PRELIMINARY ELECTRIC FIELD DIVERTOR EXPERIMENT

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A preliminary experiment to simulate an electric field divertor has been performed in the Wisconsin Levitated Octupole. As shown in Figure 1, this is a toroidal device with four current-carrying internal rings which produce the magnetic field. It has a major radius of 139 cm and a roughly square minor cross-section with a half-width of 57 cm. It can be operated either with a purely poloidal field or with a weak toroidal field added; thus the geometry is rather different from that of a tokamak. The measurements presented here were made with the poloidal field only. The magnetic field has a half-sine-wave pulse with a length of 43 msec and a strength near the outer rings at peak field of 2 kG. The rings can be "levitated" by temporarily removing the supports during the pulse, so that measurements can be done in an obstacle-free plasma. However, the data presented here will all be for the supported case.

Figure 2 shows the lines of magnetic flux in the octupole. The separatrix divides the flux lines which encircle a single ring from those which encircle all four. The "critical field line" is the last one posessing MHD stability; outside this line the volume per unit flux increases toward the wall.

For this experiment a retractable stainless steel fin was installed on the upper lid, along a major radius, with its edge shaped to follow the critical field line. Notice that, unlike the usual conception of a limiter, this fin runs parallel to the magnetic field lines. However, if a voltage is applied to one of the rings, and if the potential is constant along a magnetic field line, then the electric field is perpendicular to the magnetic field, and since the magnetic field is purely poloidal the ExB drift is in the toroidal direction, normal to the fin. This drift is perpendicular to the magnetic field; similarly, in a tokamak the purpose of an ExB divertor would be to move plasma across magnetic field lines to an outside chamber.

Particle collectors designed to measure plasma flux were mounted on either face of the fin, and on the lid on either side of the fin. These consist of many parallel conducting stripes separated by less than a Debye length, biased alternately positive and negative, which collect the plasma striking them but do not create a perturbing electric field in the plasma.

To measure density profiles, a floating double probe was used in the "bridge" region between the ring and the wall, 15° away from the fin in the toroidal direction.

In order to make the surface plasma move around the toroid, we apply a 40 volt DC potential to the upper outer ring. Figure 3 shows typical floating potential and ion saturation current profiles measured by the double probe for an ECRH plasma with this potential on the ring. At the separatrix the density is about $3\text{x}10^{10}$ cm^{-3} and the electron temperature is about 5 eV. The floating potential is constant through the main part of the plasma, and falls off near the wall. This is desirable for a divertor scheme, as the main body of the plasma experiences little electric field, but there is a large field in the low-density region near the wall. The potential distribution varies for different cases of ring bias (positive or negative, DC or pulsed) but in all cases the electric field is shielded by the plasma, and is large only in the low-density regions near the ring and wall. This is to be expected since the low-frequency dielectric constant is proportional to plasma density.

In the case shown here, then, the outer edge of the plasma has an ExB drift in the toroidal direction. The ExB velocity is about $2\text{x}10^4$ m/s, much larger than the $\nabla|B|$ and curvature drifts which total about 300 m/s, but still much smaller than the electron thermal velocity of about 10^6 m/s. This ExB drift gives a toroidal rotation period of .7 msec, much smaller than the plasma lifetime of about 15 msec.

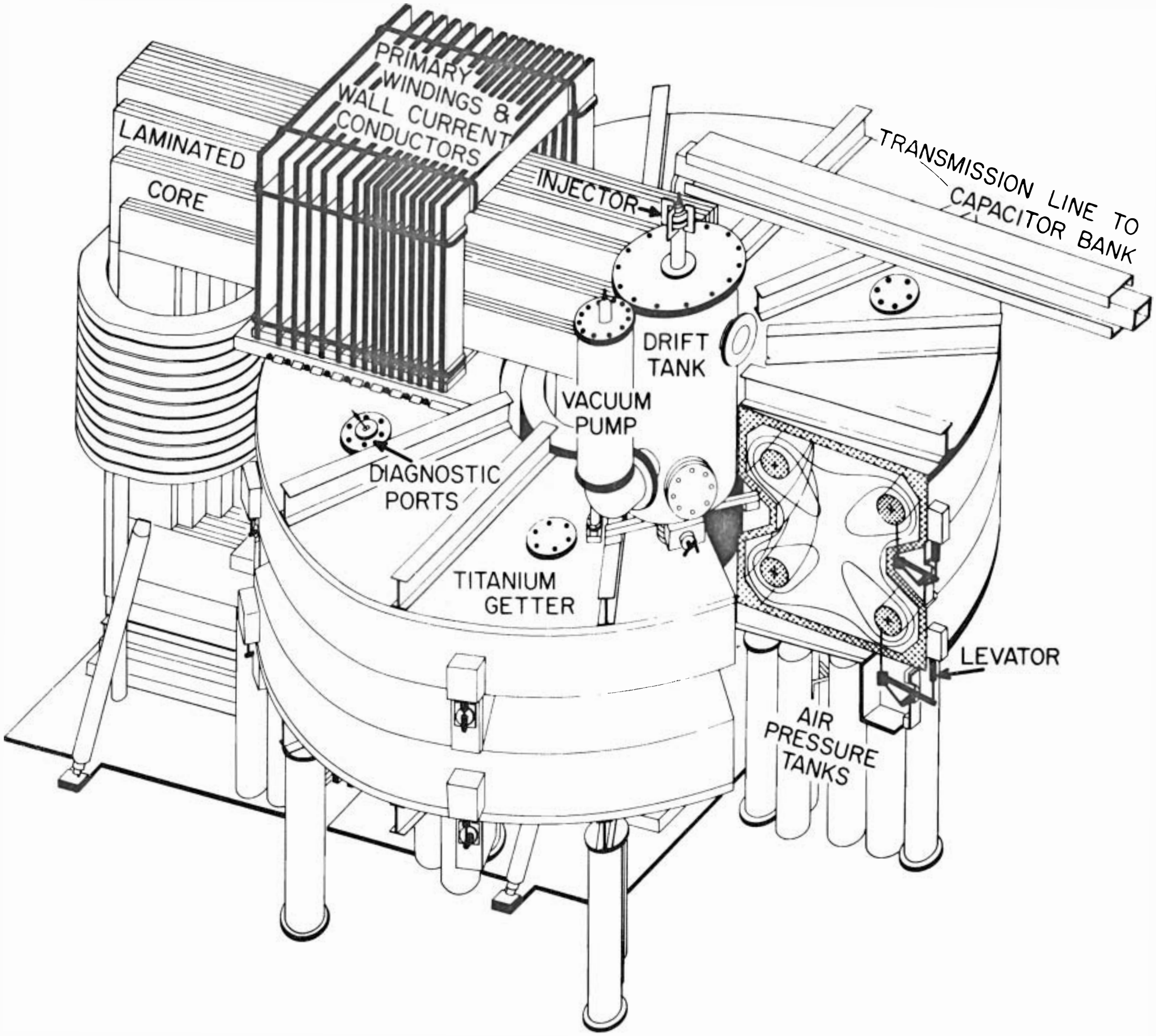
Figure 4 is a qualititive sketch of equipotential lines in the vicinity of the fin, for the cases where the ring is held at 40 V and the fin at 60 V. Preliminary data indicate that this sketch is generally correct. Equipotential lines are equivalent to streamlines for the ExB drift, and the direction of the drift is indicated. Far away from the fin, equipotentials are parallel to the wall. Near the fin, some equipotentials are diverted toward the wall and pass between the fin and the wall, while others pass beyond the fin. A separatrix divides these two classes of equipotentials; where the separatrix crosses itself beyond the edge of the edge of the fin there is a stagnation point for the ExB drift. Note that the equipotentials diverted toward the wall may include some well beyond the physical edge of the fin.

In a true divertor the plasma flow would be brought out through a hole in the wall; here it is merely brought close to the wall, and then turned parallel to it. One might expect to observe, then, increased plasma flux to collector #1, decreased flux to collector #4, and a current drawn by the fin as a large amount of plasma, trying to squeeze through the small gap between the fin and the wall, creates large losses near this gap.

To verify this, the fin and the ring were biased in the proportion shown here ($V_{fin} = 1.5V_{ring}$) and the magnitude of the bias was varied, so that the shape of the streamlines remained constant while the drift speed varied. Figure 5 shows the flux to those two collectors and the current drawn by the fin as a function of the bias magnitude. The collectors are normalized to the flux observed in the absence of the fin. The flux to collector #4, on the downstream side, drops quickly by a factor of 3 to a residual value, while the flux to collector #1 rises linearly by a factor of 20 and saturates at 40 V on the ring. The current to the fin also rises linearly with the drift speed and saturates at 40 V. The linear part of the fin current curve agrees well with an estimate that assumes all the plasma which, unperturbed, would drift through the space occupied by the fin, is lost as current drawn between the fin and the wall. From measurements of plasma flux to the wall and density near the wall in the absence of the fin, the time for plasma particles to move from the critical field line to the wall can be estimated at about 1 msec. This is about the same as the toroidal rotation period at V_{ring} = 40 V, so the saturation may be due to a modification of the density profile extending all the way around the toroid.

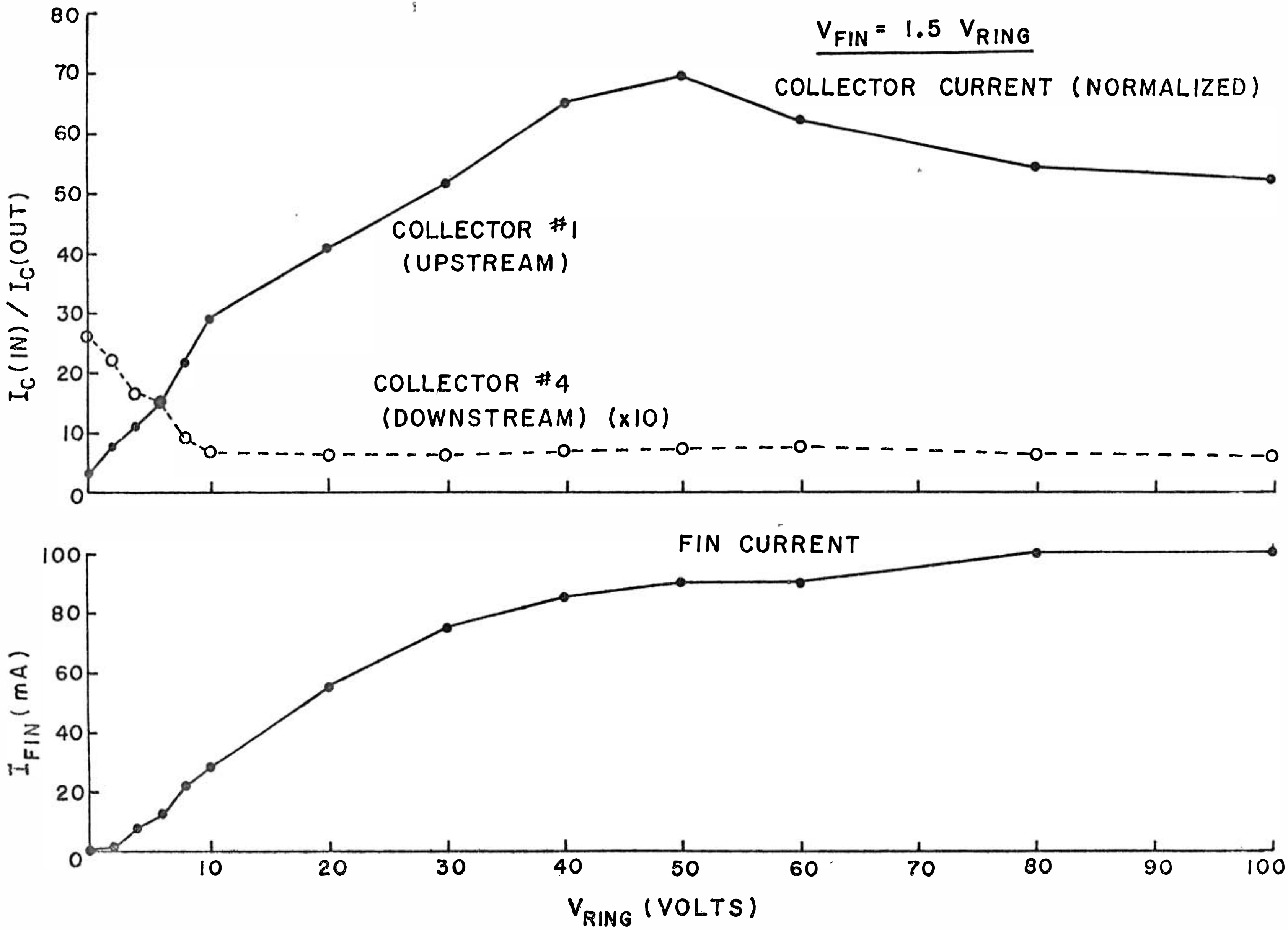
Figure 6 shows the actual modification of the ion saturation current profile for V_{ring} = 40 V, as measured 15° (about 50 cm) downstream. The density at the outer edge is reduced by about a factor of 3, while the main body of the plasma is unaffected, as is desired for a divertor or limiter.

Thus there seems to be good evidence that this simulation of an electric field divertor behaves as expected, greatly increasing wall losses in a localized area and decreasing them elsewhere, and decreasing the density at the edge of the plasma.



WISCONSIN LEVITATED OCTUPOLE

Figure 1



$V_{FIN} = 1.5\ V_{RING}$
COLLECTOR CURRENT (NORMALIZED)
COLLECTOR #1
(UPSTREAM)
COLLECTOR #4
(DOWNSTREAM) (x10)
I_C(IN) / I_C(OUT)
80
70
60
50
40
30
20
10
0
FIN CURRENT
I_{FIN} (mA)
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
100
V_{RING} (VOLTS)

Figure 5

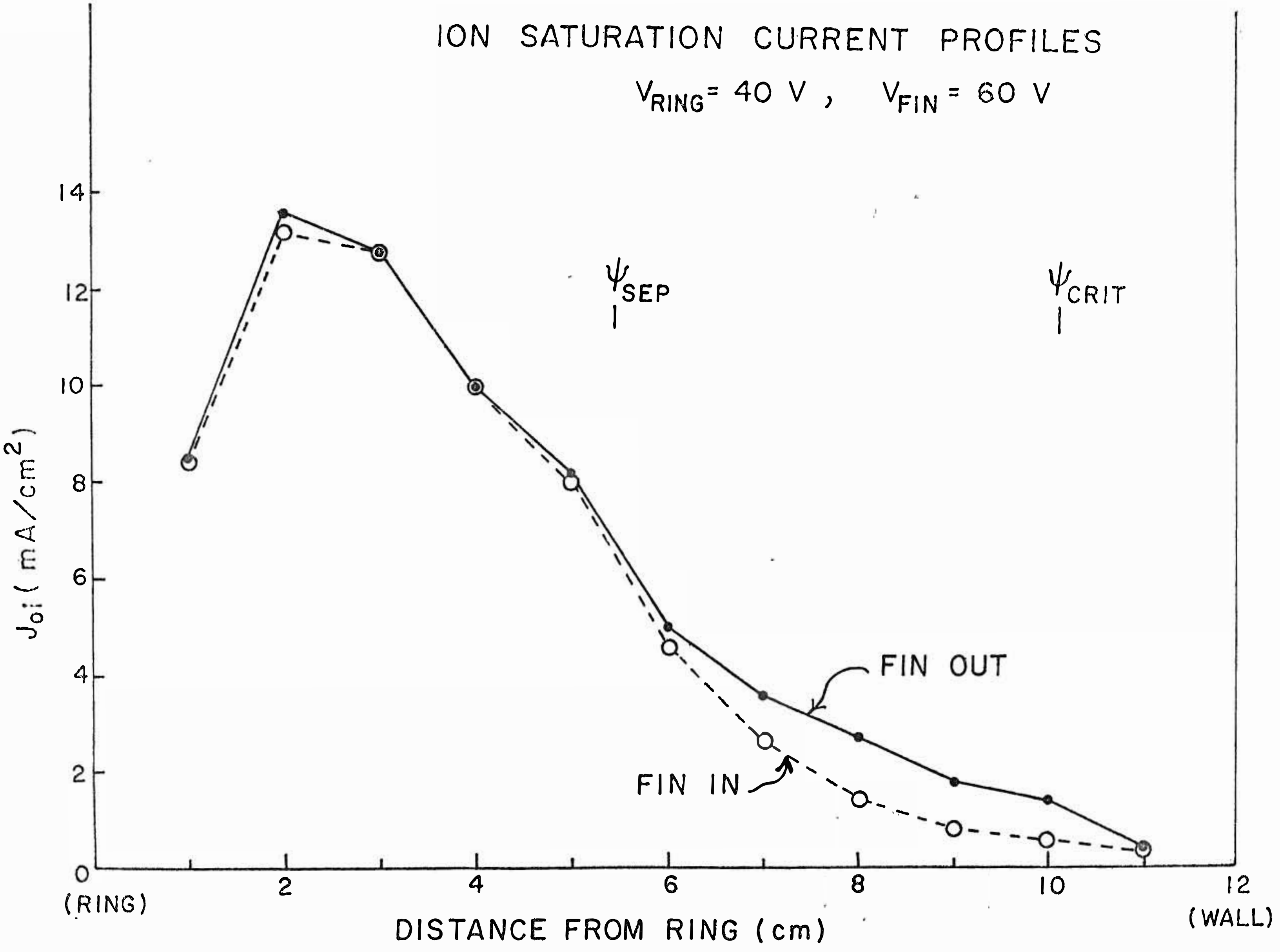

ION SATURATION CURRENT PROFILES
$V_{RING} = 40$ V , $V_{FIN} = 60$ V
ψ_{SEP}
ψ_{CRIT}
FIN OUT
FIN IN
J_{oi} (mA/cm^2)
14
12
10
8
6
4
2
0
(RING)
2
4
6
8
10
12
(WALL)
DISTANCE FROM RING (cm)

Figure 6