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Direct Measurements of the Plasma Potential by Katsumata-type Probes

R. Schrittwieser,[a] J. Adamek,[b] C. Ionita,[a] E. Martines,[c] J. Brotankova,[b] L. van de Peppel,[d] C. Costin,[e] G. Popa,[e] G. Van Oost,[f] J. Stöckel[b]

[a]Association EURATOM-ÖAW, Institute for Ion Physics and Applied Physics; Leopold-Franzens University of Innsbruck, Austria; [b]Institute of Plasma Physics, Association EURATOM/IPP.CR, Prague, Czech Republic; [c]Consorzio RFX, Associazione EURATOM-ENEA sulla Fusione, Padova, Italy; [d]Hogeschool Rotterdam, Rotterdam, Netherlands; [e]Association EURATOM-MEdC, Faculty of Physics, Al. I. Cuza University, Iasi, Romania; [f]Department of Applied Physics, Ghent University, Belgium

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 electrons 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):

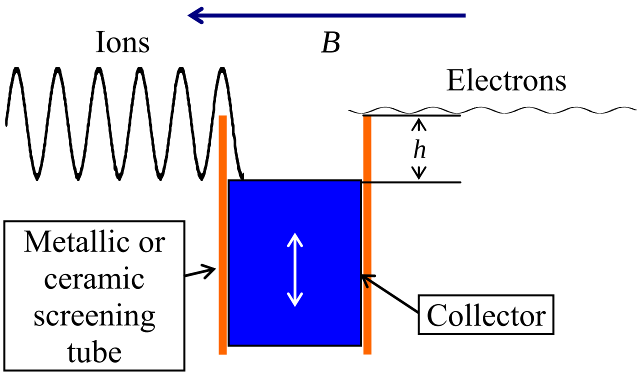


Fig. 1: Principle of a Katsumata probe: Due to the strong difference between the gyro-radii of ions and electrons, the latter can be screened off from the collector, while the ions can reach it.

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 for a sufficiently negative value of *h*.

The BPP [2,3,4] has a conical collector tip which makes it possible to adjust the magnitude of the electron saturation current precisely to the same value as that of the ion saturation current. 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]. Thus the BPP can be used as a direct diagnostic tool for measuring Φ_{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 constant and almost equal to Φ_{pl}. For typical values of the edge plasma region of CASTOR (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. 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].

2. Experimental set-up

In view of the fact that the depth of the collector inside the screening tube does not particularly matter for $h < 0$ mm, for the Katsumata-type probe (KTP) 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_{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 in the CASTOR tokamak at the Institute for Plasma Physics of the Academy of Sciences of 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 positions 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. This probe head is inserted from the top of CASTOR into the edge region of the plasma torus, and radial scans in the edge region were performed on a shot-to-shot basis. The line average plasma density was around 8×10^{18} m^{-3}. The last closed flux surface was at $r = 82$ mm. For comparison a single BPP with a 2 mm diameter collector was used.

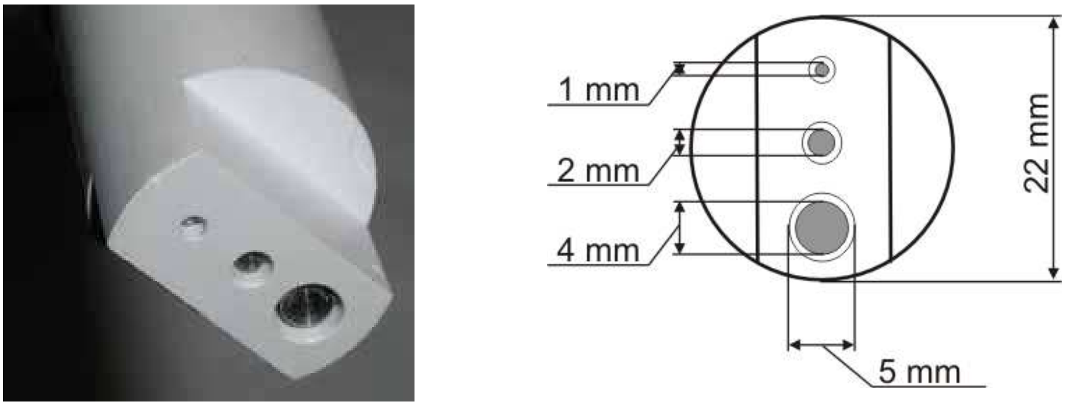
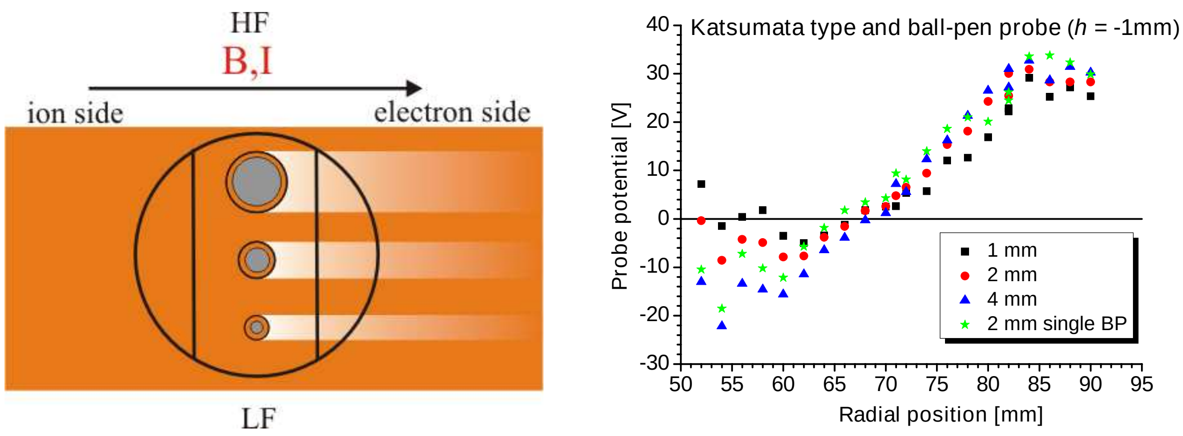


Fig. 2: Three Katsumata-type probes with different diameters with constant h = –1 mm. The probe case is of boron nitride.

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 on the same poloidal angle but toroidally shifted by 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 stronger 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 square: 1 mm diameter, red dots: 2 mm, blue triangles: 4 mm) and of the ball-pen probe (green asterisks); HF = high field side, LF = low field side. The line average density was 8.5×10^{18} m^{-3}.

These deviations 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. 3b for $r < 62$ mm. Nevertheless, we would like to point out that the probe potential values agree well with each other and with those of the BPP in spite of the considerably different construction of the two probe heads: the KTP consists of a massive boron nitride construction whereas the BPP is much more slender.

4. Conclusion

This experiment has confirmed that the diameter of the Katsumata-type probe (KTP) is not a critical construction parameter for a reliable measurement of plasma potential in magnetized plasmas. However, determination of the most preferable dimensions would require additional experiments and further simulations. Further measurements will be performed with such probes also on other toroidal fusion experiments such as ASDEX Upgrade and RFX.

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