Direct measurements of the plasma potential by katsumata–type probes

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By taking advantage of the inherent difference between the gyro–radii of ions and electrons in a magnetised plasma, we developed a method to measure the plasma potential directly. The principle is based on the concept of the Katsumata probe. The probe collector is hidden inside a tube which screens an adjustable fraction of the electron flux whereas it lets pass most of the ions. In this paper an arrangement of three Katsumata–type probes with different diameters is used in the edge plasma region of the CASTOR tokamak to investigate the influence of the dimension of the probe. The results show almost no influence of the probe diameter on the values of the plasma potential.

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1 Introduction

New types of probes, based on the Katsumata probe (Katsumata and Okazaki [1]), allowing the direct determination of the plasma potential Φ_{pl}, were developed.

These probes utilise the difference between the gyro–radii of electron and ions in a strong magnetic field. Here we present the Katsumata–type probe (KTP) as a further development of the ball–pen probe (BPP) [2, 3, 4], approaching the original principle of the Katsumata probe [1] (see Fig. 1).

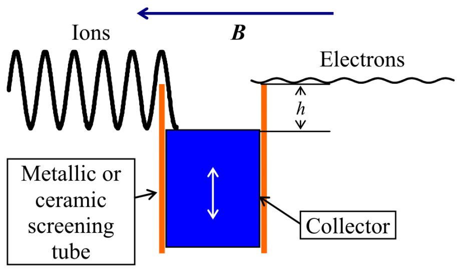


Fig. 1. Principle of a Katsumata probe: Due to the strong difference between the gyro–radii of ions and electrons, the latter can be screened off from the collector, while the ions can reach it. The position of the collector with respect to the rim of the screening tube is called h, with $h < 0$ when the collector is inside the tube and vice versa.

However, the original Katsumata probe [1] served for the purpose of measuring the ion energy distribution, either by shifting the collector up and down inside the screening tube (i.e., by varying h) or by sweeping the collector voltage at a sufficiently negative value of h.

The BPP [2, 3, 4] has a conically shaped collector tip which allows to adjust the magnitude of the electron saturation current precisely to the same value as that of the ion saturation current.For a BPP $h = 0$ signifies the case when the collector tip lies in the plane defined by the rim of the tube. We found that h needed to be just slightly negative for attaining the equality of the two particle currents. In this case, under the assumption of both charge carrier species having Maxwellian velocity distributions, it can be shown that the floating potential of this probe is equal to the plasma potential [2, 3]:

The following relation between the floating potential $V_{\rm fl}$ and $\Phi_{\rm pl}$ is valid for a usual cold Langmuir probe:

$$V_{\rm fl} = \Phi_{\rm pl} - T_{\rm e} \ln\left(\frac{I^{-}_{\rm sat}}{I^{+}_{\rm sat}}\right) = \Phi_{\rm pl} - T_{\rm e} \ln\left(\frac{j^{-}_{\rm sat} \cdot A_{\rm e}(h)}{j^{+}_{\rm sat} \cdot A_{\rm i}(h)}\right) . \qquad (1)$$

$I^{-,+}_{\rm sat}$ are the electron, respectively ion saturation currents to the probe, $j^{-,+}_{\rm sat}$ are the corresponding current densities, $A_{\rm e,i}(h)$ are the effective areas for electron, respectively ion collection. For a conventional Langmuir probe in an unmagnetized plasma these areas are assumed to be equal. In a magnetic field the conditions are usually more complicated, while for a BPP the areas become strongly dependent on the parameter h: For $h \leq 0$, $A_{\rm e}(h) << A_{\rm i}(h)$, and from Eq. (1) we see that the floating potential becomes equal to the plasma potential when the following condition is fulfilled:

$$\frac{j^{-}_{\rm sat} \cdot A_{\rm e}(h)}{j^{+}_{\rm sat} \cdot A_{\rm i}(h)} = 1 \;\Rightarrow\; V_{\rm fl} = \Phi_{\rm pl} . \qquad (2)$$

In [2, 3] we have proved that indeed Eq. (2) can be fulfilled experimentally. Thus the BPP can be used as a direct diagnostic tool for measuring $\Phi_{\rm pl}$ with good temporal and spatial resolution. We found that the value of h, as long as it is negative, is not very critical. In a wide range of $h < 0$, the magnitudes of the two saturation currents (ion and electron) are equal to each other and the floating potential of the collector of the BPP is almost equal to the plasma potential. For typical values of the edge plasma region of the CASTOR tokamak (major radius $R = 0.4$ m, minor radius $r = 8.5$ cm, electron temperature around 20 eV and magnetic field 1.3 T), we chose a collector depth of $h = -1$ mm inside the screening tube for rendering the floating potential of the BPP equal to $\Phi_{\rm pl}$. One surprising result of our investigations was that even for a strongly withdrawn collector ($h < -1.5$ mm) still a certain electron flux was detectable on the probe collector [2]. This effect is probably a sign of radial diffusion as discussed in [5].

2 Experimental set–up

In view of the fact that the depth of the collector inside the screening tube does not particularly matter as long as $h < 0$ mm, we have returned to the original concept of the Katsumata probe by using a flat collector, which facilitates its construction. The stainless steel collector is surrounded by a boron nitride tube with a larger diameter. We also observed that the diameter of the collector and thus of the screening tube seemed to have an influence on the particle flux and thus on the floating potential $V_{\rm fl}$ of the probe collector. Therefore, as a systematic continuation of our experiments we have tested the influence of the diameter of the collector, and of the surrounding massive boron nitride probe holder on the CASTOR tokamak at the Institute for Plasma Physics of the Academy of Sciences of the Czech Republic in Prague.

The set–up is shown in Fig. 2. This is a combination of three KTPs with stainless steel collectors with diameters of 1, 2 and 4 mm with their position fixed at $h = -1$ mm. The surrounding material is boron nitride, each hole having a diameter larger by 1 mm than the respective collector in order to reduce the effect of possible metal sputtering. Our construction required that, in contrast to the original Katsumata probe, the particle screening was effectuated by rather thick partition walls around and in between the three KTPs. This is discussed in the following section.

The Katsumata–type probe head is inserted from the top of CASTOR (poloidal angle $\Theta = 90°$) into the edge region of the plasma column, and radial scans were performed on a shot–to–shot basis. The line average plasma density was around 10^{19} m^{-3}. The last closed flux surface was at $r = 82$ mm. For comparison a single BPP with a movable collector with 2 mm diameter was also used in the same discharges.

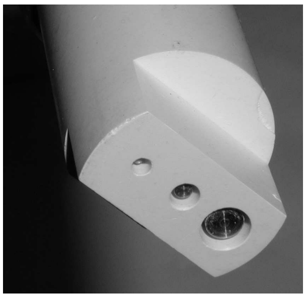
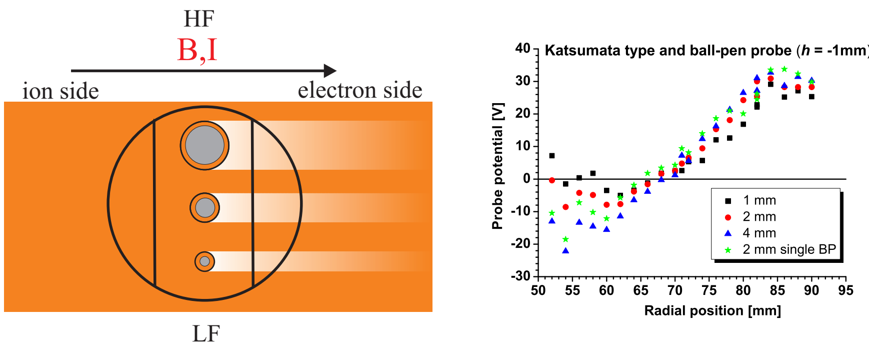


Fig. 2. Three Katsumata–type probes with different diameters with constant $h = -1$ mm. The probe casing is made of boron nitride.

3 Experimental results and discussion

Fig. 3a shows the orientation of the probe head with the three KTPs with respect to the toroidal direction of CASTOR tokamak. We presume that the three probes are approximately on the same magnetic surface. Also the BPP was inserted at the same poloidal angle, but toroidally shifted by about 180° from the KTP head.

As seen from Fig. 3b, the radial profiles of the plasma potential measured with this probe head (black squares: 1 mm diameter probe, red dots: 2 mm probe, blue triangles: 4 mm probe) and with the BPP (green asterisks) are very close to each other but there are some deviations in particular for $r < 62$ mm.



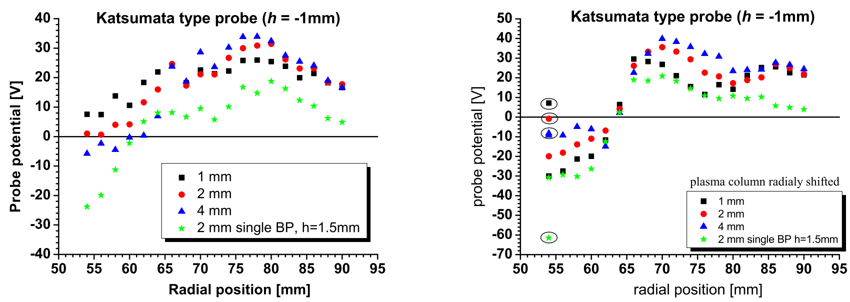
(a) (b)

Fig. 3. (a) Schematic of the insertion of the probe head consisting of three Katsumata–type probes with different diameters, (b) the corresponding radial scans of the floating potential (assumed to be equal to the plasma potential) of the three probes (black squares: 1 mm diameter, red dots: 2 mm, blue triangles: 4 mm) and of the ball–pen probe (green asterisks), with its collector on $h = -1$ mm; HF = high field side, LF = low field side. The line average density was 8.5×10^{18} m^{-3}.

The deviations between the radial profiles could be caused by possible misalignments of the positions of the three KTPs and of the BPP with respect to the magnetic surfaces. Especially for decreasing values of r, where the poloidal curvature increases, this misalignment becomes larger. This is exactly what we see in Fig. 3(b) for $r < 62$ mm. The green asterisks represent the potential values of the single BPP with diameter 2 mm and the collector at $h = -1$ mm. In spite of the aforementioned different constructions of the two probe heads (the KTP consists of a massive boron nitride construction whereas the BPP is much more slender), they provide approximately the same values of potential. This implies that the size of the boron nitride tube does not affect the measured data very strongly.

It is not clear, however, how the particle trajectories look in detail in the case of the three KTPs: By the BPP's screening tube the ion trajectories are only partly perturbed and a large number of the ions can spiral by unhindered (except by possible space charges or wall charges), eventually reaching the collector. On the other hand, in the case of the KTPs this is hardly imaginable since the partition walls are much thicker. Therefore the trajectories of ions (and electrons) reaching one of the KTP collectors must obviously be much more complex, but nevertheless the fact that the ion gyro–radius is much larger than that of the electrons must play a role also in this case, probably combined with a complex electric field structure in front and inside the respective hole.

Figs. 4a, 4b shows similar radial profiles taken with the same KTP head for ohmic discharges for two different vertical position of the plasma column while the other conditions remain the same. In this case the collector of the BPP was at $h = +1.5$ mm, thus it was protruding and the BPP acted as a conventional Langmuir probe. Consequently, the floating potential of this probe is the conventional V_{fl} and thus more negative than the plasma potential by a value which is given by Eq. (1) [2].



(a) (b)

Fig. 4. Radial scans of the floating potential (assumed to be equal to the plasma potential) of the three Katsumata–type probes (black squares: 1 mm diameter, red dots: 2 mm, blue triangles: 4 mm) and of the ball–pen probe (green asterisks); in this case the ball–pen probe with $h = +1.5$ mm acted as a normal Langmuir probe: (a) Ohmic discharges, (b) with strong vertical shift of the plasma column. The line average density was 12×10^{18} m^{-3}.

Similar to Fig. 3(b), the three floating potentials of the KTPs in Fig. 4(a) are not fully identical. The deviation can be interpreted as results of a displacement of probes with respect to the magnetic surface. For that case the plasma column was strongly shifted in vertical direction and the observed profiles are plotted in Fig. 4b. The floating potentials of the KTPs indicate a dependence on the plasma column position, which is not trivial. The potentials at $r = 54$ mm of all probes marked by a circle represent the results from the shot, which has been performed at the end of a radial scan, but with the same position of plasma column as in Fig. 4a. It is evident that the measured values are reproducible. The question remains open why the conventional floating potential V_{fl} (measured with the BPP, green asterisks) is not systematically below the value of KTPs.

4 Conclusion

We have performed an extensive investigation of Katsumata–type probes with different diameters. We have verified that these probes indeed deliver approximate direct measures of the plasma potential. The experiment has confirmed that the diameter of the KTPs is not a critical construction parameter for a reliable measurement of plasma potentials in magnetized plasmas. Several problems remain to be solved such as the detailed shape of the particle trajectories near the collector and inside its hole. Therefore additional experiments and further simulations are required to solve these problems and to determine the most preferable dimensions. Further measurements will be performed with such probes also on other toroidal fusion experiments such as ASDEX Upgrade and RFX.

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