

# MEASUREMENTS OF PLASMA POTENTIAL AND ELECTRON TEMPERATURE BY BALL-PEN PROBES IN RFX-MOD

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The ball-pen probe (BPP) is an innovative electric probe for direct measurements of the plasma potential. This probe was developed in IPP Prague and it is based on the Katsumata probe concept. Combined measurements of the plasma potential by a BPP and floating potential by a Langmuir probe provide also the value of the electron temperature. First test of the BPP on the RFX-mod reversed field pinch in Padova has been performed in November 2006. The BPP head, made of boron nitride, is equipped with four graphite collectors, which are positioned at four different radial positions  $h$  inside four shafts hollow into the probe head. The radial profile of the plasma potential and also the electron temperature were measured.

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## 1. INTRODUCTION

Understanding of the electric field and its turbulence in magnetic confinement devices is one of important tasks in the fusion research. The transport phenomena are guided by changes of plasma potential in the edge of the plasma. This research is thus relevant for ITER, for the lifetime of the first wall components. Direct plasma potential measurements are also essential for understanding of the SOL physics and for the verification of the numerical simulations of the SOL [1, 2]. Up to now, emissive probes [3] and heavy ion beam probes [4] have been used for the determination of the plasma potential in tokamaks. However, use of these techniques is hampered by various technical problems and peculiarities in measured data interpretation.

The Ball-pen probe was developed in the Institute of Plasma Physics AS CR in Prague [5-8] for direct measurements of the plasma potential. It was used in several experimental devices: in tokamaks CASTOR [5-8] and ASDEX Upgrade. The BPP was also used in the reversed field pinch RFX-mod in Padova [9], a Reversed Field Pinch toroidal device with major radius  $R=2$  m and minor radius  $a=0.459$  m in order to verify the behavior of the probe also in low magnetic field ( $\sim 0.1$  T). In this paper, the first results of the measurements in RFX-mod are referred.

## 2. PRINCIPLE OF THE BALL-PEN PROBE

The Ball-pen probe takes advantage of the difference between the electron and ion Larmor radii. It was developed on the basis of the Katsumata probe concept [10]. The BPP is made of a ceramic tube with a metal collector of a conical shape inside. The probe head is oriented perpendicularly to the magnetic field lines. The ions can penetrate deep into the shaft due to their larger gyro-radii, while certain part of the electrons is shielded.

According to the Langmuir probe theory for Maxwellian plasmas, the floating potential of the collector  $V_{fl}$  can be expressed as

$$V_{fl} = \Phi - \frac{k_B T_e}{e} \ln \left( \frac{I_{sat}^-}{I_{sat}^+} \right), \quad (1)$$

where  $\Phi$  is the plasma potential,  $T_e$  is the electron temperature,  $I_{sat}^-$  and  $I_{sat}^+$  is the electron and ion saturation current, respectively. For a certain position of the collector, the  $I_{sat}^-$  and  $I_{sat}^+$  are balanced and the corresponding BPP potential is equal to the plasma potential.

## 3. EXPERIMENTAL SET-UP

The BPP head developed for the RFX-mod experiment is shown in Fig. 1. The probe head is made of boron-nitride material with four shafts where the collectors are located. The collectors are made of graphite at different positions  $h$  with respect to the mouths of the shafts: 0 mm, -3 mm, -6 mm, -9 mm. Collectors have diameter of 4 mm and the probe head itself has a diameter of 50 mm and length of 90 mm.



*Fig. 1. The ball-pen probe head for the experiment on RFX-mod*

The measurements with floating ball-pen collector were performed with two different values of  $F$  parameter.  $F$  is called reversal parameter, it is the ratio between the value of toroidal magnetic field at the wall position  $B_\phi(a)$ , and the averaged toroidal magnetic field:  $F = \frac{B_\phi(a)}{\langle B_\phi \rangle}$ . First of the series was with  $F = -0.2$ , the second one with  $F = -0.04$ .

The BPP operated on the low field side of the RFX-mod vessel at the mid plane. The measurements were performed with the different radial positions of the BPP on shot-to-shot basis. The main plasma parameters for the data reported in this paper were low plasma current  $I_p \sim 300$  kA, plasma density  $n \cong 1 \cdot 10^{19} \text{ m}^{-3}$ , the electron temperature at edge  $T_e \cong 20 \text{ eV}$ . In these discharges the poloidal magnetic field at edge is  $B \cong 0.12 \text{ T}$ ,

#### 4. RESULTS

Radial profiles of the potential of the collectors are plotted in Fig. 2. Each radial position contains four points. They represent values of the potential measured by the BPPs with four different depths of the collectors. The radial position is considered not as the radial position of the collectors themselves, but as the radial position of the probe head. Fig. 2 shows that there is a saturation of the potential for depths of the collector of -3 mm and more. Results of the experiments from the CASTOR tokamak ( $B_{tor} \cong 1 \text{ T}$ ) show that saturated potential of the BPP collector indicates the value of plasma potential.

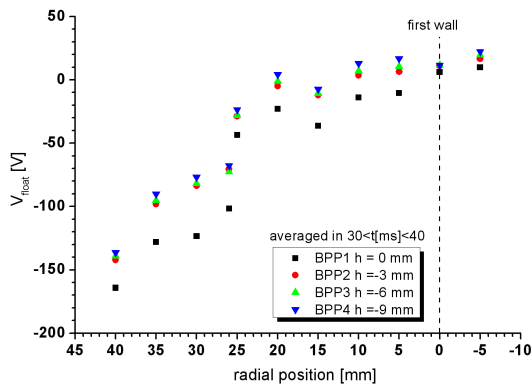


Fig. 2. Radial profiles of the potential of the BPP collectors with different depths ( $h = 0 \text{ mm}$ ,  $-3 \text{ mm}$ ,  $-6 \text{ mm}$ ,  $-9 \text{ mm}$ ). The first wall of the RFX-mod vacuum vessel is located at the radial position  $0 \text{ mm}$

The collector at the position  $h = 0 \text{ mm}$  operates as a standard Langmuir probe in plasmas with low magnetic field. The value of the potential therefore corresponds to the value of the floating potential  $V_{fl}$ . These values are lower than the potential of the deeper collectors, as is shown in the Fig. 2. The values of plasma potential show qualitative agreements with previous measurements [11]. We can derive the electron temperature from the difference of the plasma and the floating potential as

$$T_e = \frac{\Phi - V_{fl}}{\alpha}, \quad (2)$$

where the coefficient  $\alpha = 2.89$  for hydrogen plasmas. Resulting radial profile of  $T_e$  is plotted in Fig. 3. The previous measurements [11] show higher values in the plasma bulk. This quantitative discrepancy can be due to the suprathermal electrons which might have influenced the triple probe measurements in [11].

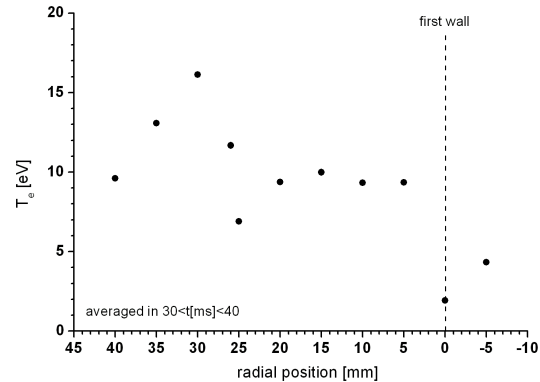


Fig. 3. Radial profile of electron temperature

#### 5. CONCLUSIONS

The Ball-pen probe was tested at the RFX-mod reversed field pinch in Padova. The probe head was inserted into the edge plasma up to the radial position of 40 mm from the limiter. Saturation of the collector potential occurred from the depth of 3 mm. Radial profile of plasma potential as well as of the electron temperature were obtained.

We conclude that the BPP is well-suited diagnostic tool for routine measurements of the plasma potential in the edge plasma region of fusion devices, yielding sufficiently high spatial and temporal resolution. Furthermore, the BPP is a very robust construction, surviving even high power loads

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#### **ИЗМЕРЕНИЕ ПОТЕНЦИАЛА ПЛАЗМЫ И ЭЛЕКТРОННОЙ ТЕМПЕРАТУРЫ ШАРОПОДОБНЫМИ ЗОНДАМИ В RFX-MOD**

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Шароподобный зонд – новый тип зонда для прямых измерений потенциала плазмы. Данный зонд разработан в ИФП, в Праге, и основан на концепции зонда Катсуматы. Комбинированные измерения плазменного потенциала шароподобным зондом и плавающего потенциала Ленгмюровским зондом дают также величину электронной температуры. Первые испытания зонда в пинче с обращенным полем на RFX-mod в Падове проведены в ноябре 2006 г. Головка зонда, сделанная из нитрида бора, оснащалась четырьмя графитовыми коллекторами, которые размещались в четырех различных радиальных положениях  $h$  внутри четырех пустотелых цилиндрических отверстий в головке зонда. Измерены радиальный профиль потенциала плазмы и электронная температура.

#### **ВИМІРЮВАННЯ ПОТЕНЦІАЛУ ПЛАЗМИ ТА ЕЛЕКТРОННОЇ ТЕМПЕРАТУРИ КУЛЕПОДІБНИМИ ЗОНДАМИ У RFX-MOD**

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Кулеподібний зонд – новий тип зонду для прямих вимірювань потенціалу плазми. Цей зонд розроблено у ІТП, в Празі, та засновано на концепції зонду Катсумати. Комбіновані вимірювання плазмового потенцілу кулеподібним зондом та плаваючого потенціалу Ленгмюрівським зондом дають також величину електронної температури. Перші випробування зонду в пінчі з оберненим полем на RFX-mod у Падові було проведено у листопаді 2006 р. Головка зонда, вироблена з нитриду бора, була оснащена чотирма графитовими колекторами, які були розташовані в чотирьох радіальних положеннях  $h$  усередині чотирьох порожнистих циліндричних отворів в голівці зонда. Виміряно радіальний профіль потенціалу плазми й електронну температуру.