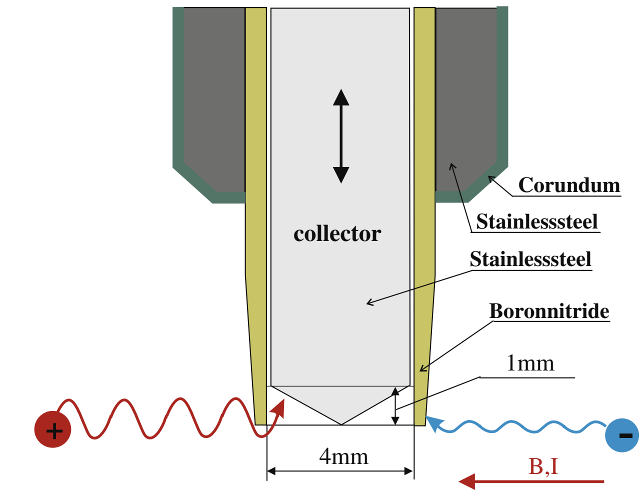

Fig. 1. Schematic picture of the single ball-pen probe and its position with respect to the magnetic field lines. This probe head was used on CASTOR tokamak during campaigns in 2004 – 2006.

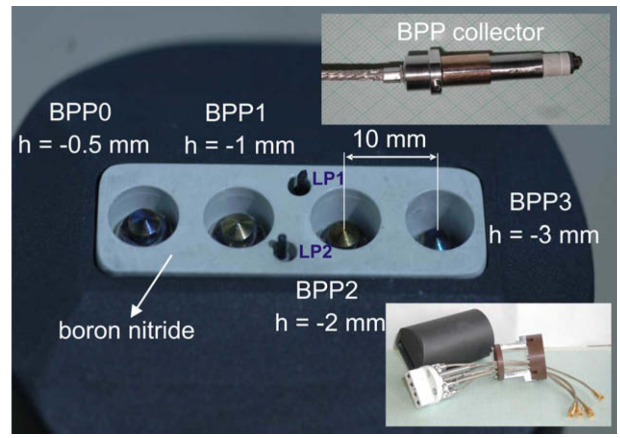

Fig. 2. Photo of the quadruple ball-pen probe used in AUG during the campaign in 2007. The probe has four stainless steel collectors with conical tips retracted into the boron nitride screen with various depths h: from left to right $h = -0.5$ mm, -1 mm, -2 mm and -3 mm. In addition there are two graphite Langmuir probe pins. The whole probe head is protected from the plasma heat flux by a carbon shield.

experimental data from the BPP were collected during shot #21986.

During the shot the probe head was inserted four times for duration of 100 ms each and a few millimeters into the edge plasma region on the low field side. The first two strokes were performed with a neutral beam injection (NBI) power of 5 MW, but with different levels of gas puffing. The third one was made with reduced NBI power (2.5 MW) and the last one in the ohmic regime. The toroidal magnetic field $B_T = 2.5T$ and the plasma current $I_P = 0.8$ MA were constant during all strokes. Strokes 1, 2, 3 represent measurements in an ELMy H-mode plasma with different levels of the D_α-signal at the outer and the inner divertor. The last stroke has been performed in the ohmic discharge.

4. Experimental results

The temporal evolutions of the plasma potentials measured by the BPP0 (magenta line), BPP2 (green line) and BPP3 (black line) during stroke 2 are plotted in Fig. 3. The temporal resolution of plotted potentials is given by the sampling frequency $f = 0.5$ MHz of the data acquisition system. The exposure time of the probe head to the plasma outside the limiter shadow lasted from $3.11 < t < 3.13$ s. The BPP1 with $h = -1$ mm (red line) started to work only at $t = 3.2$ s (the end of stroke 2) due to a short circuit inside the probe head. Several type I ELM events on the BPP signal are clearly visible and also detected by the intensities of the D_α-lines at the outer (blue line) and the inner (black line) divertor, respectively. The periodicity of ELM events is approximately 147 Hz. The systematic difference between the plasma potential of the three probes is due to the different location of each probe with respect to the magnetic flux surfaces, the BPP0 being the deepest inside the plasma. Taking into account the curvature of the magnetic flux surfaces in poloidal direction, the radial distance between this probe and the BPP3 is about 5 mm. Therefore, the radial positions (major radius R) of the BPPs are mapped to the midplane. To

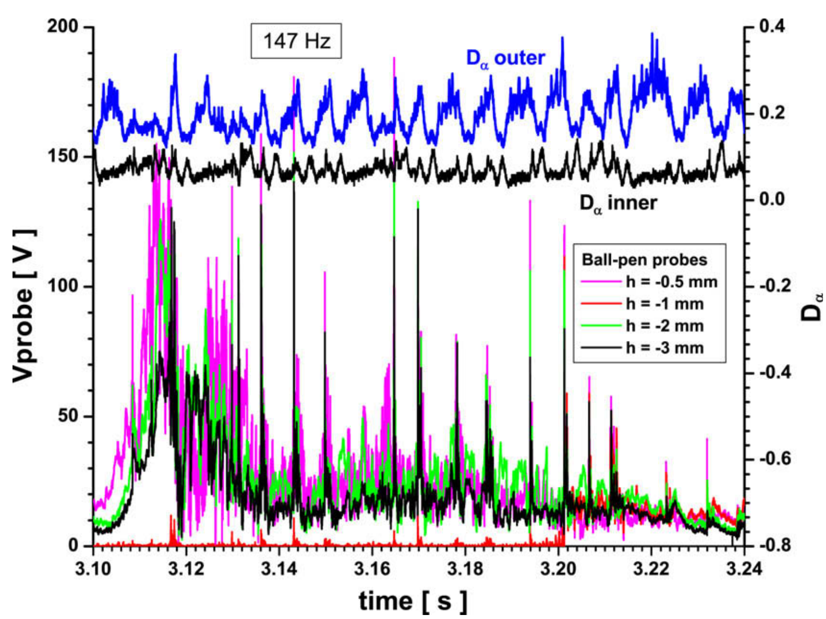

Fig. 3. Temporal evolution of the plasma potential of the BPPs during stroke 2 and an ELMy H-mode (5 MW of NBI). The probe head was localized outside the limiter shadow only by a few millimetres for $3.11 < t[\mathrm{s}] < 3.13$.

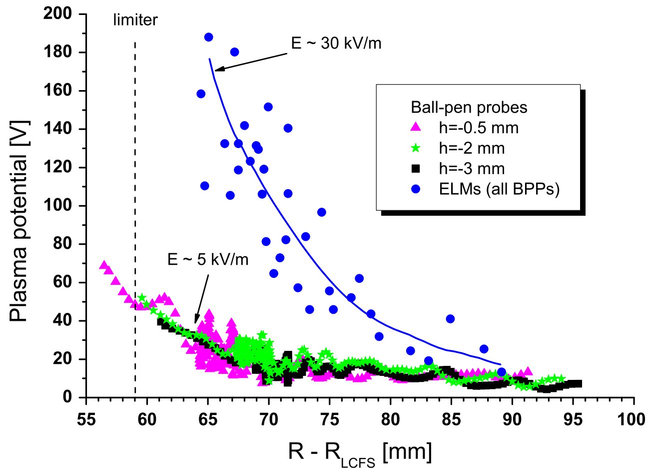

Fig. 4. Radial profiles of the plasma potential of BPP0 (triangle, magenta), BPP2 (asterisk, green) and BPP3 (square, black). Higher frequencies than 250 Hz were filtered out from the raw signal. The blue circles represent the maxima of the plasma potential of BPP0, BPP2 and BPP3 during ELM events. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

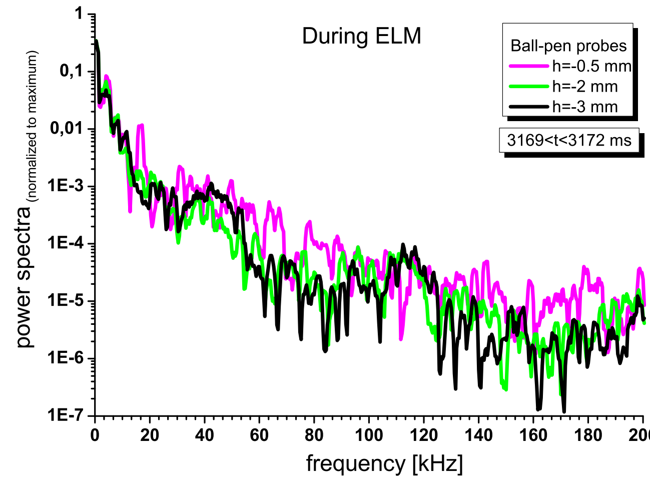

Fig. 6. Power spectra of the plasma potential of BPP0 (magenta), BPP2 (green) and BPP3 (black) during ELM event for $3.169 < t[s] < 3.172$ in stroke 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

account for the limiter geometry field line tracing was used for the mapping.

Fig. 4 shows two different types of radial profiles of the plasma potential. The position of each BPP is calculated with respect to the last closed flux surface (LCFS), $R - R_{LCFS}$. The first type of radial profiles is obtained from the plasma potential of BPP0, BPP2 and BPP3, where frequencies higher than 250 Hz are filtered out from the raw signal in order to significantly eliminate the contribution of turbulent plasma and ELM structures. The resulting profiles show that all BPPs measure the same radial profile of the plasma potential. It indicates that the plasma potential measurements are independent of which BPP signal is used and of the corresponding collector position. The same behaviour was observed during many systematic measurements on CASTOR tokamak [3,4]. The electric field is approximately 5 kV/m in the vicinity of the limiter. On the other hand, the second profile is obtained from the maxima of the plasma potentials of BPP0, BPP2 and BPP3 during ELM events. The electric field is approximately 30 kV/m deep inside the limiter shadow.

The power spectra of the BPP probe potentials between ELMs, normalized to their maximum values, are plotted in Fig. 5. A strong

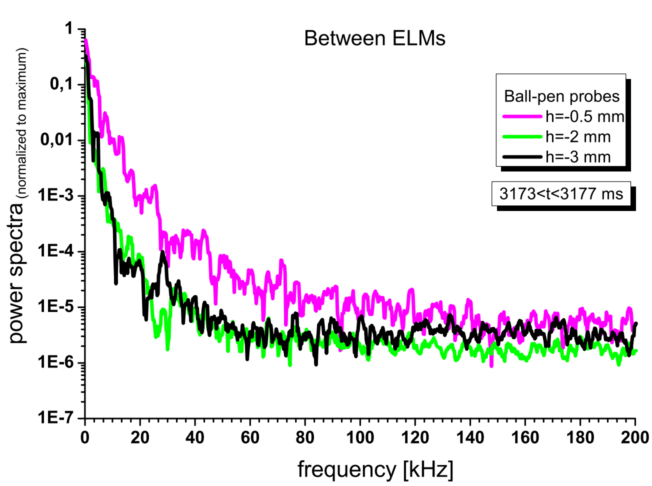

Fig. 5. Power spectra of the plasma potential of BPP0 (magenta), BPP2 (green) and BPP3 (black) in between ELM events for $3.173 < t[s] < 3.177$ in stroke 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

damping of higher frequencies is observed for the deeply retracted collectors. Therefore, the time resolution of the plasma potential measurement is lower for the deeper retraction of the BPP collector because the absence of higher frequencies in the power spectra. The same feature has been observed during similar measurements with BPPs on CASTOR tokamak [9]. On the other hand, the BPP0 with the collector at $h = -0.5$ mm provides more reliable information about the plasma potential fluctuations up to roughly 100 kHz. The higher frequencies ($f > 100$ kHz) of the plasma potential fluctuations of all BPPs are already fully suppressed. The retraction depth $h = -0.5$ mm is the minimum for reliable operation of the BPP and direct measurements of the plasma potential. However, it is still not yet understood why the higher frequencies in the power spectra are damped for the deeply retracted collectors.

The power spectra of the BPP probe potential during ELMs, normalized to its maximum value, is independent of the collector retraction as seen in Fig. 6. It is evident that the power spectra and consequently the time resolutions of the plasma potential measurements during ELMs are not affected by the retraction of BPP collector. However, the time resolution is limited by the sampling frequency (0.5 MHz) and detection limit of the data acquisition system. However, it is not yet clarified why the power spectra of the plasma potential fluctuations is independent of the collector retraction.

5. Conclusions

Ball-pen probes were used for measurements of the plasma potential during ELMy H-mode shots on ASDEX Upgrade. The probe head was exposed to the edge plasma in the vicinity of the limiter. It was found that all ball-pen probes directly measure the radial profile of the plasma potential independently of the position of their collectors ($h = -0.5, -2, -3$ mm), which is in good agreement with measurements on the CASTOR tokamak [1,2]. The electric field close to the limiter in between ELMs is approximately 5 kV/m. During ELM events the electric field is significantly higher by a factor of about 6.

Acknowledgements

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