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Fast ion temperature measurements using ball-pen probes in the SOL of ASDEX Upgrade during L-mode

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Abstract

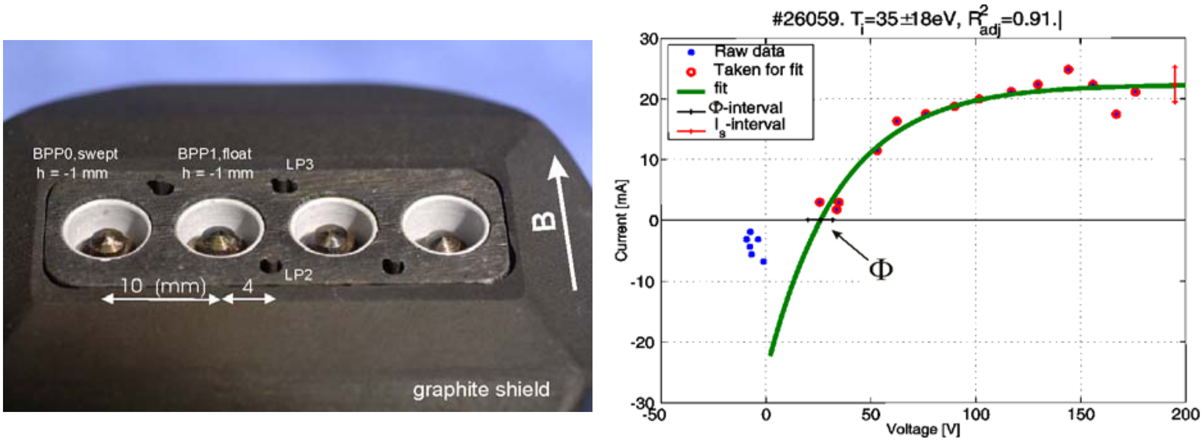
We describe a novel probe method for ion temperature measurements by using a swept ball-pen probe (BPP) with special fitting routines and error analysis. Originally BPPs were developed to directly measure the plasma potential in DC regime. We report results of the first measurements with fast swept BPPs fixed on the midplane manipulator of ASDEX Upgrade (AUG) during L-mode to determine the ion temperature with a time resolution of 10 µs.

1. Introduction

The ion temperature, T_i, is one of the most important but also most elusive parameters of toroidal fusion plasmas. In the scrape-off layer (SOL) of tokamaks, retarding field analyzers [1] are routinely used to provide T_i with low time resolution. Ion sensitive probes, especially Katsumata probes [2], can also be used to determine the ion temperature with higher time resolution. This technique requires simultaneous sweeping of collector and metal shielding to measure only ion current. Thus, it is difficult to identify the pure exponential part of the *I-V* characteristics [2]. We have developed a novel method to measure T_i, using a swept ball-pen probe (BPP) [3,4]. Originally BPPs were developed to measure the plasma potential, Φ, since in a magnetized plasma their floating potential becomes equal to Φ [3-6]. The BPP is similar to the ion sensitive probe but has only one conducting part, the collector, which is retracted into a ceramic tube. Therefore, most electrons are screened off the BPP collector so that its *I-V* characteristic becomes symmetric, the ratio of ion and electron saturation current is close to one, $I_{sat^-}/I_{sat^+} \approx 1$ [3,4]. The electron branch of the *I-V* characteristic contains the exponential decay of the ion current magnitude with the coefficient T_i, starting at the plasma potential which here is equal to the collector's floating potential. The electron current is mainly saturated or linearly increasing with the probe voltage. The fitting procedure starts at an exact value where the probe current is zero and the probe potential is close to the plasma potential, i.e. $I = 0$ A and $V \approx \Phi$. Note that in case of a Katsumata probe or BPP the ions are partially transported across the magnetic field into the shielding tube by Larmor motion. The ions and electrons are also transported inside the shielding tube by $\boldsymbol{E}\times\boldsymbol{B}$ drifts, as was recently found by 3D PIC simulations [7]. Therefore T_i can be deduced from the exponential part of the *I-V* characteristics of the BPP if the collector is retracted by a value equal to about two times the ion Larmor radius.

2 Experimental arrangement

The BPP head (see Fig.1a) is mounted on the mid-plane manipulator of ASDEX Upgrade (AUG) and inserted several times during L-mode discharges into the SOL with $B_T = -2.5$ T, $I_P = 0.8$ MA, $n = 4{\cdot}10^{19}$ m^{-3}, $P_{ECRH} = 0.8$ MW. The single BPP0 was swept from 0 to +200 V with a frequency of 50 kHz. It provides about 20 data points per each characteristic since the sampling frequency is 2 MHz, as seen in the example of an *I-V* characteristic in Fig. 1b. The probe collector was retracted by $h = -1$ mm into the shielding tube, which is comparable with the ion Larmor radius ($\rho_i = 0.5$ mm for $T_i = 50$ eV, $B = 1.9$ T in the SOL). The electron temperature T_e is provided by the difference of the BPP1 and LP2 potentials divided by 2.2 [3].



(a) (b)

Figure 1. a) Quadruple ball-pen probe of AUG. b) Example of *I-V* characteristic of swept BPP0 with exponential fit. The red points are used for the fit procedure, the green line shows the resulting fit of the electron branch.

3. Fitting of the *I-V* characteristics and its errors

The electron branch of the *I-V* characteristic of the BPP, where the ions are retarded by the potential $V - \Phi$, can be fitted in a similar way as for a Langmuir probe. We assume that the electron current is constant and equal to I_{sat^-} for positive probe voltage with respect to the plasma potential, $V > \Phi$. The electron current saturation at sufficiently positive voltage is seen in Fig. 1b. Therefore, the fitting formula is

$$Y = I_{sat}\left[1-\exp\left(\frac{\Phi - V}{T_i}\right)\right] \tag{1}$$

where Y is the fit estimation of the measured current I with three unknown parameters p = [I_{sat},T_i,Φ]. The value I_{sat} is the electron saturation current plus the retarded ion current. Using the standard least-square method for the non-linear three-parameter fitting [8], the residuum

$$S = \sum_{k=1}^{N}\left(Y_k - I_k\right)^2 \rightarrow \min \tag{2}$$

is minimized to obtain the most probable value of the parameters of each individual *I-V* characteristic. However, the total number N of the measured data is very small (in our case N < 20) per each *I-V* characteristic, and therefore a realistic estimate of the error of this 3-parameter fit is crucial. We allow the free parameters p to vary during a single voltage sweep. The matrix F_{kj}, based on statistical methods [9] is expressed as

$$F_{kj} = \frac{\partial S(V_k, p)}{\partial p_j} \quad \rightarrow \quad F = \left[\frac{I}{I_{sat}}, \frac{(I - I_{sat})\cdot(V-\Phi)}{T_i^2}, \frac{I - I_{sat}}{T_i}\right] \tag{3}$$

Then, we can find the errors of the fitting using the diagonal terms of the square error matrix

$$\left[\sigma_{I_{sat}}, \sigma_{T_i}, \sigma_{\Phi}\right] = u_\alpha \sqrt{\frac{S(p)}{N-3} diag\left[F^{\perp}F\right]^{-1}} \tag{5}$$

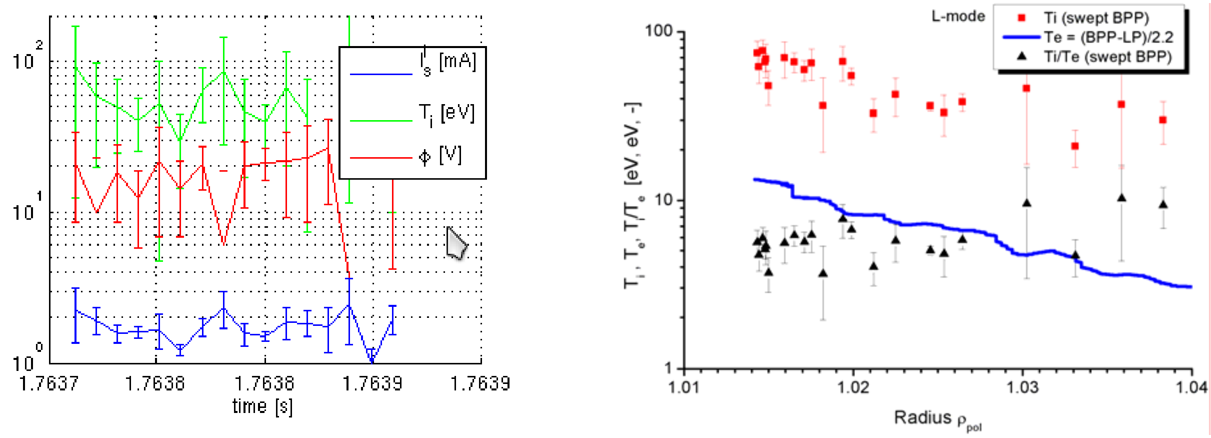
where u_α = 1.644 corresponds to the selected 95% of credibility, which is used everywhere within this paper. We also use another standard method for the overall fit quality, which is the so-called *adjusted index of determination* R_{adj},

$$R^2 = \frac{\sum_{k=1}^{N}\left(Y_k - \langle Y\rangle\right)^2}{\sum_{k=1}^{N}\left(I_k - \langle I\rangle\right)^2}, \qquad R_{adj}^2 = 1-(1-R^2)\frac{N-1}{N-3} \tag{6}$$

The example of the fitting curve with R_{adj}^2 = 0.9 and the value of the ion temperature T_i = 35 ± 18 eV is plotted in Fig. 1b.

4. Results

An example of the temporal evolution of the ion temperature, the corresponding plasma potential and saturation current is shown in Fig. 2a. Only values with R_{adj}^2 > 0.5 and with relative errors [σ_{Isat}/I_{sat}, σ_{Ti}/T_i, σ_{Φ}/T_i] of the fitting parameters less than 75 % are used. It means than only T_i values of very good fits are taken into account. In general only about 2 % of all measured *I-V* characteristics delivered T_i values with these restrictive error parameters. This could be caused by the sweeping frequency which is in not high enough to capture ion temperature fluctuations. Radial profiles of ion and electron temperatures are plotted in Fig. 2b.



(a) (b)

Figure 2. a) Example of the temporal evolution of the ion temperature (green line) and corresponding plasma potential (red line) and of I_{sat} (blue line), b) The averaged radial profiles of the ion and electron temperature.

Both profiles provide averaged values with corresponding error bars. We see an increase of the ion temperature towards the separatrix from 30 eV to 80 eV. The ratio T_i/T_e is exponentially decreasing down to approximately 5 at a normalized radius of 1.015 (≅ 10 mm from the separatrix). Similarly different values of the ratio T_i/T_e are also reported in [10]. The ratio varies from 2 to 3.5 on the separatrix on AUG during L-mode discharges.

5. Conclusions

The fast swept BPP delivers the ion temperature with a time resolution of 10μs. However, the sweeping frequency must be higher to capture also fluctuations. The ratio *Ti/Te* decays exponentially towards the separatrix from 10 to 5. The BPP has simple and compact design.

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References

[1] M. Kocan et al., Rev. Sci. Instrum. 79 (2008), 073502.

[2] J. Adamek et al., Contrib. Plasma Phys. 48 (2008), 1-5 / **DOI** 10.1002/ctpp.200810000.

[3] J. Adamek et al., Contrib. Plasma Phys. 50 (2010), 854-859 / DOI 10.1002/ctpp.201010145.

[4] J. Adamek et al., Czechoslovak J. Phys. 55 (2005), 235.

[5] J. Horacek et al. Nuclear Fusion 50 (2010), 105001.

[6] H.W. Müller, Nucl. Fusion 2011, in print.

[7] M. Komm et al., Plasma Phys. Control. Fusion 53 (2011), 015005 (7pp).

[8] J.P. Gunn et al., Rev. Sci. Instrum. 66 (1995), 154.

[9] Andel J., 1993, Statisticke metody, 1st edition, MATFYZPRESS, Prague

[10] M. Kocan et al., Plasma Phys. Control. Fusion **50** (2008) 125009