

Simultaneous Measurement of Electron and Ion Temperatures with a New Kind of Langmuir Probe

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1. Introduction

The ion temperature T_i remains one of the most elusive parameters of the tokamak edge plasma. In order to measure the ion energy distribution with a probe it is necessary to remove the electron component of the incident plasma flux. This imperative inspired the concept of the Katsumata ion-sensitive probe [1,2]. However, a reliable calibration of the Katsumata probe requires 3D, self-consistent particle-in-cell (PIC) simulations because the magnetic field is perpendicular to the cylindrical axis of the probe.

A new kind of Langmuir probe, baptized "tunnel probe", was recently developed [3,4] to measure the electron temperature T_e . The magnetic field and cylindrical axis are parallel to each other. In this contribution we show how a slight modification of this probe transforms it into a kind of Katsumata probe, thereby providing access to reliable measurements of the perpendicular ion temperature $T_{i\perp}$. The addition of a diaphragm in front of the orifice shields the concave tunnel surface from electrons. A retarding voltage is applied to the tunnel in order to scan the perpendicular ion energy distribution, from which $T_{i\perp}$ can be determined. The electron temperature is obtained simultaneously from the current-voltage (I - V) characteristic of the diaphragm. This probe geometry presents the advantage that it can be simulated easily using the XOOPIC code [5]. We report on the first measurements of simultaneous ion and electron temperatures in the CASTOR tokamak and kinetic simulations of the ion current characteristic.

2. Experimental set-up

Fig. 1 shows the modified tunnel probe used in our experiments in order to measure in both directions simultaneously, i.e., to the ion side and to the electron side. The left-hand side of

the probe head is equipped with an additional diaphragm in front of the entrance orifice, which transforms it into an ion-sensitive (Katsumata) probe [1,2,6]. In this way, the electrons are prevented from reaching the tunnel. By sweeping the potential across the tunnel, the $I-V$ characteristics are measured.

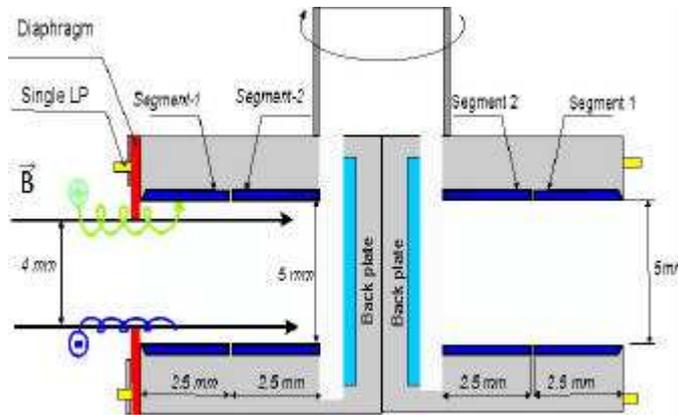


Fig. 1: The double tunnel probe: the left-hand side shows the modified tunnel probe with a diaphragm in front, by which it becomes an ion sensitive probe (Katsumata probe). The right-hand side probe is a purely segmented tunnel probe.

Since in our case the magnetic field is parallel to the axis of the tunnel, the only $E \times B$ drift is azimuthal. This is an advantage of this probe over the Katsumata design, because the probe can be precisely calibrated using a 2D kinetic code. In these experiments the tunnel was split into two electrically isolated segments in order to investigate also the axial distribution of ion flux. The right hand

side of the probe head represents the classical tunnel probe where the tunnel is split axially into two segments. This modification is envisaged for future measurements of the parallel ion temperature, when an extensive PIC simulation of this configuration will be available. However, here we concentrate on the measurements with the Katsumata tunnel probe.

3. Results and discussion

Fig. 2a,b shows typical current-voltage characteristics of the left-hand side tunnel (with diaphragm). The sweeping voltage is applied to the diaphragm and the tunnel segments. We noticed that the back plate draws a lot of electrons during the positive biasing portion of the ramp. This disturbs the ion currents to the segments and even the plasma current. Due to this effect, the back plate was left floating. All sweeping voltages were kept equal in order to avoid arcing.

The $I-V$ characteristics of Fig. 2 have been registered at a radial position of $r_p = 79$ mm, the Katsumata tunnel is oriented upstream to the toroidal plasma current. During a part of the flat top phase of the discharge, an additional electrode, inserted radially to the position of the last-closed flux surface (LCFS) at $r_E = 60$ mm was biased to a voltage of +100 V. Fig. 2(a) shows the $I-V$ characteristics during the ohmic part, Fig. 2(b) shows those during biasing. The upper characteristics are those of the diaphragm, from which the indi-

cated T_e -values ($T_e \cong 9.9$ eV for the ohmic and $T_e \cong 12.5$ eV for the biasing phase of the discharge) have been determined. These values appear to be rather reliable.

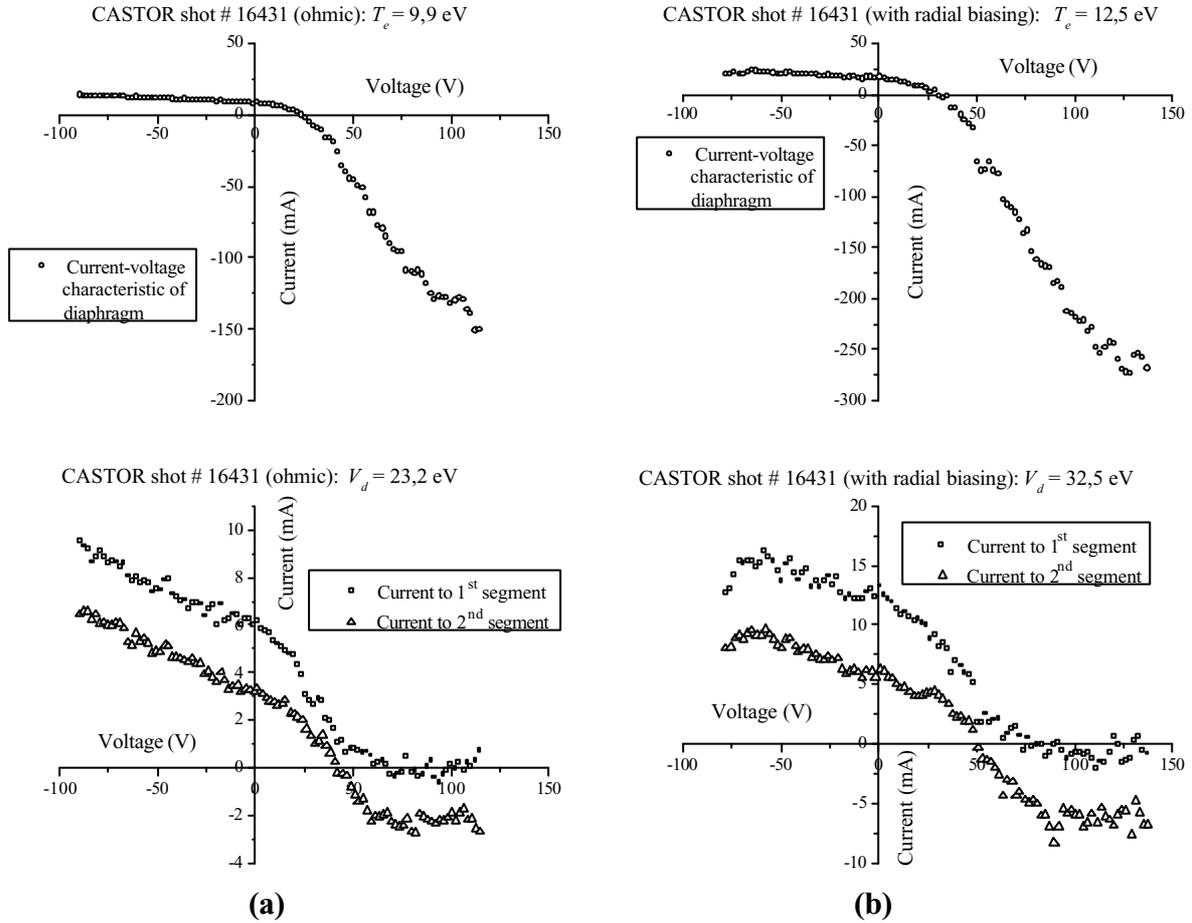


Fig. 2: Typical current-voltage characteristics registered by the left-hand side tunnel (with diaphragm) during ohmic discharges (a) and with edge biasing (b). The upper curves (circles) show the characteristics of the diaphragm. The lower curves show the characteristics of the first tunnel segment (squares) and of the second tunnel segment (triangles).

We notice that with biasing, T_e is somewhat higher than without. The lower plots are I - V characteristics of the first and the second segment. As can be seen from the figure, all the characteristics are of a similar shape. When the sweeping voltage V_s increases from negative values, the ion current decays approximately linearly. For V_s (voltage applied to the segments) higher than the floating potential (see the I - V characteristics of the diaphragm) the ion currents start to decay exponentially as $I \approx \exp(-V_s/V_d)$. It is seen that the electron screening by the diaphragm works properly only for the first segment, where the current decays to zero as it was expected. However, a non-negligible electron current is seen to reach the second segment. Consequently, the indicated values of the exponential decay $V_d = 23.2$ eV (ohmic) and 32.5 eV (bias) were determined only from the characteristics of the first segment. Again we observe that the value for the ohmic part of the discharge is lower than that one for biased part.

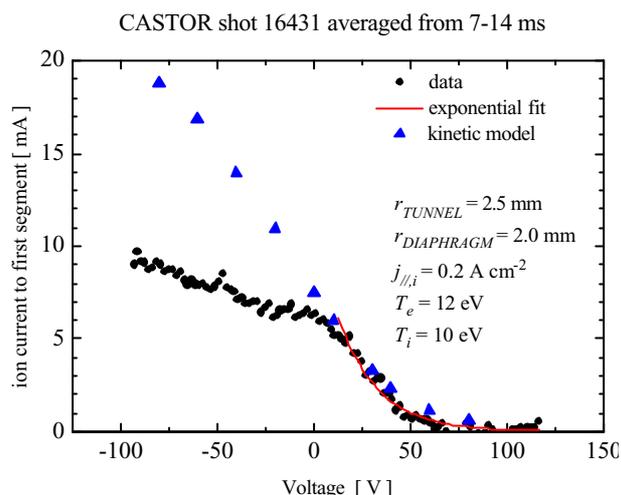


Fig. 3: Real I - V characteristic (solid circles) of the first segment (same as Fig. 2a below) and simulated characteristic (triangles) obtained from an XOOPIC code simulation with the parameters indicated. The solid line shows the exponential fit from which a value of $T_{i\perp} \cong 30$ eV was determined.

the measured characteristic (solid circles) of the first segment for the ohmic part of the discharge (from Fig. 2a). The code reproduces the ion current for positive retarding voltages quite well, although the inverse slope V_d of its logarithm is roughly three times $T_{i\perp}$.

In conclusion, these preliminary measurements with the Katsumata tunnel look promising. The PIC simulations are able to describe some features of the probe performance. However, more effort is definitely required to reach concordance between the simulations and measurements for the whole range of applied voltages. It is clear that the observed collection of electrons by the second tunnel can not be simulated by PIC code, unless collisions or other phenomena are taken into account. It is evident that the Katsumata tunnel can be routinely used for measurements of the edge ion temperature only after solving all above mentioned problems.

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References

- [1] I. Katsumata and M. Okazaki, *Japan J. Appl. Phys.* **6** (1967), 123.
- [2] I. Katsumata, *Contrib. Plasma Phys.* **36** (1996), 73.
- [3] J. P. Gunn, *Phys. Plasmas* **8** (2001), 1040.
- [4] J.P. Gunn et al., *Czech J. Phys.* **52** (2002), 1107.
- [5] J. Verboncoeur et al., *Comput. Phys. Commun.* **87** (1995), 199.
- [6] K. Uehara, A. Tsushima, H. Amemiya and JFT-2M Group, *J. Phys. Soc. Japan* **66**, 921 (1997).

In order to interpret the measurements, we have done preliminary kinetic simulations of the measured I - V characteristic to the first segment. The XOOPIC code was run several times varying the tunnel and diaphragm voltage. The initial plasma parameters were chosen as $T_i = 10$ eV, $T_e = 12$ eV, and $j_{//,i} = 0.2$ A/cm², where this latter quantity is the parallel

ion current density into the tunnel, determined from the ion saturation current of the diaphragm. Fig. 3 shows a comparison of the simulation results (triangle) with