PLASMA CONVECTION IN A TOROIDAL OCTUPOLE

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Spatial variations of floating potential and density are reported for a toroidal octupole. Large scale convective structures are observed. A definite correlation is observed between known magnetic perturbations and the density-potential structures, as well as between these structures and the azimuthal variations in plasma loss.

Anomalous plasma loss has been observed in several multipole experiments. This loss cannot be explained by diffusion due to electric field fluctuations,[1,2] magnetic field diffusion into conducting boundaries, or loss caused by obstacles such as rod supports penetrating the plasma-containment region.[3] Previous experiments show a large diffusion coefficient near the unstable boundary of the plasma; however, this large coefficient does not penetrate a sufficient distance into the plasma containment region to explain the observed losses. Toroidal quadrupole experiments at General Atomic are the only case where a fluctuation level in the main body of the plasma was judged large enough to cause the losses observed in a multipole.[4]

Measured particle loss at the plasma boundary of the Wisconsin octupole exhibits variations or structures which were quite stationary in time leading to speculation that their origin was large, stationary, convective cells.[5] Spatial mapping of the density and floating potential in the Princeton linear multipole showed variations which are commensurate with spatial convective cells.[6] These cells were large enough in magnitude to explain the observed losses even though there was an uncertain correlation between the density variations, potential variations, and the wall loss.

Convection due to the rod supports in the Wisconsin octupole has been reported.[3] Potential and density steps across dummy supports were observed but the particle convection due to these structures was not sufficient to explain the observed loss in this device.

The objective of this experiment was to determine the extent of the azimuthal variations in the density and potential. To facilitate this determination, Langmuir probes were mounted on a rotatable ring situated on the bottom wall of the toroidal octupole under the zero-field region. The ion saturation current to a Langmuir probe gave the plasma density with the assumption that the azimuthal variation of the ion temperature was small. This is justified since it would require ion temperature variations of approximately one order of magnitude to produce the observed variation in ion saturation current. The floating potential was measured by a 10-MΩ high-impedance attenuated probe. With only a few exceptions, the plasma density and floating potential were measured at only one point on a given field line and it was assumed that these quantities were constant along the magnetic field.

The gun-injected hydrogen plasma had the following parameters: $n \leq 5\times10^9$ cm^{-3}, $T_i \leq 40$ eV, and $T_e \leq 10$ eV. Most of the measurements were made 400 μsec after the plasma injection. The turbulent injection process subsides between 50 and 100 μsec after the plasma enters the octupole. The lifetime of the plasma as determined by microwaves was approximately 2 msec.

The floating potential was measured on two flux surfaces inside the separatrix near each of the lower inside and lower outside rods, and on five flux surfaces outside the separatrix. These measurements were made at as many as eighty azimuthal positions. The shot-to-shot variation of the floating potential at these positions was less than 0.25 V on the separatrix and 1 V near the wall. The square root of the square deviation of the floating potential from its average $\langle(\varphi-\langle\varphi\rangle)^2\rangle^{1/2}$ as a function of ψ the flux coordinate is shown in Table I. The average is over the azimuthal angle θ. The variation of the floating potential on

Table I. The variation averaged over azimuth of floating potential and density for various flux surfaces between the current-carrying rods ($\psi=-5.0$) and the wall ($\psi=+5.0$).

ψ	$(\langle\delta\varphi^2\rangle)^{1/2}$ (V)	$(\langle\delta n^2\rangle)^{1/2}/n$ (%)
−4.0	2.4	13.6
−2.5	0.8	6.8
ψ_s	0.4	2.5
−0.5	0.8	12.9
+0.7	2.3	32.1
+1.5	3.8	

the separatrix is small ($\langle\langle\delta\varphi^2\rangle^{1/2} < 0.5$ V) but increases rapidly toward the plasma boundaries in both directions from the separatrix. Absolute maxima or minima in the floating potential were not observed in the regions scanned by the probe. The floating potential variations increased monotonically toward the plasma boundaries. This is in sharp contrast with the Princeton observations where closed cells were observed near the separatrix.

The contours of constant floating potential are shown in Fig. 1(a) for the flux surfaces outside the separatrix. Similar but not detectably correlated floating potential contours are observed inside of the separatrix. The contours on both sides of the separatrix depict large negative potentials originating near the plasma boundary and extending into the plasma. Floating potential variations larger than 14 V are observed on flux surfaces near the wall. The position of most of the negative potential peaks remains the same when the polarity of the magnetic field is reversed. The potential structures are not symmetric around the injection port or any other position, and for this reason their invariance to field reversal indicates that most of these structures did not originate in the turbulent injection process. The positions of the spatial structures were independent of time, but their magnitude decreased slowly at a rate commensurate with the electron cooling. Measurements were carried out with the rods biased relative to the wall so as to impose a net radial electric field drift and azimuthal drift on the plasma; however, the potential structures remained stationary. Large negative potential peaks were centered on the largest magnetic perturbations: the injection port, the insulated gap, and the resistive wall coupling opposite the gap.

In previous measurements of the effect of rod supports, azimuthal potential and density steps were observed at the position of the supports. Maximum floating potential steps as large as 4 V and density steps of 100% were observed when the obstacle was biased negative so as to collect a large electron flux. Only small steps occured when the obstacle was insulated. For the measurements reported here, the hoop supports were insulated so that only a very small part of the large potential structures observed can be ascribed to support effects.

The ion saturation current was measured for the same operating conditions utilized for the

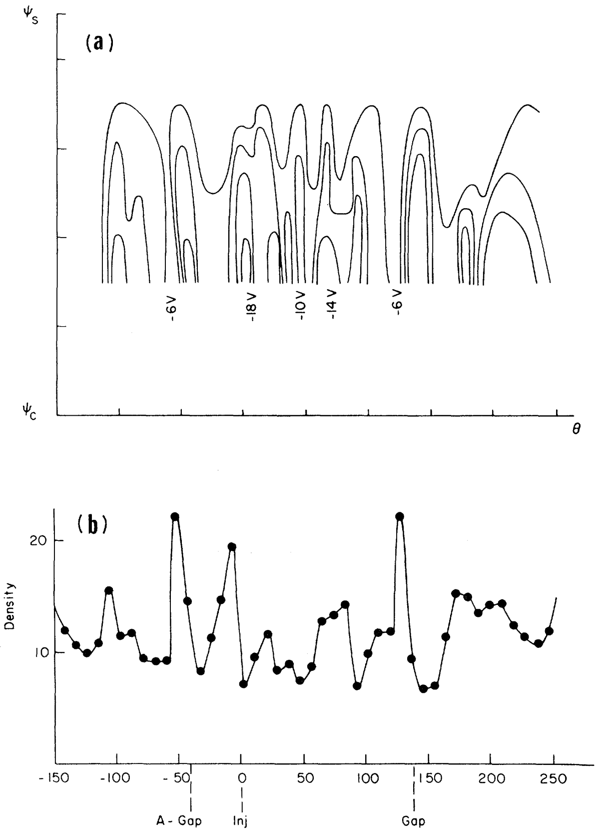

FIG. 1. (a) Contours of constant floating potential in ψ (flux function)-θ (azimuth) space, between the separatrix (ψ_S) and the magnetohydrodynamic stability limit (ψ_C). (b) Density variation on a surface of constant ψ.

floating potential measurements. The variation in density $\langle\delta n^2\rangle^{1/2}/n$ as a function of θ is shown in Table I. The density variation exhibits the same properties as the floating potential, being very small, $\langle\langle\delta n^2\rangle\rangle^{1/2}/n < 2.5\%$ on the separatrix and increasing toward the plasma boundary. Variations of greater than 30% are observed on the flux surface passing 5 cm from the wall on the vertical midplane. This was the flux surface closest to the wall on which density measurements were made. Figure 1(b) is a plot of the density as a function of the azimuthal angle θ for this flux surface. The association between the density maxima and the potential flow lines can be observed by comparing Fig. 1(a) with Fig. 1(b). This association is further demonstrated by the density-potential cross correlation shown in Fig. 2(a). This cross correlation is defined by

$$C_{n\varphi}(\theta) = (1/2\pi)\oint n(\theta')\varphi(\theta'+\theta)d\theta'.$$

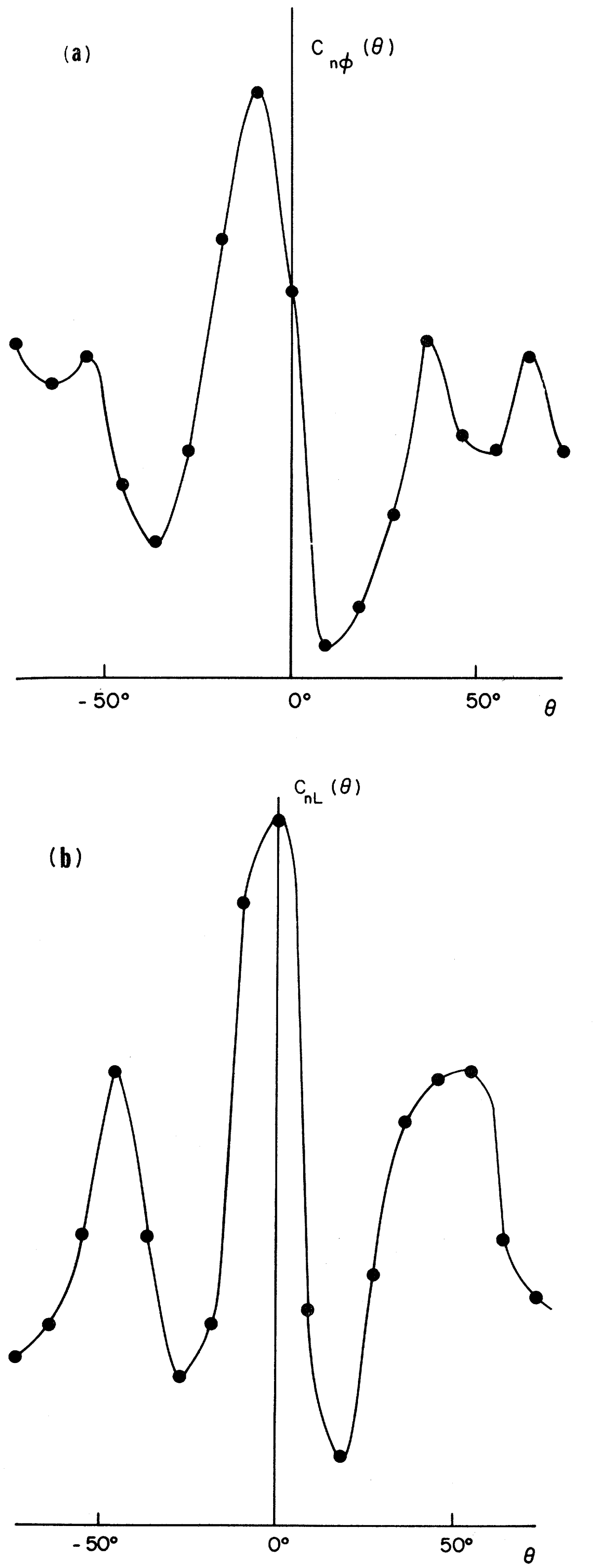

FIG. 2. Cross correlations between (a) density and floating potential (b) density and wall loss as a function of azimuth (θ).

The differentiation of $C_{n\varphi}(\theta)$ yields the cross correlation of the density and azimuthal electric field. Figure 2(a) illustrates that the density maxima are in phase with the azimuthal component of the electric field. The direction of the $\vec{E} \times \vec{B}$ flow due to this electric field is outward from the high-density region at the separatrix as would be expected. When the polarity of the magnetic field was reversed the density structures shifted relative to the potential, which stayed fixed, so that the direction of the electric field drift at the positions of the density maxima was again outward from the separatrix.

The periodicity of the density variations inside the separatrix is similar to the variations outside the separatrix. However, the density variations show no significant correlation across the separatrix. As seen in Table I, the variations inside the separatrix are smaller than outside. The density-potential correlation inside the separatrix was small compared to the correlation outside the separatrix.

The density peaks remain stationary in time but decrease with the decrease in the average density so that the density variation as defined above was approximately constant. Very late in the multipole field pulse, a large density increase occurs at the azimuthal position of the insulated gap where the magnetic field lines are leaving the octupole.

The density was measured near the wall at the intersections of a flux surface with both the horizontal and vertical midplanes. The density showed the same structure on both midplanes, demonstrating that the density peaks were common to all quadrants of the octupole.

The azimuthal variation of the losses to the wall were measured and reported previously.[5,7] The correlation between the losses to the wall and the density variations shown in Fig. 1(b) was computed. This correlation is shown in Fig. 2(b). The density and potential structures are correlated with the observed loss. From Fig. 2(b) it can be concluded that the maximum loss occurs at the positions of maximum density and maximum outward flow from the separatrix. The loss rate to the wall calculated from the observed potential and density structures is consistent with the observed loss.

Limited electron-temperature measurements were possibly only near the separatrix. These measurements indicated some electron-temperature variations as would be expected when radial plasma flow is present. This plasma flow should interact with the minimum-B magnetic well to produce electron- and ion-temperature variations. The ion-temperature variation should not be sufficient to seriously effect the density measurement; however, the electron-temperature variations could have a serious effect on the potential measurements and these measurements should be treated accordingly.

These measurements demonstrate that the potential and density structures observed in the octupole are strongly correlated with the anomalous plasma loss to the wall. The measured properties of these structures indicate that they are in large part due to azimuthal asymmetry in the magnetic surfaces. These structures are likely responsible for a large part of the losses, and their elimination should greatly improve the containment time of the octupole.

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DEUTERON ACCELERATION AND NEUTRON PRODUCTION IN PINCH DISCHARGES*

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Deuteron trajectories have been calculated for the crossed electric and magnetic fields generated by a rapidly constricting current distribution in a z-pinch discharge. The results show that many ions are accelerated to high energies with a large value for their time-averaged axial velocity. A neutron-production model based upon nuclear collisions by these deuterons easily accounts for the observed characteristics of neutron emission.

Average energy shifts of up to 250 keV were exhibited by the axially emitted neutrons from deuterium-filled linear pinches.[1-3] To explain this energy shift, a beam-target model was introduced in which linearly accelerated deuterons strike stationary ions. For example, in one analysis the deuterons are accelerated axially by the electric field generated along the neck of each $m=0$ sausage instability.[1] Presently plasma-focus types of z pinches emit more than 10^{10} d-d neutrons per discharge, and average energy shifts greater than 400 keV have been measured.[4,5] Such an energy shift corresponds to the reacting deuterons having an axial velocity averaging 2×10^8 cm/sec, which is an order of magnitude greater than the maximum velocity of the radially collapsing plasma. However, neutron-flux measurements have shown that the flux anisotropies in plasma-focus devices are much smaller than that predicted by the simple beam-target model.[5-7] This has led to the currently popular model of a moving thermal plasma, but recent observations give evidence that the neutron source is not thermonuclear.[8] In this Letter, I report a new acceleration model based on computing deuteron trajectories in a pinched plasma discharge. The resulting velocities show that many high-energy deuterons can be produced by acceleration in the crossed electric and magnetic fields generated by a rapidly constricting current distribution. Most important is the result that the deuteron velocities are not linearly directed along the axis; therefore the neutron production based on these calculated deuteron velocities is consistent with the characteristics of neutron emission.