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Probe investigations of the Pilot-PSI plasma

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1. Introduction

Pilot-PSI is a magnetized linear plasma device designed for investigations of plasma-surface interactions at ITER relevant parameters. Plasma parameters such as electron density, electron temperature and plasma angular rotation were studied by optical methods [1,2]. Recently electrical probe diagnostics were employed in order to complete the spectrum of plasma parameters by the plasma potential, electric field and plasma fluctuations.

This work reports on experimental investigations of the radial distribution of the plasma potential measured by an emissive probe [3] for various discharge currents, different magnetic field strengths and target biases. The emissive probe is externally heated until its floating potential almost equals the plasma potential. Without heating, the probe could also be used as cold probe for comparison. The radial component of the electric field was derived from the radial potential distribution. The electric drift velocity of the plasma column, in azimuthal direction, can be estimated by calculating $\boldsymbol{E}\times\boldsymbol{B}/B^2$. This velocity is usually greater than the total azimuthal drift velocity which depends on several other parameters, as it is elaborated further in the paper.

2. Experimental set-up

Plasma is produced by a cascaded arc discharge working in argon, hydrogen or argon-hydrogen mixture [4]. The discharge was operated in hydrogen at a pressure of 1 to 5 Pa and a discharge current of 80 to 150 A. An axial magnetic field of 0.03 to 0.4 T confines the plasma on the axis of the vessel in form of a 0.5 m long column of about 1-2 cm diameter, with the following typical

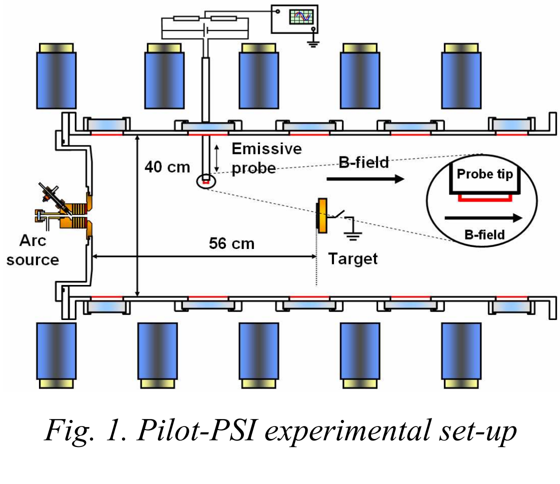

Fig. 1. Pilot-PSI experimental set-up

parameters at high magnetic field: plasma density ~ 10^{20} m^{-3}, electron temperature ~ 1-2 eV, ion temperature ~ 2-4 eV [1,2].

The plasma potential was measured by an emissive probe of tungsten wire with 0.35 mm diameter in form of a rectangular loop as shown in the insert of Fig.1. The active part of the loop of 3 mm length is oriented parallel to the magnetic field lines. The probe is radially moveable and was inserted into the vessel at about half the distance between the arc-source and the target (Fig. 1).

3. Results

A radial scan of the floating potential measured with the emissive probe heated by I_{heat}= 12.4 A and unheated (in which case it should act as cold probe) is plotted in Fig. 2. Inside the plasma column ($r \leq 5$ mm), both emissive and cold probe measure the same floating potential, which is approximately equal to the plasma potential. This showed that in such a dense plasma (~ 10^{20} m^{-3}) [1] even a cold probe becomes emissive under the bombardment with charged particles [5].

Outside the plasma column, the floating potential of the cold probe is negative with respect to that of the emissive one, which is the expected behaviour in a low-density plasma due to the higher mobility of the electrons. This result illustrates that for a high-density plasma as in this case the floating potential of an unheated probe can be a good approximation of the plasma potential since the probe is heated to emission by the plasma itself. Consequently, being interested in the radial distribution of the plasma potential, further results were obtained with the unheated probe.

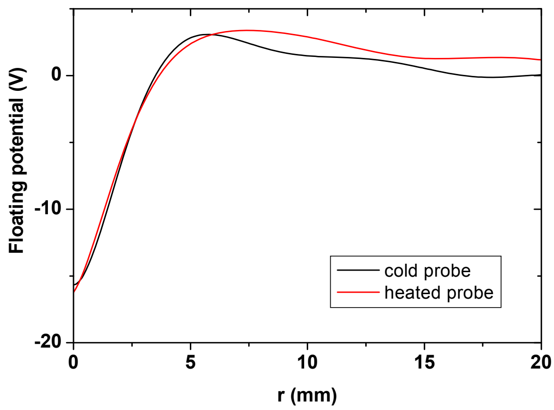

Fig. 2. Radial profile of the floating potential measured with both cold and emissive probes (I_d = 120 A, p = 1.6 Pa, B = 0.4 T)

Fig. 3(a) shows the radial dependence of the floating potential measured in the plasma column for different magnetic field strengths for a discharge current I_d = 120 A, a background pressure during operation of 1.6 Pa and for floating target. In the plasma column, the floating potential becomes more negative with increasing magnetic field due to the better confinement of the electrons (electron cyclotron radius $a_{ce} \sim 1/B$) and, implicitly, of the plasma on the axis. The better plasma confinement is also shown by steeper gradients of the potential at the edge.

For the same magnetic field strength of 0.4 T, the radial profile of the floating potential is plotted in Fig. 3(b) with the target bias as parameter. We recall that the probe is situated about 25 cm from the target, i.e. far outside the target's space charge sheath. However, in view of the strong variation of the profile we notice that the target bias strongly influences the plasma column as a whole. We also observe that the plasma potential is more negative with respect to the floating target case, be the target either positively or negatively biased.

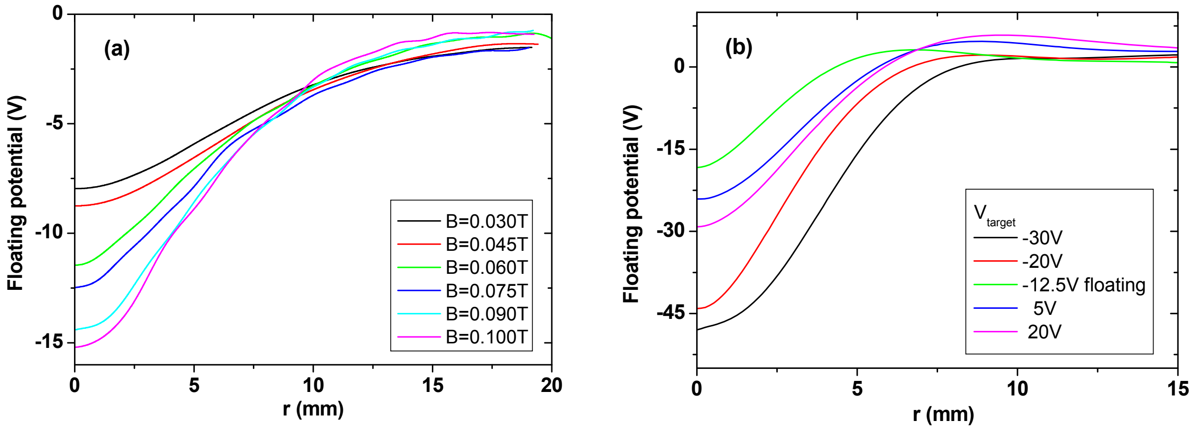

Fig. 3. Radial profile of the floating potential, having as parameter:
(a) the magnetic field; (b) the target bias (at B = 0.4 T).

The radial electric field in the plasma can be derived from the radial potential distribution. Furthermore, the term $\boldsymbol{E}\times\boldsymbol{B}/B^2$ delivers the electric drift velocity of the charge carriers. The drift velocities corresponding to the potential distributions plotted in Fig. 3. are shown in Fig. 4.

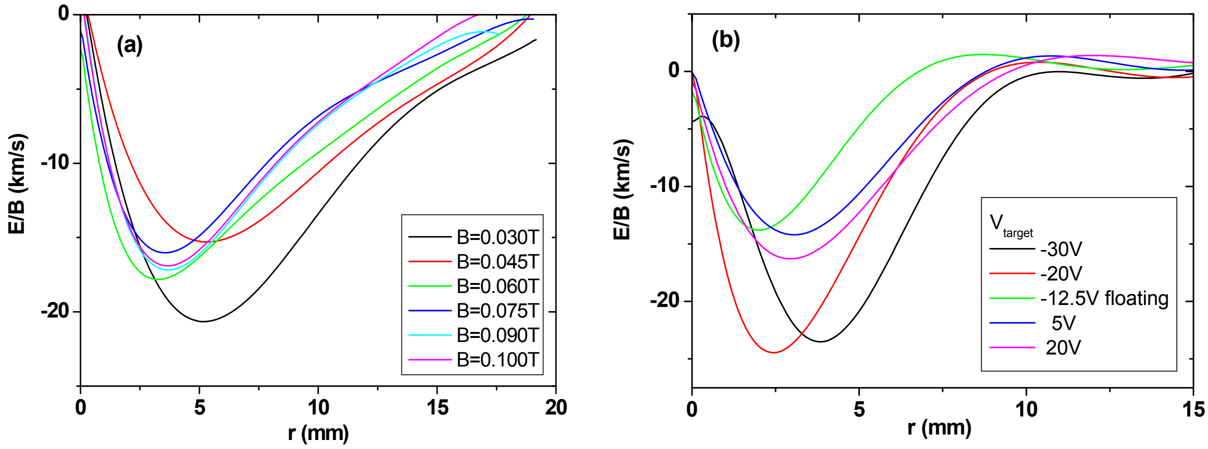

Fig. 4. Radial profile of E/B velocity having as parameter:
(a) the magnetic field; (b) the target bias (at B = 0.4 T).

These velocities characterize the azimuthal drift of a collisionless or weakly-collisional plasma for which the ion collision frequency (ν_i) is much smaller than the ion cyclotron frequency (ω_{ci}). For a collisional plasma, which is the case in Pilot-PSI, a first rough approximation of the drift velocity can be expressed in a simplified way as [6]:

$$\mathbf{v}_E = \frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2}\frac{1}{1+\left(\nu_i/\omega_{ci}\right)^2}.$$

According to the above formula, when the ratio between the two frequencies approaches or becomes higher than one, the drift velocity decreases. The collision frequency ν_i contains all possible ion collisions with neutral atoms and molecules, electrons, different ions, etc. These collisions are difficult to evaluate without knowing the spatial distribution of each involved species. However, we note that if the ion collision frequency equals the cyclotron frequency, the drift velocity decreases by half. This leads us to the conclusion that in Pilot-PSI the real drift velocities should be lower than those shown in Fig. 4. More detailed analysis on the effect of the collisionality, viscosity, particles density and electric field gradients, etc. on the azimuthal drift velocity will follow.

4. Conclusions

The plasma column of Pilot-PSI was investigated by a radially moveable emissive and cold probe. Although the emissive probe has the advantage of a direct measurement of the plasma potential, it was shown that in dense plasmas (~ 10^{20} m^{-3}) the unheated probe becomes self-emissive, behaving similarly as the emissive one. The enhancement of the plasma column confinement for increasing magnetic field is reflected in the radial profile of the plasma potential. The plasma column parameters depend not only on the arc-source characteristics but also on the target conditions (e.g. target bias). Probe measurements allow the estimation of the maximum value that can be attained by the azimuthal $\boldsymbol{E}\times\boldsymbol{B}$ drift velocity.

5. References

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