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On the Measurement of Electric Fields in Magnetized Plasmas by Means of Probes

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Abstract
It is shown experimentally that the floating potential of a plate rotating within a magnetic flux surface in TEXTOR-94 varies significantly with the angle of the surface to the magnetic field. This result renders the generally applied method to determine electric fields by means of probes in experiments such as tokamaks doubtful. A close relationship between the floating potentials and electric currents collected from the plasma is found.

Introduction
Radial electric fields and their shear are considered to have an important influence on the transport in tokamaks. In general it is attempted to measure them in the edge plasma by means of electric probes. The method consists in the determination of the radial gradient of the plasma potential U_{plasma} which one tries to derive from the measured values of the floating potential $U_{floating}$ of a probe and the electron temperature T_e. To this end it is usually assumed that the sheath potential drop is given by
$U_{plasma} - U_{floating} = -0.5\ kT_e \ln[(2Bm_e/m_i)(1+T_i/T_e)(1-(\ _{SE})^{-2}] \ /\ f(T_e)$ where for deuterium $f(T_e)\ .\ 3\ kT_e$ is generally taken, ($_{SE}$ = secondary electron emission coefficient.
This method seems to be well established for non-magnetized plasmas in equilibrium, however, their applicability to strongly magnetized plasmas or plasmas deviating from equilibrium has never been demonstrated and can even not be expected: theory [1] predicts that $U_{plasma} - U_{floating}$ can deviate significantly from the value of $3\ kT_e$, depending on the degree of magnetization and the temperature ratio T_i/T_e, but also on the size of the floating probe pin. Moreover, it is known that the value of the floating potential depends also on electric currents and plasma flows hitting the probing wall. The latter influence has been studied theoretically in some detail in [2]. The plasmas in tokamaks are in fact highly magnetized, and in TEXTOR significant plasma flows (up to Mach numbers M = 0.8) have been found at nearly every position investigated in the edge plasma, [3].

Experimental Setup
The measurements have been performed in the edge plasma of the tokamak TEXTOR-94 in Ohmic discharges with the toroidal magnetic field B_{tor} = 2.25 T, the plasma current I_p = 0.35 MA and the mean core densities $<n_e>$ = 2@and 5@$10^{19} m^{-3}$. The separatrix is defined by the limiter ALT-II at the minor radius r = 46.7 cm. The probe is mounted at the outboard side in the equatorial plane, Fig. 1 ,[3]. Its axis is aligned perpendicular to the magnetic field flux surfaces, its radial position can be changed between the discharges and it is rotated during the discharge around its axis with a frequency of about 2 Hz. The "sandwich probe" head, [4], Fig. 2, consists of two rectangular graphite plates of 40 mm length and 5 mm radial width. The plates are imbedded in a boron nitride corpus. During the rotation the plates remain practically on the same magnetic flux surface. The floating potential of one of the

plates with reference to the connected ALT-II limiter and liner has been measured as function of the rotation angle, i.e. the pitch angle of the magnetic field relative to the plates‘ surfaces. The electric current between the two floating plates - which have been electrically connected by different resistors- has been measured by means of a current probe.

Results

Fig. 3 shows the probe current as a function of the rotation angle (time) when the voltage with triangular time shape and a frequency of 200 Hz is applied to the probe and switched off for periods of 40 ms, alternately. (A signal to indicate " = 0 is superimposed on the voltage signal). The application of the Mach probe method results in a Mach number of the plasma flow of M . 0.5 if the envelopes of the ion saturation current of Fig. 3 are analyzed and theoretical results of ref. [2] are used. Also during phases when the voltage is switched off an electric current collected from the plasma is measured flowing between the two plates which are connected by a R_{ext} . 0 resistor. The measurement has been performed in the shadow of the ALT-II limiter at r = 50 cm.

For Fig. 4 no external power supply is connected to the probe and the figure shows the electric current as collected by the floating plates and the floating potential of one of the plates as function of the rotation angle measured in two consecutive „identical“ discharges. For the current measurement the plates are connected by a short-circuit and for the potential measurement by means of a R_{ext} = 2.3 kS resistor. The measurements are again performed in the limiter shadow at r = 50 cm. The mean value of the floating potential is about equal to that of the limiter when the measuring plate is directed towards the limiter which is used as reference electrode as expected. When oriented away from the limiter the mean value of the floating potential of the measuring plate is positive relative to the limiter. This observation is as expected if one considers the different electron temperatures relevant for the probe and the limiter. There is a significant dependence of the floating potential on the rotation angle indicating that it depends also on other parameters than the electron temperature.

From the fact that the floating potential is not symmetric to " = 90E, 270E, etc. follows that it does not scale with the size of the plate as predicted in [1] and that - at least for the present conditions - the larger effect on the floating potential is related to the measured current.

Similar measurements have been performed in the core plasma radially about 1 cm in front of the leading edge of the ALT-II limiter. Fig. 5 shows the electric current collected by the floating probe plates and the floating potential of one of the plates as functions of the rotation angle. No external voltage is applied to the probe and the plates are connected by means of a resistor of 30 S. (A signal to indicate " = 0 is superimposed on the voltage signal). The mean value of the floating potential relative to the limiter potential is negative as expected since the electron temperature at the probe is larger than at the limiter being the reference electrode. The asymmetry of Fig. 4 attributed to the close distance to the limiter does not occur in Fig. 5, as expected. But again a significant modulation of the floating potential with the rotation angle is observed which impedes a reliable determination of electric field values. The collected electric current attains its maximum amplitudes when the magnetic field is about perpendicular to the probe plates. Then also the floating potential reaches its maxima, whereas the minima coincide with zero current and parallel alignment of the plates to the magnetic field. The dashed line in Fig. 5 interpolates the floating potential for the cases when no current exists. The excursion of the floating potential from the value for vanishing collected current is to more positive values both when the collected current is positive or negative.

Discussion and Conclusions

It has been shown that the floating potential of a probe in the edge plasma of TEXTOR-94 can depend to a large degree also on plasma parameters other than the electron temperature. Since the generally applied method relies on the assumption that the relation between the plasma and the floating potential depends only on the electron temperature, this experimental result casts severe doubt on the results of electric field measurements by means of probes as well as on the conclusions based on such measurements concerning e.g. particle and energy transport. The plasma conditions investigated are considered to be typical for TEXTOR but also similar to those in other tokamaks.

The experimental results demonstrate a close relationship between the value of the floating potential and the electric current collected by the probe. It is in fact expected that an electric current or a plasma flow [2] has an effect on the value of the floating potential but it seems not straightforward to discriminate between the contributions of the two. In this context it is of interest that the direction of the plasma flow as determined from the envelope of the ion saturation current is about parallel to the magnetic field, Fig. 3, while the maximum of the electric current is collected at bias angles (about 45 E to the magnetic field direction).

An interesting feature of the floating potential in Fig. 5 is that the excursions of the floating potential from the values where the current is about zero go to less negative values both, when the plate measuring the floating potential collects a positive or a negative electric current. This observation supports the following picture: The effect of an electric current collected by the two plates leads to different excursions of the floating potential on the up-stream and the down-stream side compared to the current-free case if the plates are insulated from each other. A short circuit between the two plates leads indeed to the same value of the floating potential on the up-stream and down-stream side. This common floating potential is, however, different from the floating potential in the current-free case. A connection of the two plates via a resistor R_{ext} 0 generates a difference of the potential at the up-stream and down-stream side as seen in Fig. 5. The difference in amplitude of the consecutive humps of the floating potential is of the order as the expected value R_{ext} @I .

There seems to be no way to save the results on „electric field" measurements by means of probes in tokamaks with the argument that for an all-metal probe pin the up-stream and down-stream sides are electrically connected. From Fig. 5 it is concluded that for a short circuit between the two plates the common floating potential differs from that for vanishing electric current. The difference would be zero only in the case that the shifts would be symmetric to the case of vanishing current, an assumption which is not supported by the experimental results and is also not expected from theory on Mach probes, [2].

Even with an advanced theory including e.g. the influence of electric currents and plasma flows a reliable measurement of electric fields in the edge of tokamaks does not seem to be possible as long as the electric current is not properly measured or the other important parameters are even not yet all identified.

The criticism put forward against the measurements of quasi stationary electric fields by means of probes should apply similarly also to measurements intended to determine electric field fluctuations.

References

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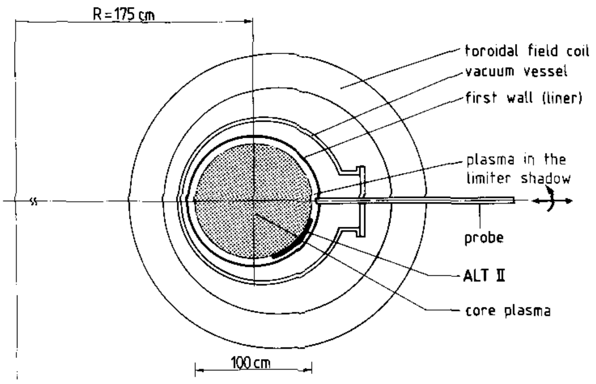

Fig. 1: Rotating Probe on TEXTOR-94

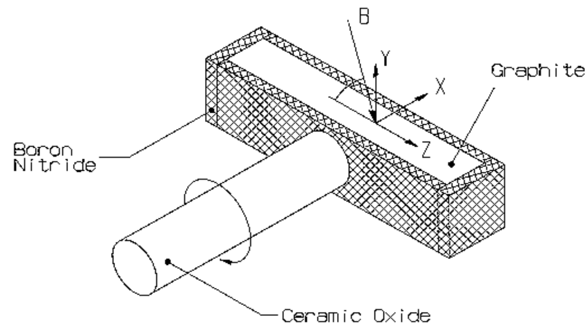

Fig. 2: Geometry of the Rotating Double Probe (Sandwich Probe)

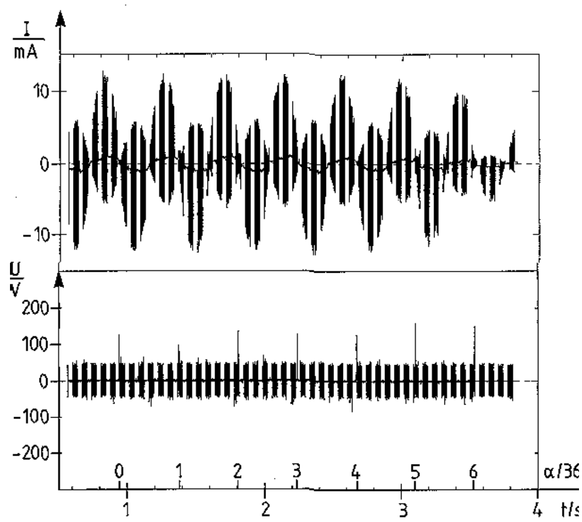

Fig. 3: Probe current and probe voltage as functions of the rotation angle, r = 50cm, $\langle n_e \rangle = 2\ \Phi 0^{19}\ m^{-3}$

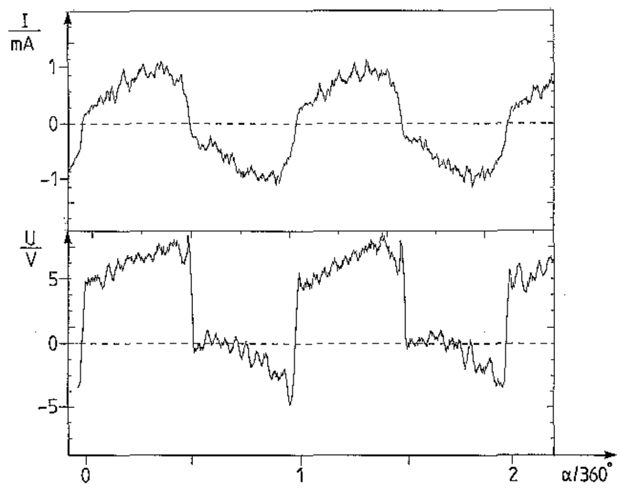

Fig. 4: Electric current and floating potential as function of the rotation angle, r = 50 cm, $\langle n_e \rangle = 2\Phi 0^{19}\ m^{-3}$

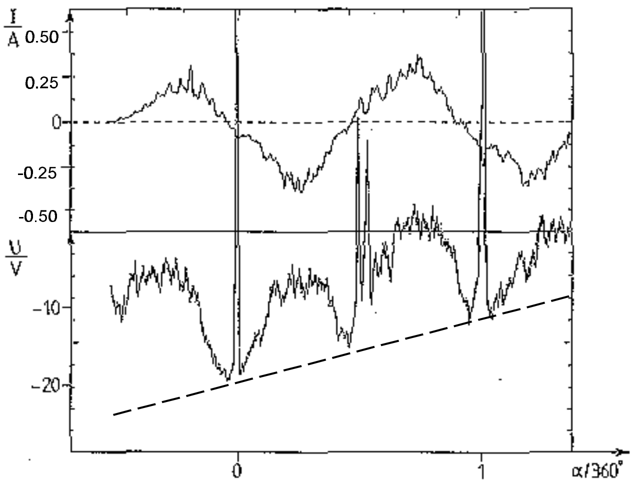

Fig. 5: Collected electric current and floating potential as functions of the rotation angle, r = 45.5 cm, $\langle n_e \rangle = 5\Phi 0^{19}\ m^{-3}$