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Observation of floating potential asymmetry in the edge plasma of the SINP tokamak

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Abstract. Edge plasma properties in a tokamak is an interesting subject of study from the view point of confinement and stability of tokamak plasma. The edge plasma of SINP-tokamak has been investigated using specially designed Langmuir probes. We have observed a poloidal asymmetry of floating potentials, particularly the top-bottom floating potential differences are quite noticeable, which in turn produces a vertical electric field $(\mathbf{E_v})$. This $\mathbf{E_v}$ remains throughout the discharge but changes its direction at certain point of time which seems to depend on applied vertical magnetic field $(\mathbf{B_v})$.

Keywords. Floating potential; vertical magnetic field; vertical electric field reversal; vertical electric field reversal time.

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1. Introduction

The motion of plasma in a toroidal magnetic field leads to a separation of charge particles through charge dependent toroidal drifts. This creates a vertical electric field which along with the toroidal magnetic field gives an outward motion of the plasma column. In a semi-toroidal device Il'enko *et al* [1] observed not only a vertical electric field, but also a horizontal electric field, which they explained as due to the difference of Larmer radii of ions and electrons. Nakao *et al* [2] measured the vertical electric field produced by the electrons' toroidal drift in the current-less WT-2 toroidal device. They found that the dominant particle loss was due to the $\mathbf{E} \times \mathbf{B}$ drift. By applying a vertical magnetic field they were successful to reduce the drift loss. It is well known that inclusion of poloidal magnetic field can reduce this vertical electric field by offering a short-circuit path. But it is found in the literatures [3] that due to finite resistivity of plasma complete removal of this vertical electric field may not be possible by poloidal magnetic field alone. With the application of a constant vertical magnetic field from the start of the discharge Valovic [4] had observed a high particle loss in the avalanche phase in CASTOR-tokamak. He argued that the motion along the vertical magnetic field leads to the separation of charge particles, in the avalanche phase of a tokamak discharge. And after the commencement of the rotational transform these initial electric fields vanish. But in this paper we report that a careful observation shows, there still exist some floating potential asymmetries throughout the discharge duration.

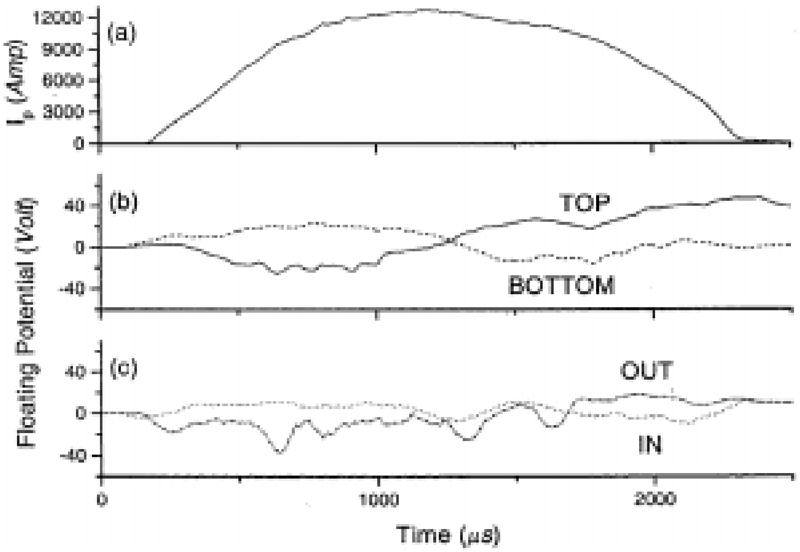

Figure 1. For normal operation (B_T clockwise from top) (**a**) plasma current, (**b**) floating potentials: solid line: top (R, a), dashed line: bottom $(R, -a)$. (**c**) Floating potentials: dotted line: in $(R - a, 0)$, dashed and dotted line: out $(R + a, 0)$.

2. Experiments

The experiments were carried in the iron-cored SINP-tokamak (major radius, $R = 30$ cm, maximum minor radius, $a = 7.5$ cm, maximum toroidal field, $B_T = 2.2$ Tesla) [5]. To avoid the initial high particle loss as obtained in the CASTOR-tokamak, we have applied a ramping vertical magnetic field with a rise-time of 2.2 ms. A constant toroidal magnetic field, $\mathbf{B_T}$, was there from the start of the discharge. In the basic configuration, plasma current and toroidal field directions are anti-parallel, where the plasma current is directed anti-clockwise seen from above the torus. This is the normal SINP-tokamak operation. In its reverse-operation the $\mathbf{B_T}$ direction is also anti-clockwise from top i.e. parallel to plasma current direction. Plasma floating potentials were measured with Langmuir probes at the edge of the plasma column. The probes were mounted on a SS-ring and the probe tips were at minor radius 6.9 cm. In our experiment, plasma minor radius was 7.0 cm. Typical plasma parameters were: loop voltage, $U_L = 27$ V, toroidal magnetic field, $\mathbf{B_T} = 0.33$ Tesla, H_2 filling pressure $= 3 \times 10^{-4}$ torr, plasma current ≈ 12.0–15.0 K Amp. At the edge region electron temperature ≈ 10–15 eV and density ≈ 2–3×10^{18} m^{-3}. Experiments were mainly done with different vertical magnetic fields, keeping other parameters constant.

3. Results and discussion

Typical floating potential behaviors at the top (R, a), bottom $(R, -a)$, in $(R - a, 0)$ and out $(R + a, 0)$ are shown in figure 1 for usual SINP-tokamak operating condition

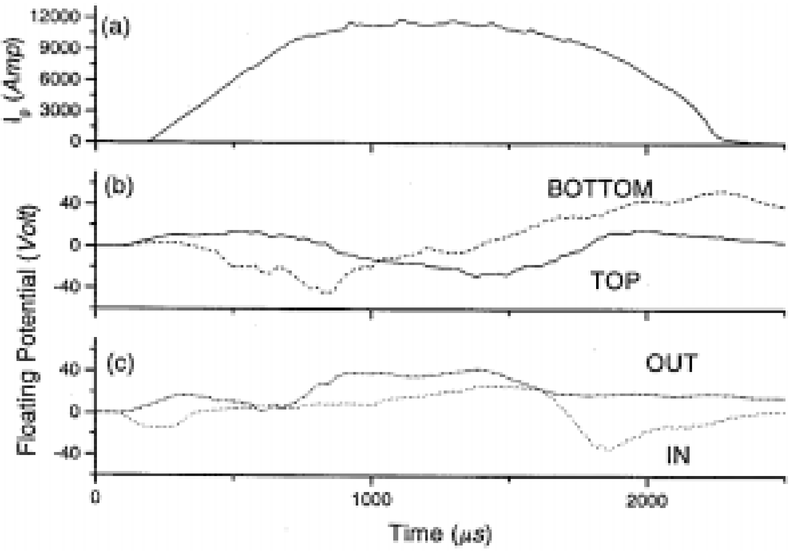

Figure 2. For reverse operation (B_T anti-clockwise from top) (**a**) plasma current, (**b**) floating potentials: solid line: top (R, a), dashed line: bottom $(R, -a)$. (**c**) Floating potentials: dotted line: in $(R-a, 0)$, dashed and dotted line: out $(R+a, 0)$.

(B_T clockwise from top). The same for reverse B_T-operation are shown in figure 2. The potential behavior at the top probe in figure 1 is almost same at the bottom probe for reverse operation (figure 2). Similar exchange of behavior for bottom probe of figure 1 with top probe of figure 2 have been observed. Horizontal and vertical shifts of the plasma column for a typical discharge measured using $\cos\theta$ and $\sin\theta$ coils are shown with plasma current in figure 3.

Since the vertical shift (figure 3c) is negligible for these discharges we can assume that the top and the bottom floating potentials were measured on the same magnetic surface. Considering plasma temperature being constant over a flux surface we take the top-bottom floating potential difference as an equivalent vertical electric field. During a discharge this vertical electric field changes its direction at a certain point of time. This is when the floating potentials (or plasma potentials) at the top and the bottom intersect each other in figures 1b and 2b. This time will be referred as VEFRT (vertical electric field reversal time) throughout this paper.

In the case of floating potentials measured by the inner and the outer probes, it is very difficult to use similar argument, since horizontal plasma position is inward and varying. So floating potential measurements perhaps not done at the same flux surface, and hence the assumption of constancy of temperature is no more valid. For this reason we are not in a position to try to explain the physics behind this in-out asymmetry. Figure 4 shows the dependence of VEFRT with the peak vertical magnetic field, which, at least qualitatively, indicates that VEFRT reduces with increasing peak vertical magnetic field. In figure 5 the exact value of vertical magnetic field at the time of reversal of vertical electric field is plotted against VEFRT. The best fit line indicates vertical electric field reverses at a particular value of vertical magnetic field, when the other parametric dependence are carefully

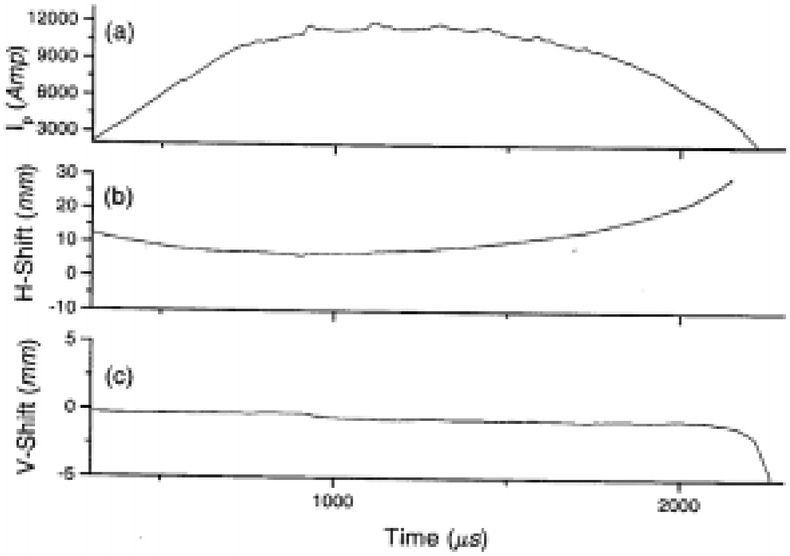

Figure 3. (**a**) Plasma current, (**b**) horizontal position (positive sign signifies inward direction), (**c**) vertical position (positive sign means downward direction).

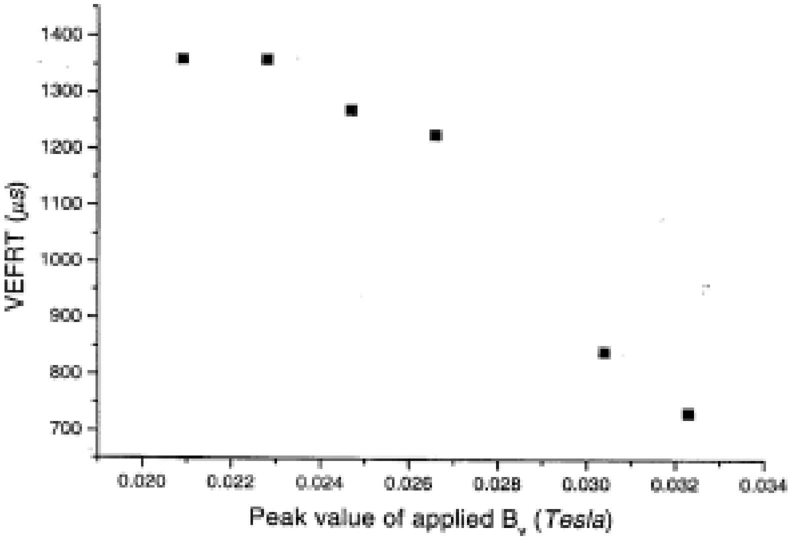

Figure 4. Dependence of vertical electric field reversal time (i.e. VEFRT) on peak applied vertical magnetic field.

omitted. The other parameters which might have some influences to control the vertical electric field – like temperature, density and their temporal behavior, and indeed, the poloidal magnetic field, were somewhat taken care by the similarity of plasma currents

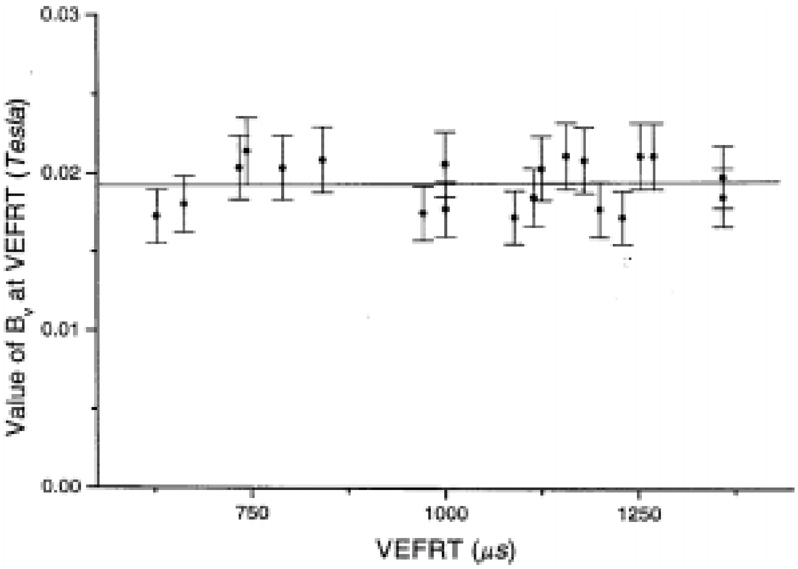

Figure 5. Exact value of B_v plotted against VEFRT and fitted with a line. 10% error-bars are shown with the points.

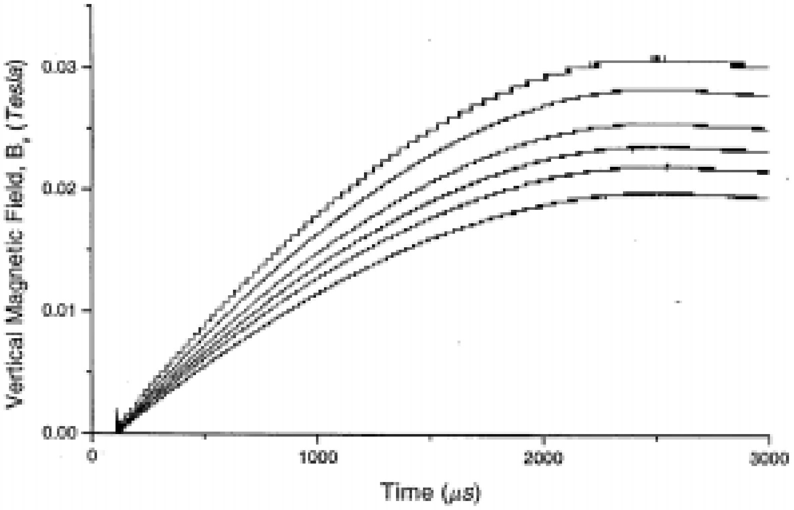

Figure 6. The temporal behavior of B_v.

considered for analysis for this paper. In our case rate of rise of plasma currents and also the total currents were almost same. So the only parameter left to change the VEFRT is the vertical magnetic field. Vertical magnetic field nature is shown for few peak-values in figure 6. Since the vertical magnetic field has a constant rise time, with a large peak value the vertical magnetic field reaches to that desired value, for vertical electric field reversal, in less time than with a low peak value. This is the reason for variation of VEFRT with peak $\mathbf{B_v}$.

Nakao model [2] predicts for current-less toroidal devices, motion of electrons along the vertical magnetic field opposes the electrons' drift velocity. And the drift loss is completely removed when $v_d = v_{B_v}$, where v_d is electrons' toroidal drift velocity and v_{B_v} is the vertical velocity of electrons due to the motion along the magnetic field constructed by B_T and B_v.

Now we will see what happens in the presence of poloidal magnetic field. It is well known that the poloidal field gives a low resistance, short-circuit path, which allows the charge particles (mainly electrons) to flow in the direction of the existing vertical electric field. In this process the driving force comes from the existing vertical electric field itself. If the existing vertical electric field vanishes, there will be no force to continue the flow of electrons and make that electric field to reverse. So reversal of this electric field is not possible by this process. In case of a tokamak where plasma current is huge and poloidal magnetic field plays the primary role for reduction of vertical electric field, Nakao model seems to be still valid with a little modification. It can be said, qualitatively, that in case of a tokamak the reduced toroidal drift velocity, by the presence of poloidal magnetic field, is further opposed by v_{B_v}.

4. Conclusions

From the present experimental studies we have been able to say that plasma polarization can be reduced or removed not only by rotational transform i.e. combination of poloidal and toroidal magnetic field but also by adjusting vertical magnetic field. Further research is necessary for quantitative explanation of the role of the vertical magnetic field in influencing the plasma polarization.

Acknowledgement

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