EXPERIMENTAL TESTS OF A LARGE NONCIRCULAR RFP

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Within a large noncircular conducting shell, originally that of the Wisconsin Levitated Octupole, we have examined reversed-field-pinch (RFP) plasmas in order to (1) investigate plasma control aspects of a large RFP ($R=1.4$ m, average minor radius$=0.5$ m), (2) establish that an RFP with noncircular boundary can be sustained by dynamo activity, (3) examine the effect of poloidal magnetic field curvature on RFP stability (the shell contains a 35% indentation at the midplane), and (4) investigate the possibility of obtaining sustained RFP plasmas in a poloidal divertor configuration.

The device is unconventional in that the 5 cm thick aluminum vacuum vessel with single poloidal and toroidal gaps serves as both the vacuum liner and conducting shell. The poloidal gap is protected with a 20 cm wide ceramic strip and self-reversed RFP plasmas are initiated with a toroidal loop voltage of ~200 volts/turn. The best plasmas have peak currents of 300 kA and are sustained 10 msec (over ten resistive diffusion times). The conductivity temperature is ~20 eV while the impurity carbon doppler width temperature is ~60 eV. Unlike typical RFP experiments, no reduction in fluctuation level accompanies the toroidal field-reversal.

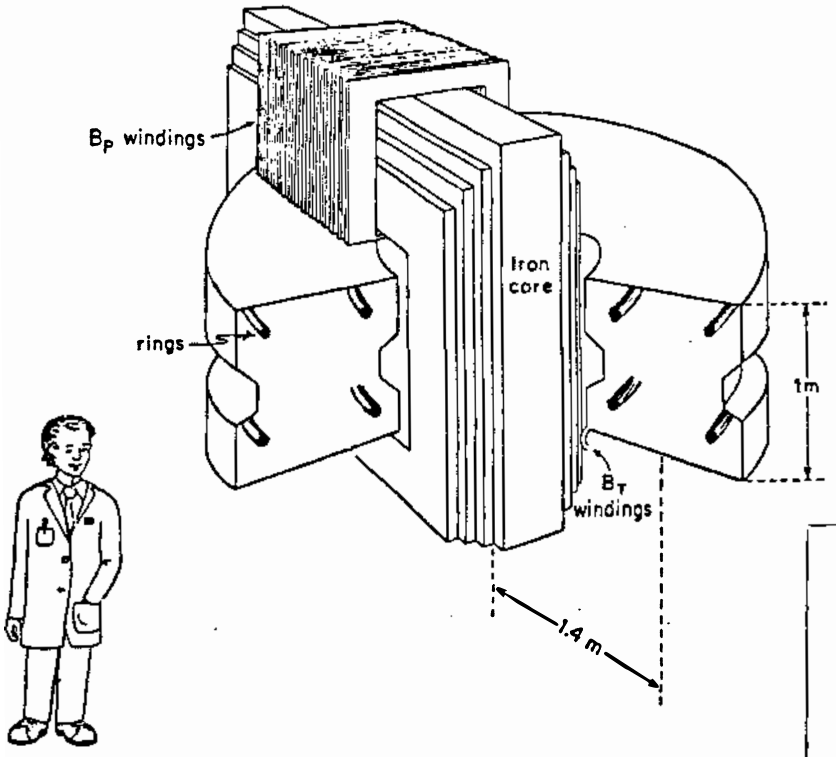
To gain experimental information on whether fluctuations in an RFP are current-driven or pressure-driven instabilities generated by unfavorable poloidal curvature, we have measured the edge magnetic fluctuations in the separate good and bad poloidal curvature regions on a given magnetic surface. In addition to RFP discharges, we have examined non-reversed plasmas with edge safety factor $q\sim0.4$ (poloidal-curvature-dominated) and $q\sim1.4$ (toroidal-curvature-dominated). For $q\sim0.4$ plasmas, all components of the magnetic field fluctuation peak strongly in the bad curvature region, whereas for $q\sim1.4$, only the radial component of the magnetic field fluctuation peaks in the bad curvature region. For RFP plasmas there is only weak peaking of the magnetic field fluctuation in the bad curvature region. For most cases, the fluctuating magnetic field is roughly perpendicular to the equilibrium field.

To investigate an RFP in a poloidal divertor configuration, four conducting rings have been installed within the vacuum vessel to produce a four-node poloidal separatrix. A similar experiment was conducted on the Tokapole II device, normally operated as a small divertor tokamak. Using aided-reversal, transient reversed-field discharges were produced in Tokapole II. Although not sustained, the magnetic equilibria decay time was longer than ideal MHD instability timescales, and detailed analysis of equilibrium magnetic field profile data showed that $\lambda_{\parallel}=J_{\parallel}/B$ falls sharply near the separatrix much like it does near the vacuum liner in a circular RFP. Initial operation of the Octupole tank experiment with aided-reversal produces similar transient, non-sustained plasmas, although operational optimization studies are in progress.

*Work supported by U.S.D.O.E..

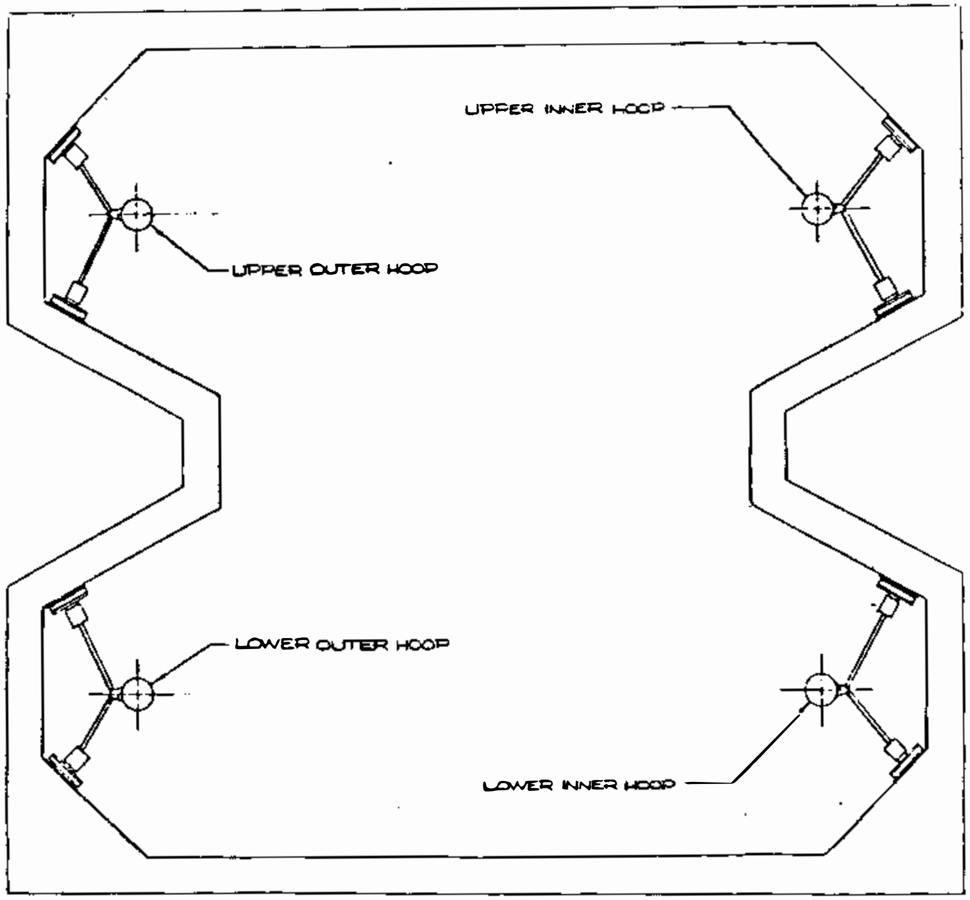
INTRODUCTION

Beginning Nov. 1984, the old Wisconsin Levitated Octupole was modified to operate as a reversed-field pinch (RFP). The large, non-circular cross section and the ability to insert poloidal divertor rings provided opportunities to explore such topics as curvature effects on fluctuations in the RFP (the non-circular cross section creates flux surfaces with good and bad poloidal curvature regions) and the efficacy of a poloidal divertor RFP. The modifications required to operate this device as an RFP were substantial the most noteable being operation without a thin, resistive metal liner which is the present day standard technique for protecting the high voltage poloidal gap.

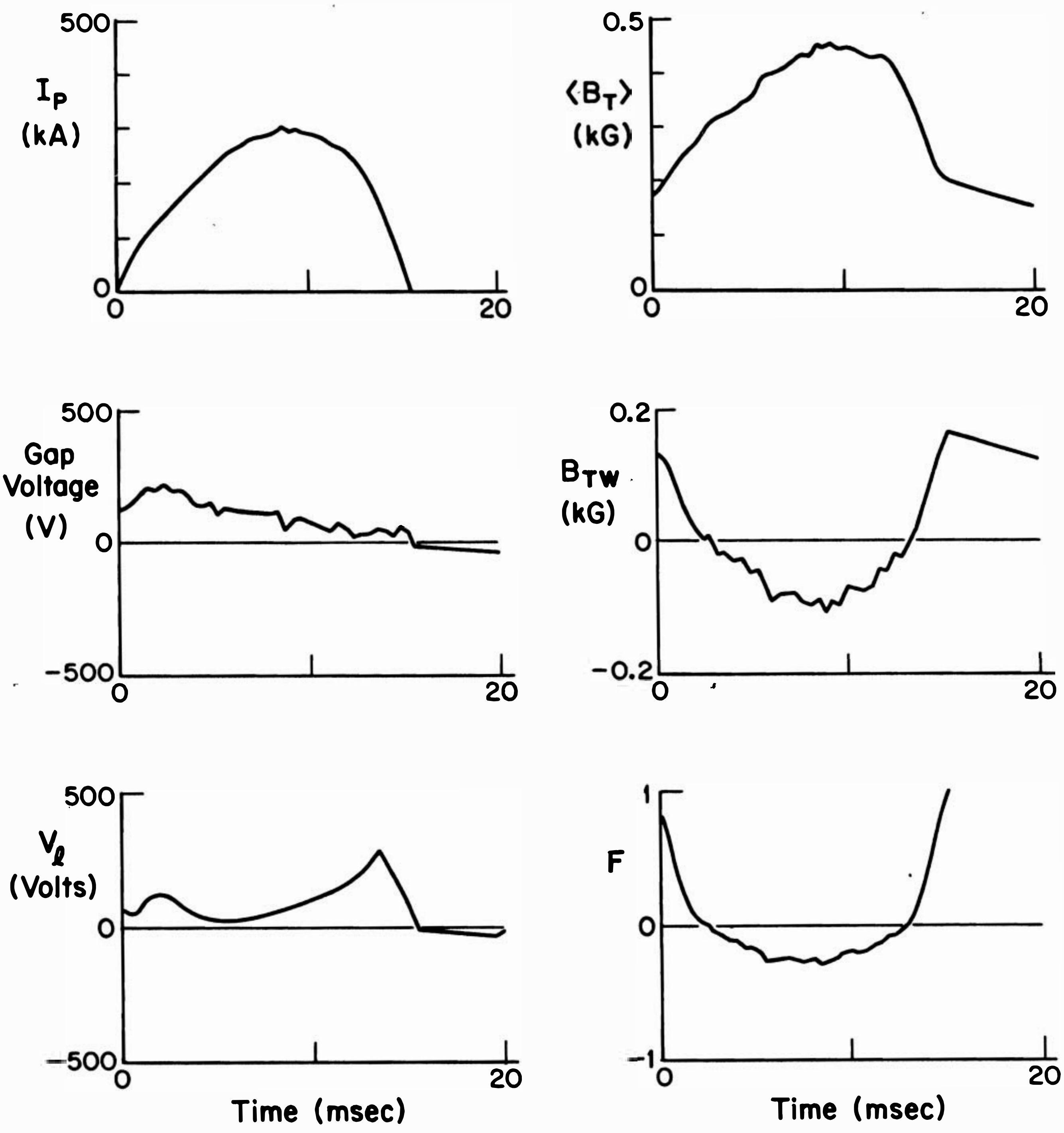


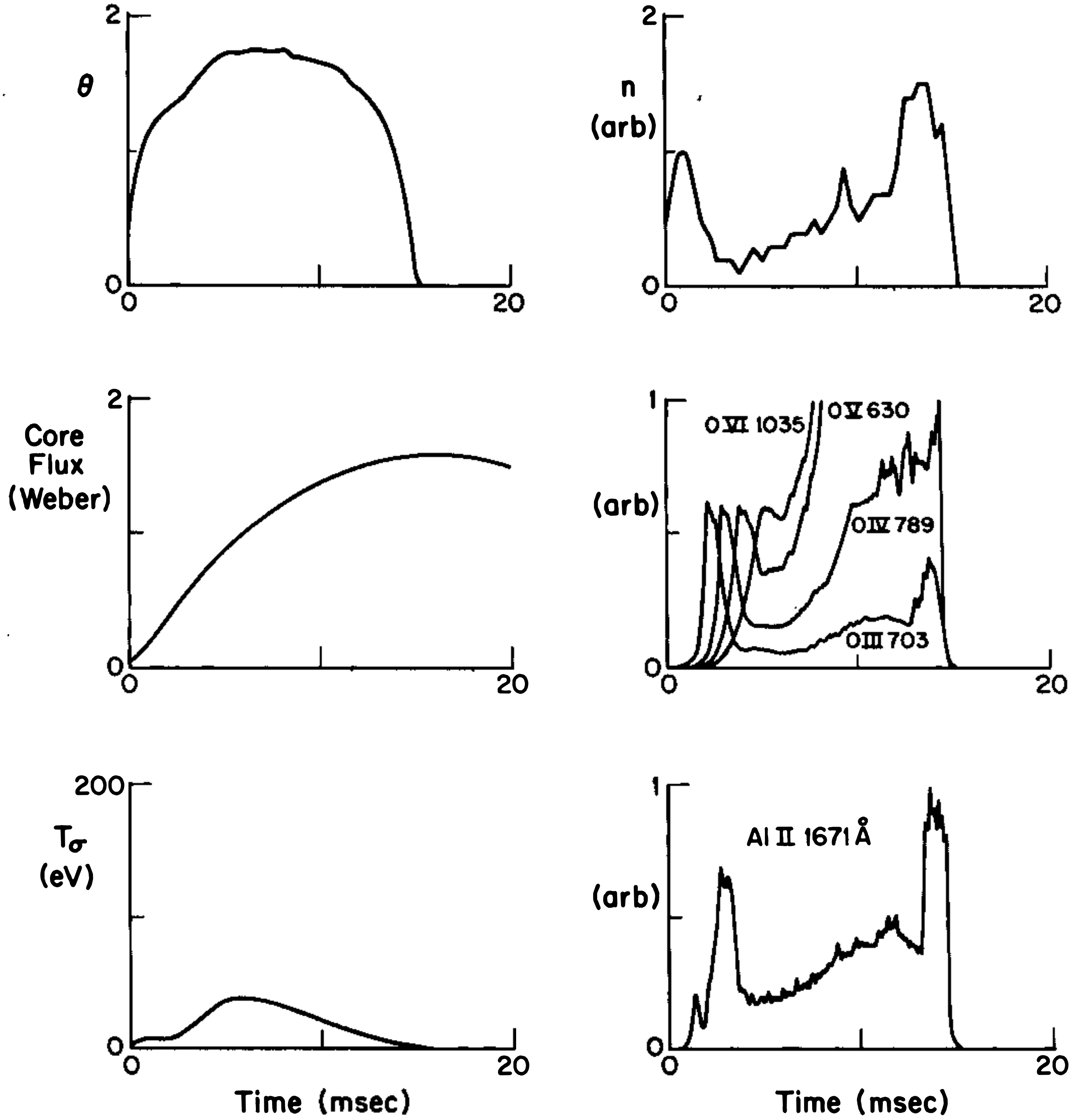
MACHINE SPECIFICATIONS

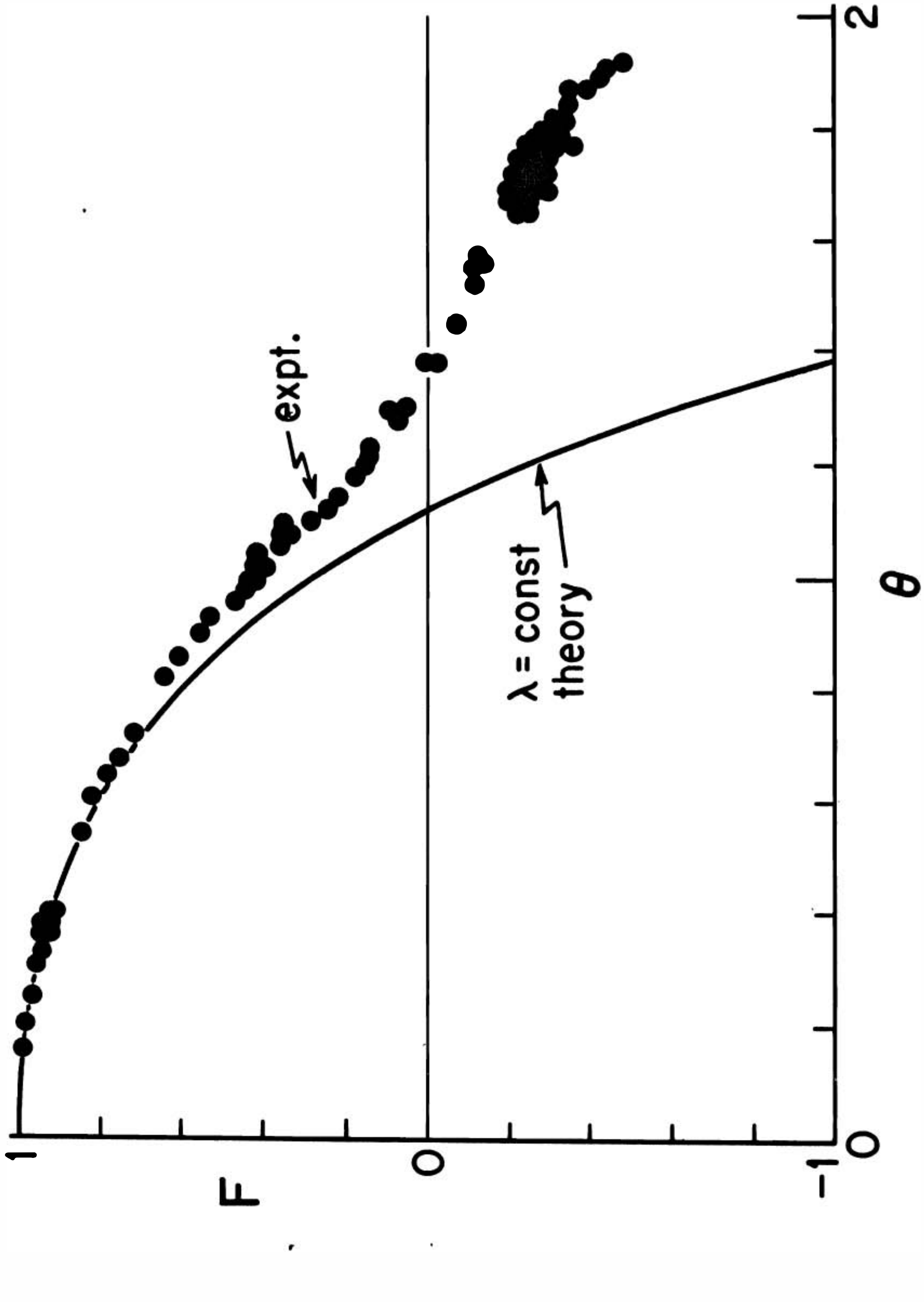
Major Radius	1.39 m	
Minor Dimensions	1.1 x 1.2 m	
Walls	5 cm 1100 Aluminum	
Iron Core Volt-Seconds	1.9	
RINGS	INNER	OUTER
Material	2219-T8 Aluminum	
Resistance	256	511 microhms
Major Radius	.94 m	1.87 m
Minor Diameter	4.13 cm	4.13 cm
Hanger Sets	6	8
Maximum Total Current	500 kA	



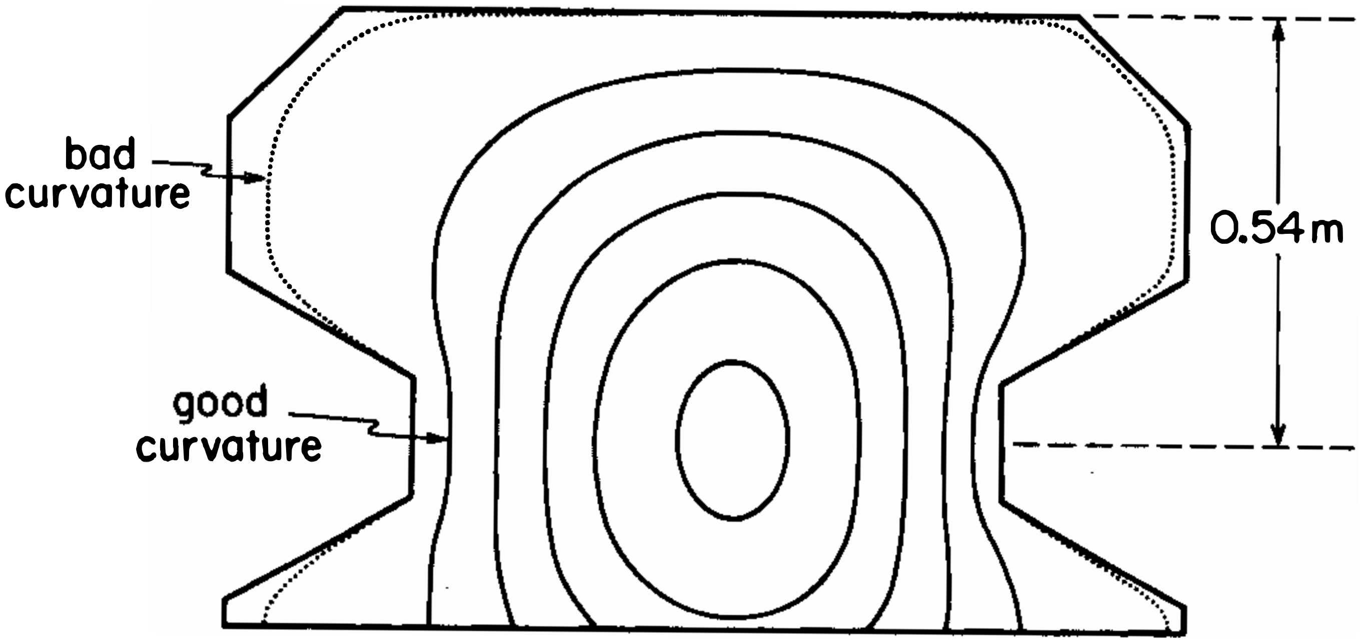
TYPICAL NON-CIRCULAR RFP DISCHARGE



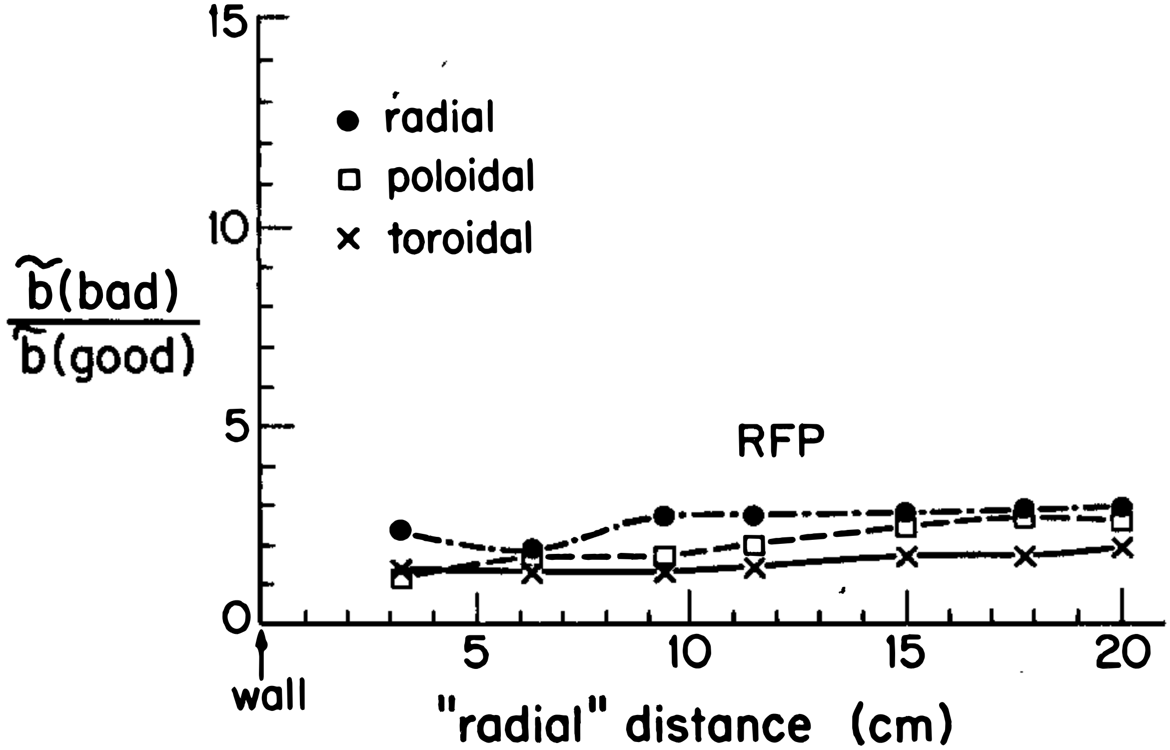

θ
2
0
0
20
n (arb)
2
0
0
20
Core Flux (Weber)
2
0
0
20
(arb)
1
0
0
20
O VI 1035
O V 630
O IV 789
O III 703
T$_\sigma$ (eV)
200
0
0
20
Time (msec)
Al II 1671 Å
(arb)
1
0
0
20
Time (msec)


F
1
0
−1
0
2
θ
expt.
λ = const
theory

FLUX PLOT:
REGIONS OF GOOD AND BAD
CURVATURE ARE INDICATED



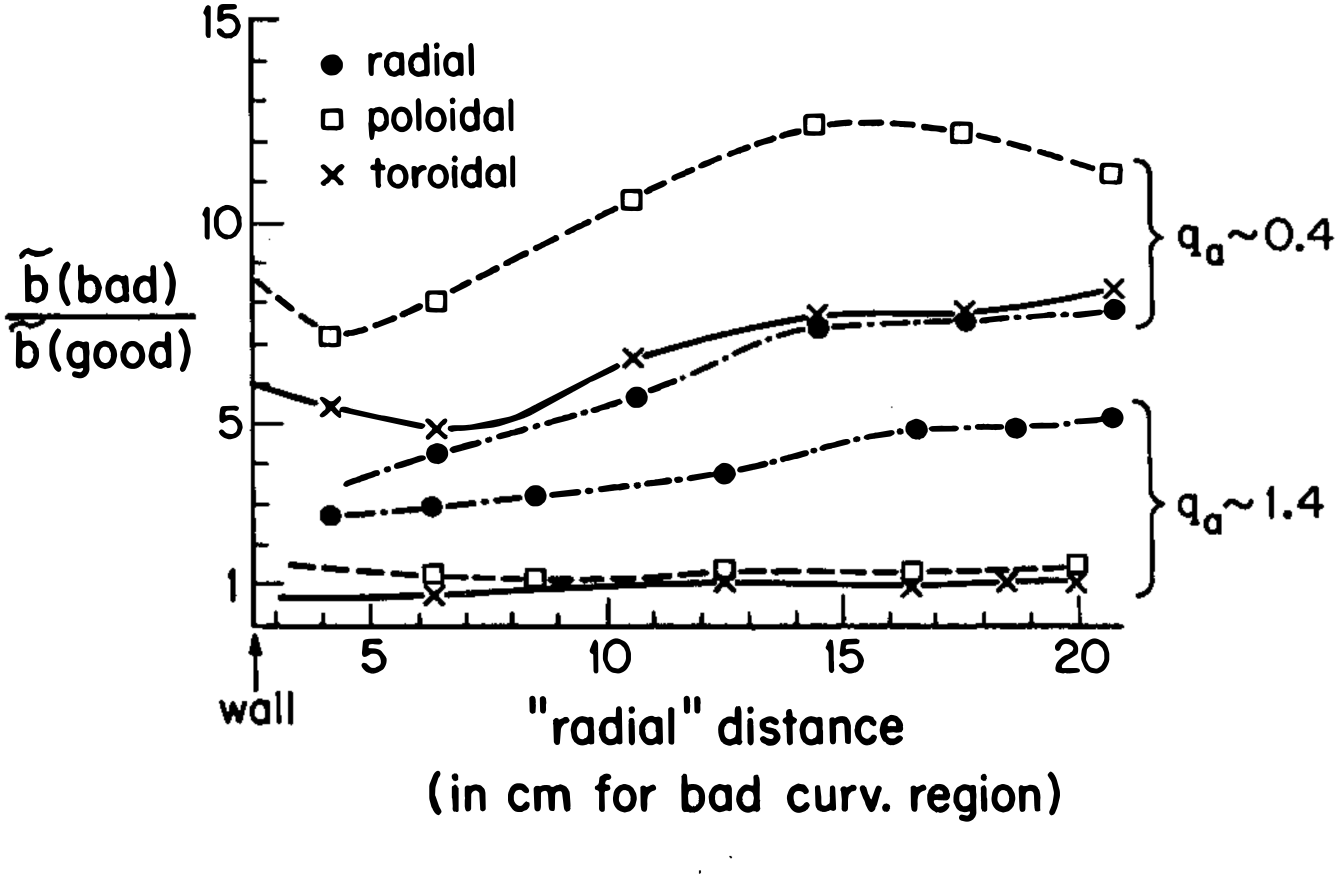
EFFECT OF POLOIDAL CURVATURE ON FLUCTUATIONS



$$\tilde{b} \equiv \frac{\dot{\tilde{B}}}{B}$$

$\dot{\tilde{B}}$ = TIME DERIVATIVE OF THE FLUCTUATIONS

B = EQUILBRIUM FIELD STRENGTH AT THE WALL



15
10
5
1
● radial
□ poloidal
× toroidal
b̃(bad) / b̃(good)
qa~0.4
qa~1.4
wall
5
10
15
20
"radial" distance
(in cm for bad curv. region)

SUMMARY OF LARGE NON-CIRCULAR RFP

1. SELF-REVERSED, RAMPED CURRENT DISCHARGES ARE OBTAINED WITH TYPICAL PEAK PARAMETERS:

   $I_p \sim 300$ kA

   $\langle B_T \rangle \sim 450$ G

   $F \sim -0.2$

   $\theta \sim 1.8$

   $T_e \sim T_i \sim 100$ eV

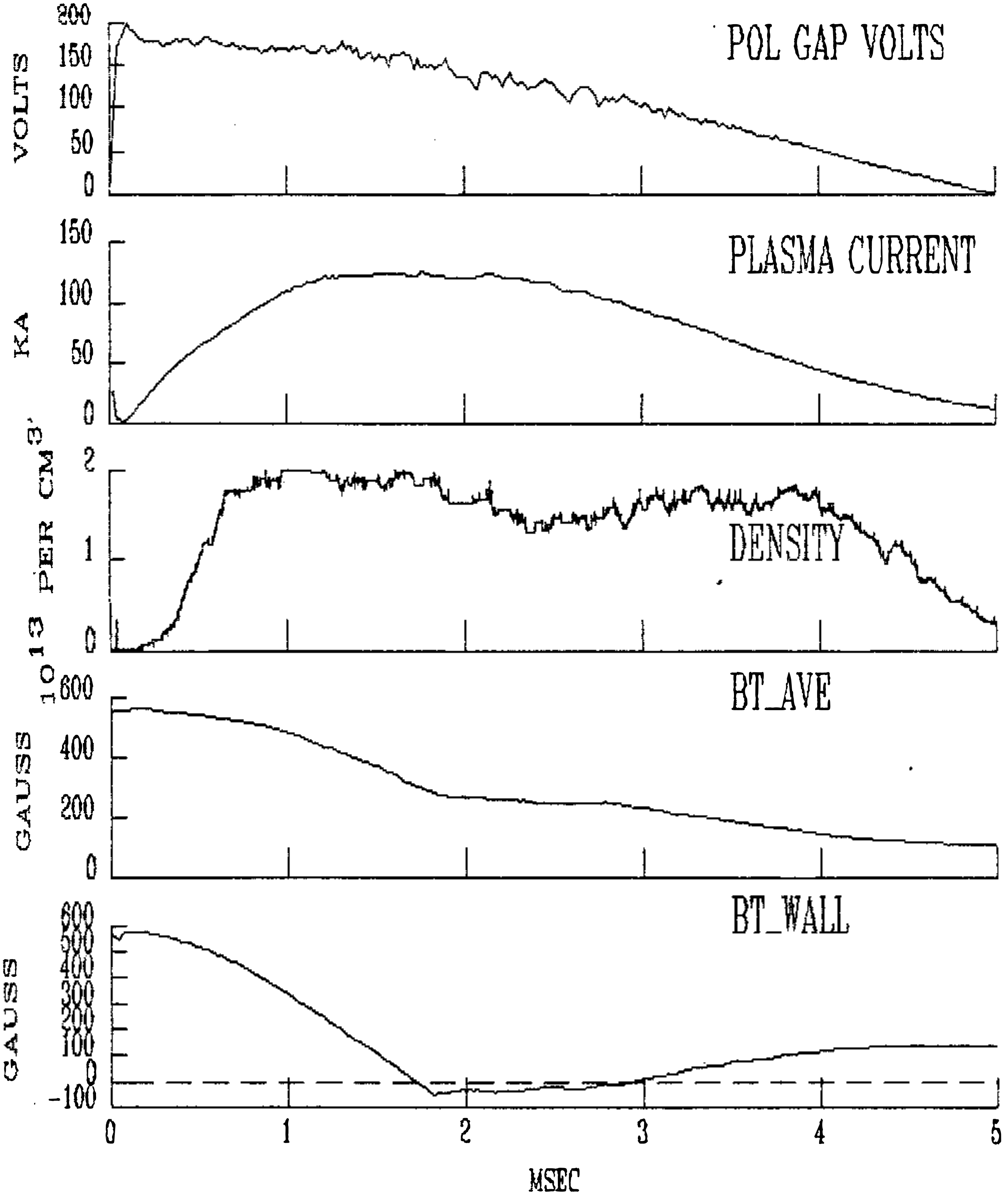
   $n_e \sim 5 \times 10^{12}$ cm^{-3}

   $\tau_E \sim 0.1$ msec

   $Z_{eff} \sim 3$

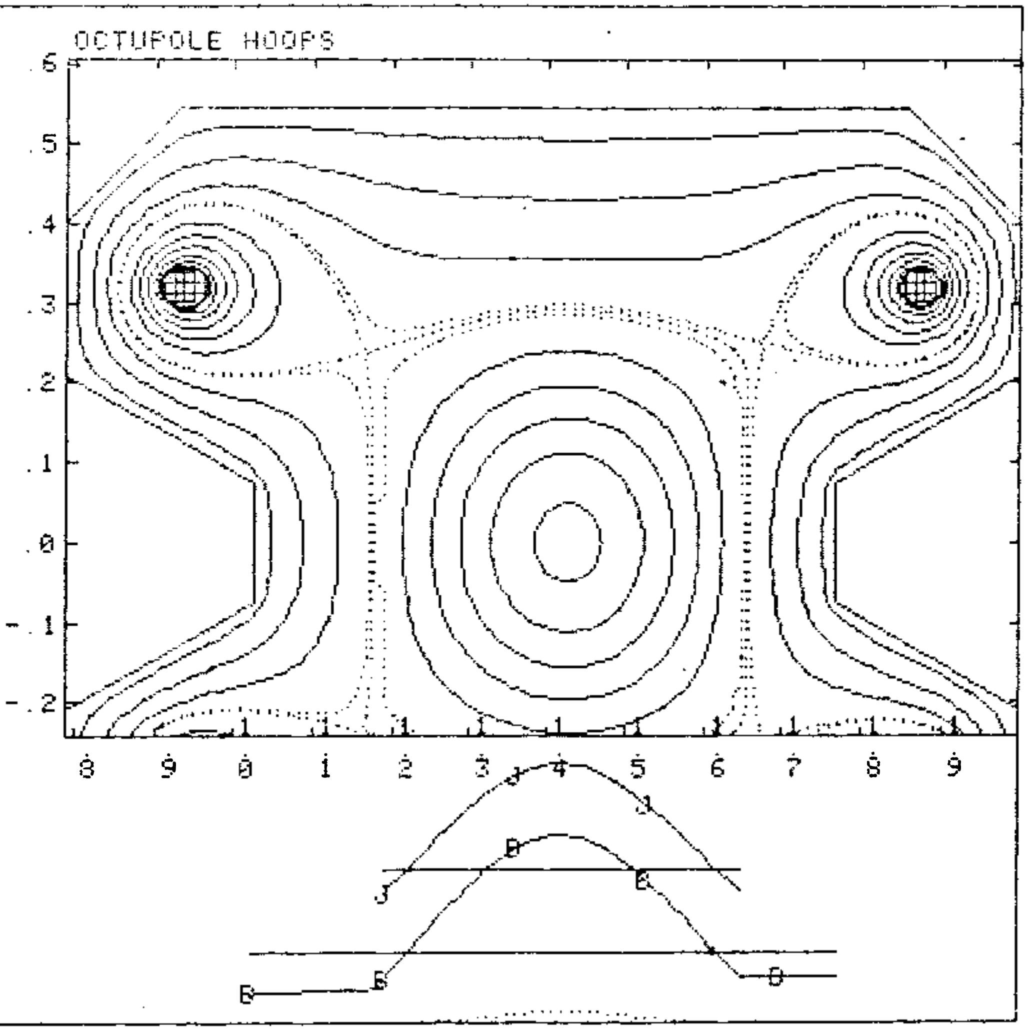
2. MAGNETIC FLUCTUATION LEVEL PEAKS STRONGLY IN BAD POLOIDAL CURVATURE REGIONS ONLY IN THE LOW q TOKAMAK CASE. INTERESTINGLY, THE FLUCTUATIONS DO NOT PEAK IN THE RFP, WHICH IS ALSO POLOIDAL CURVATURE DOMINATED.

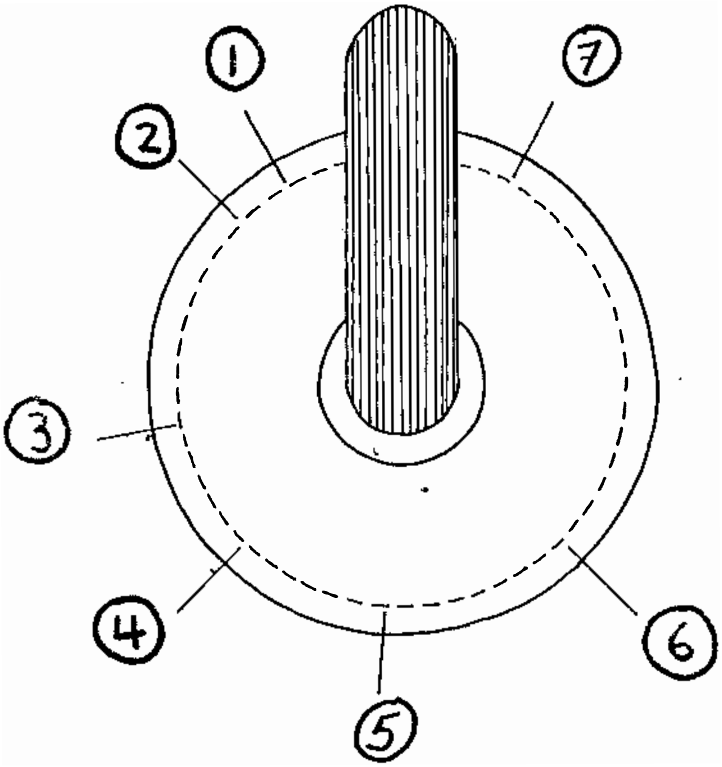
TYPICAL DIVERTOR RFP DISCHARGE USING AIDED-REVERSAL



FLUX PLOT FOR DIVERTOR RFP

```
D 6/05/12  20:53
1.43:RM   0.13:Q
1.00E-01 ` 2.00
-1.00 KG ` 0.80
 3 77:L 3.03:DR
    0%:B   4.86:G
B  2.2 -0.56 KG
Ip=100KAMP ` 1.00
0.16:YL 0.52:YT
0.38:YO 0.22:DY
HOOP/SEPS/SHELL
DYPRI  0.28  0.29
YSEP   0.15  0.15
YRING  0.43  0.43
IR=500kA   171    79
MH CM   2.1   2.1
XH CM  14.5108.0
YH CM  32.0  32.0
---STATISTICS--
VAC   92   1 54  S
INI   80   1.52  S
OUT  150   8.81  S
INR  361  12.34  T
—DY,RMS  %R,G  J
V 0.000% 0.000%
  0.000% 0.000%
I 0.023% 0.100%
  0.020% 0.050%
O 0.203* 0.100*
  0.083* 0.005*
` 0.002% 0.160%
10.9676 1.0000
```

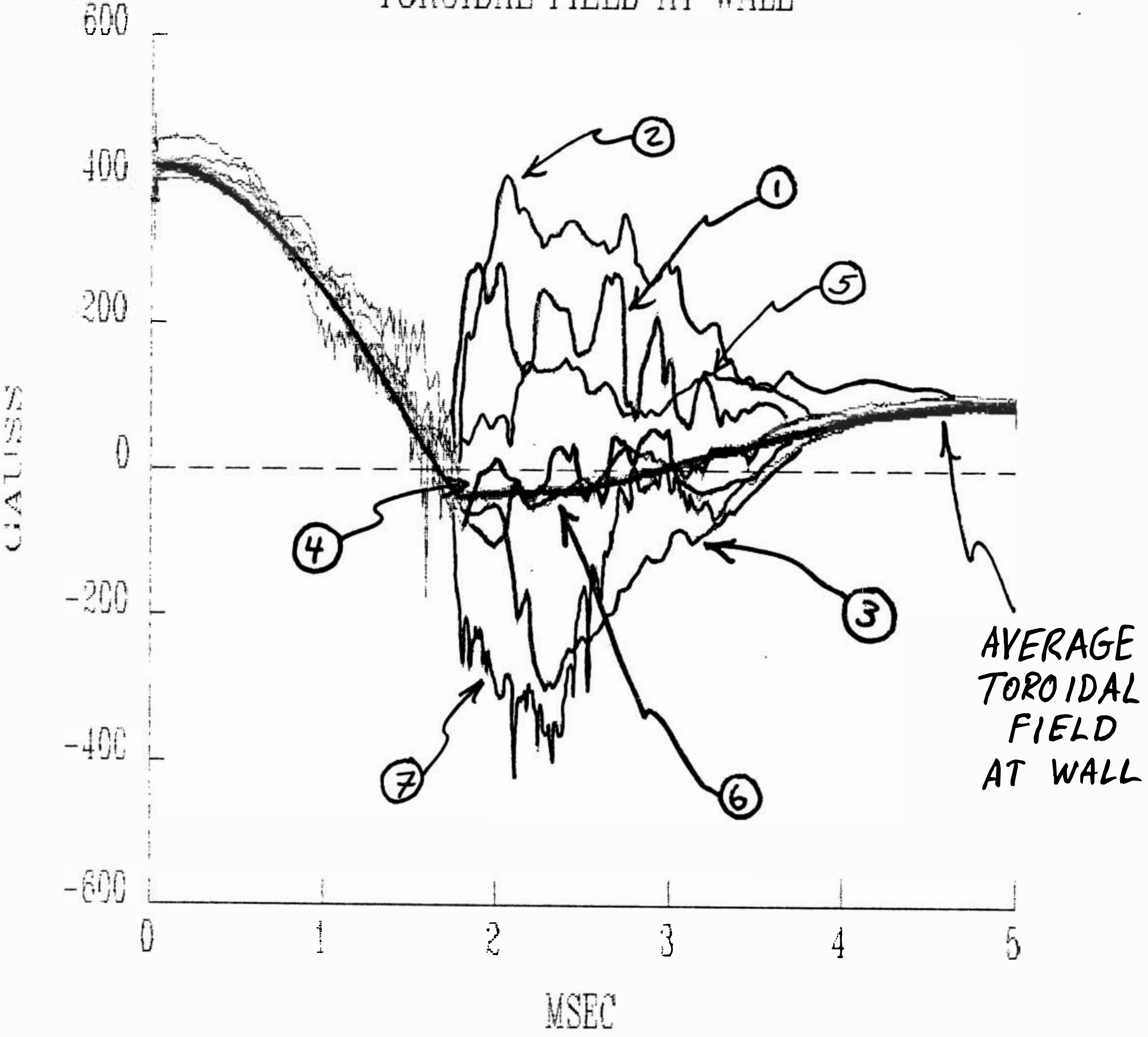




SEVEN SMALL $\dot{B}$ PROBES SEPARATED TOROIDALLY USED TO CHECK TOROIDAL SYMMETRY. COILS ARE LOCATED NEAR THE VACUUM VESSEL WALL ON THE MIDPLANE.

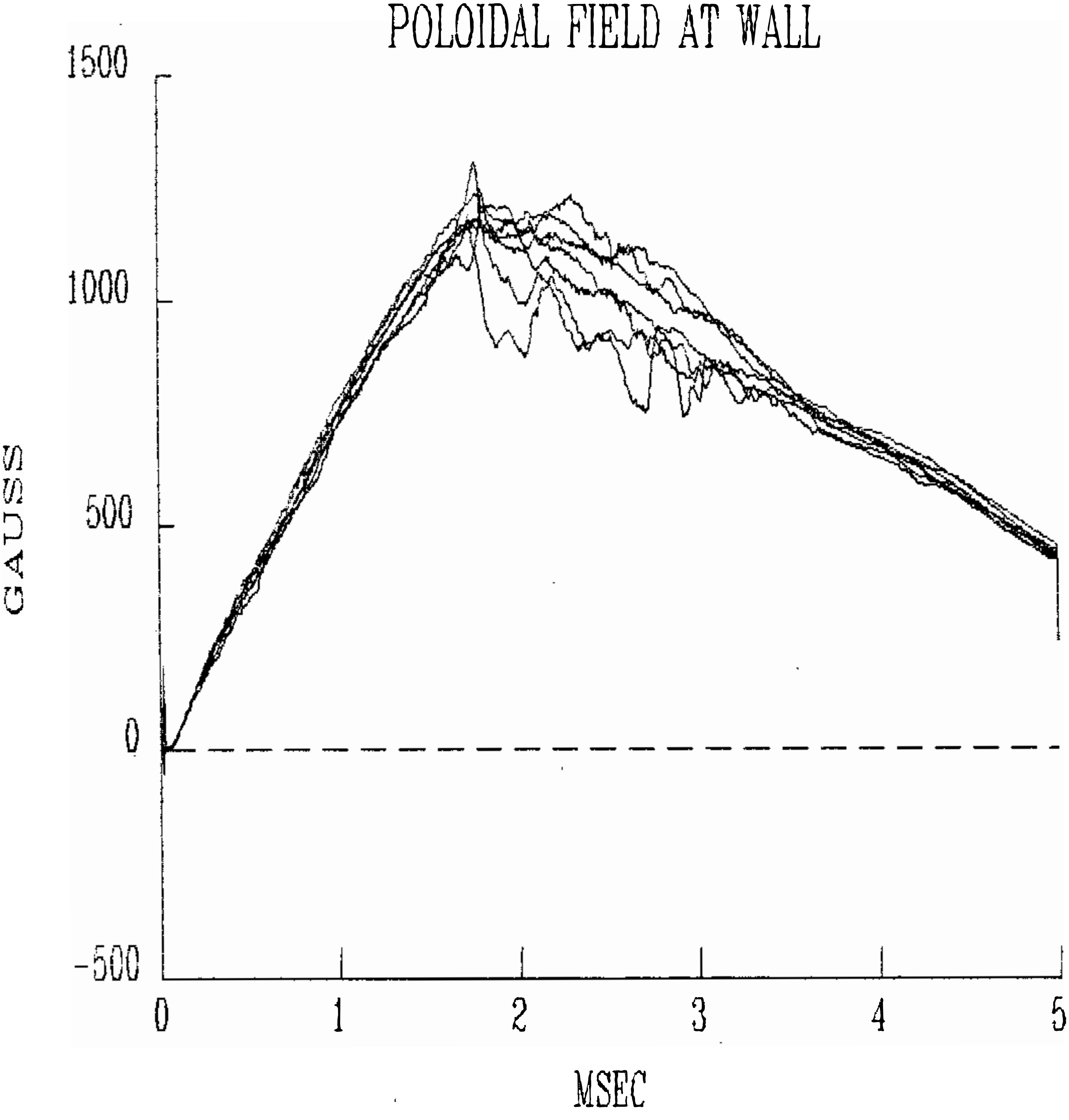
TOROIDAL ASYMMETRY

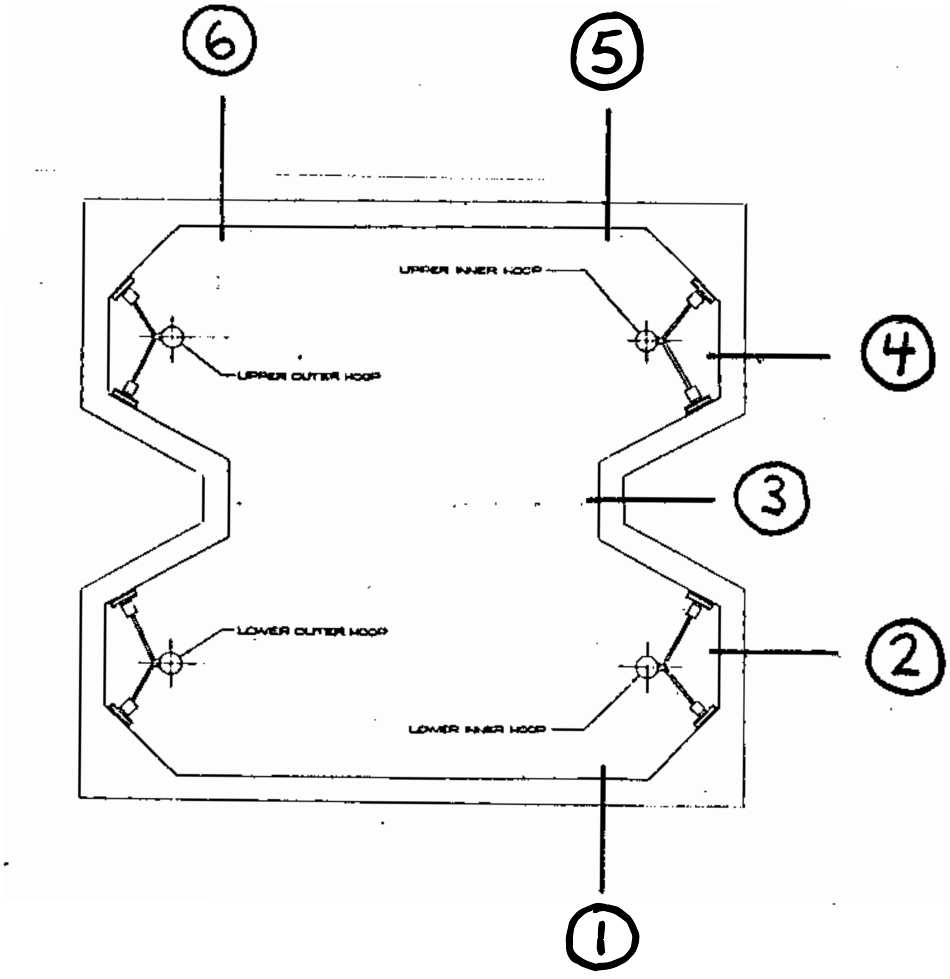
TOROIDAL FIELD AT WALL



TOROIDAL ASYMMETRY

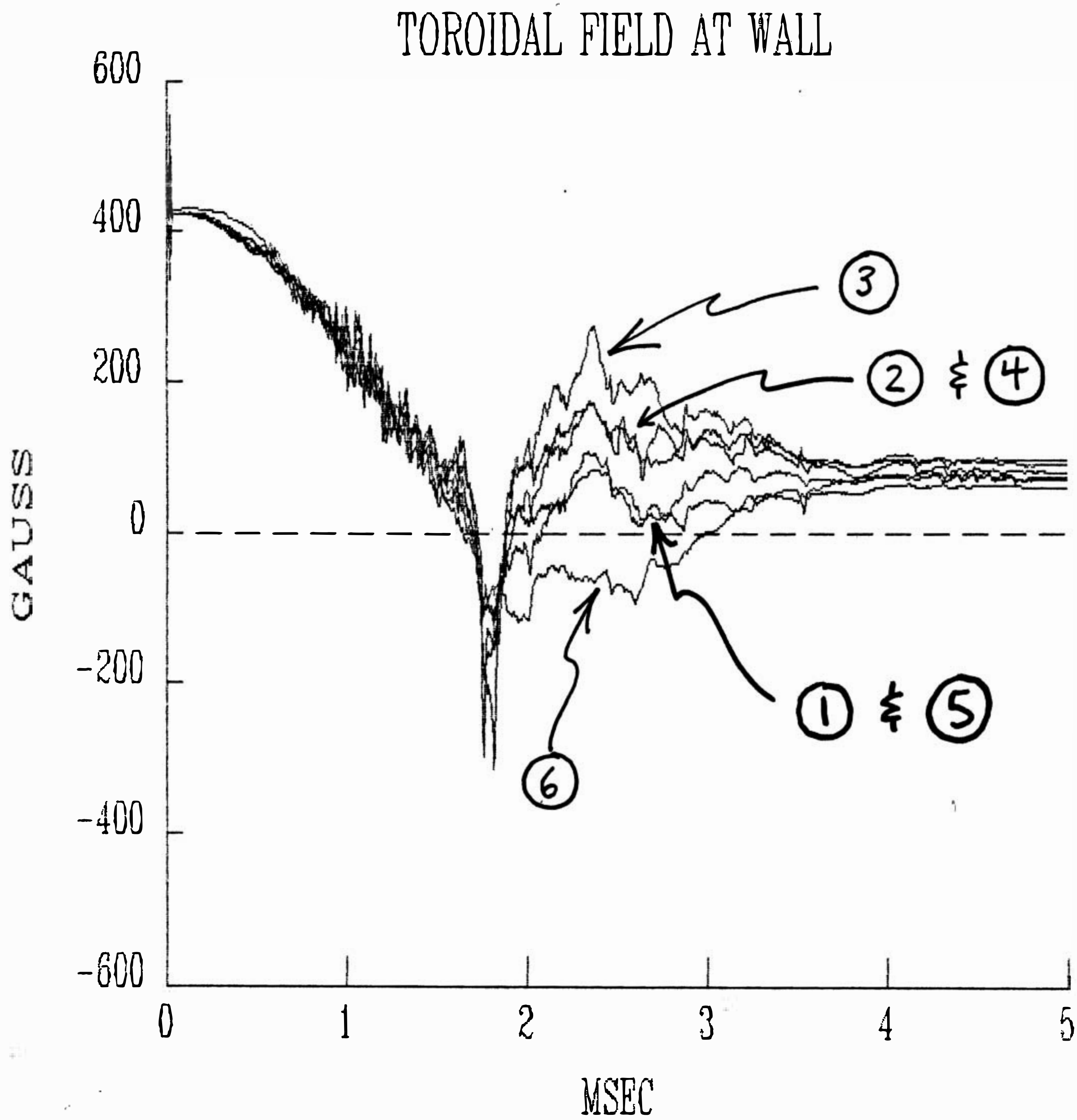
POLOIDAL FIELD AT WALL



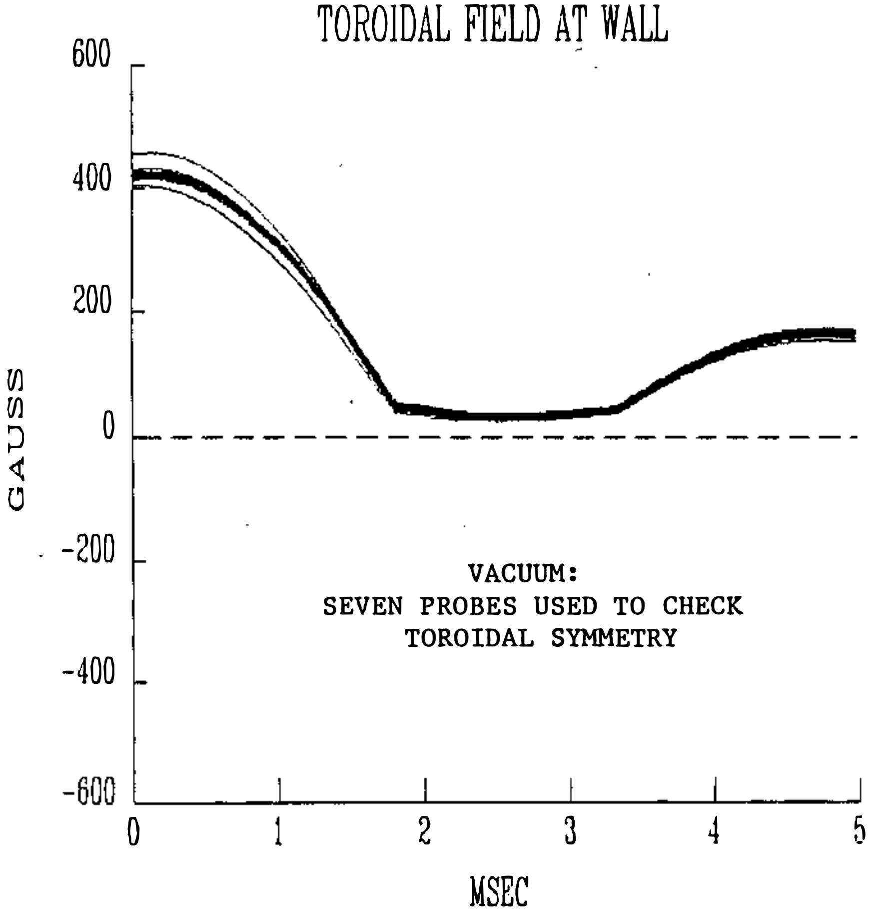


SIX SMALL $\dot{B}$ PROBES SEPARATED POLOIDALLY USED TO CHECK POLOIDAL SYMMETRY. COILS ARE LOCATED NEAR THE WALL AT THE 225° TOROIDAL AZIMUTH. WE COMPARE THE VALUES OF RB_ϕ/R_3; R_3 IS THE MAJOR RADIUS AT WHICH COIL ③ IS LOCATED.

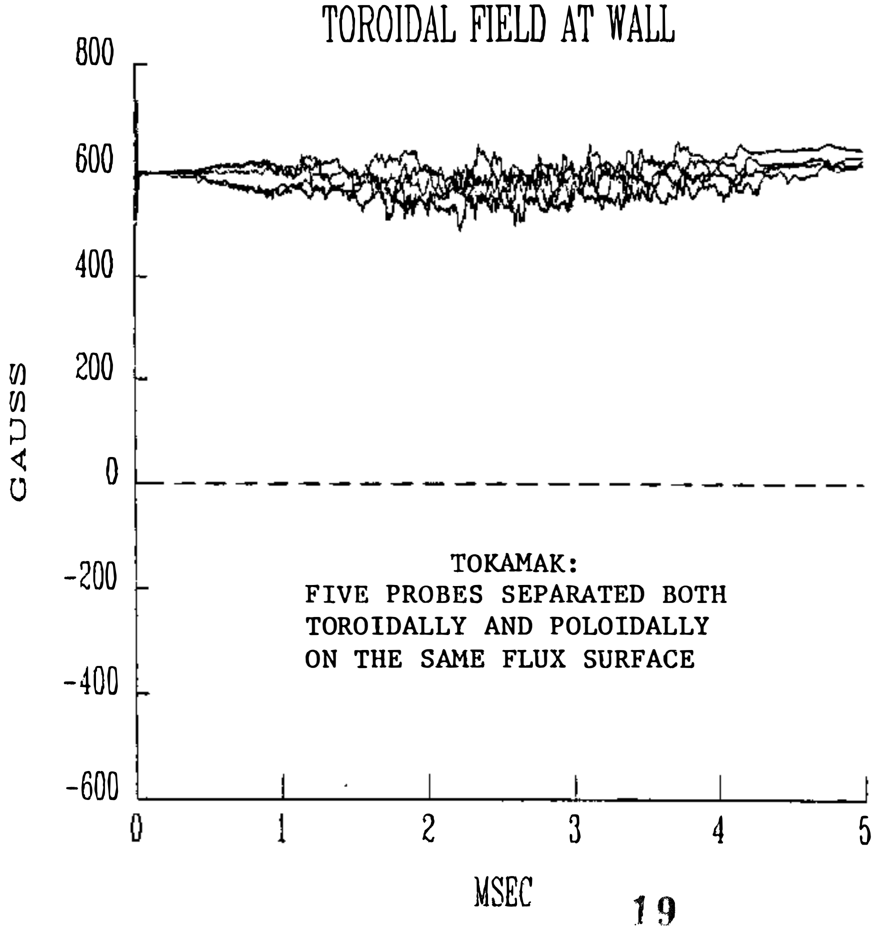
POLOIDAL ASYMMETRY



LOW q DIVERTOR TOKAMAK AND VACUUM FIELDS ARE SYMMETRIC



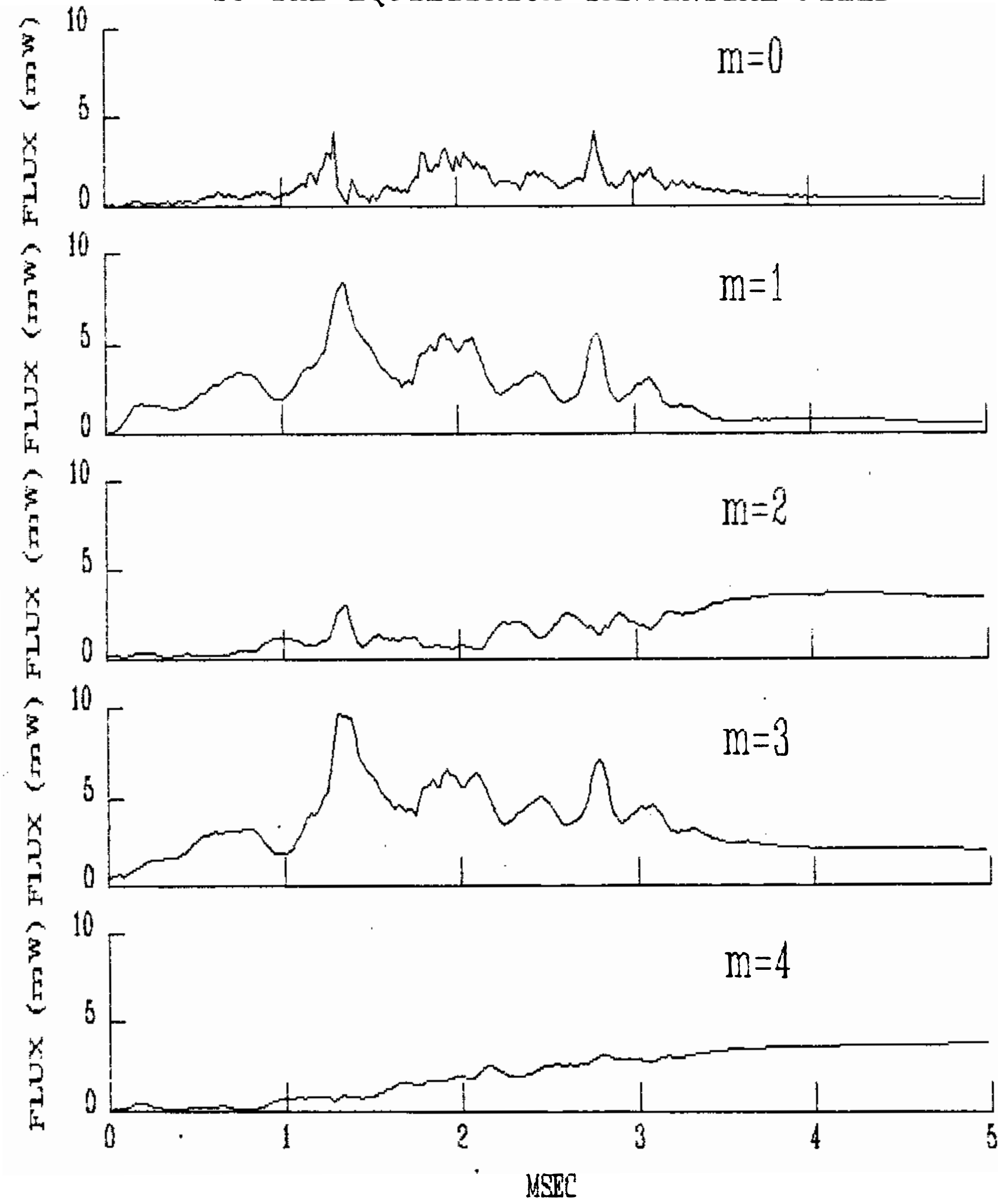
VACUUM:
SEVEN PROBES USED TO CHECK
TOROIDAL SYMMETRY



TOKAMAK:
FIVE PROBES SEPARATED BOTH
TOROIDALLY AND POLOIDALLY
ON THE SAME FLUX SURFACE

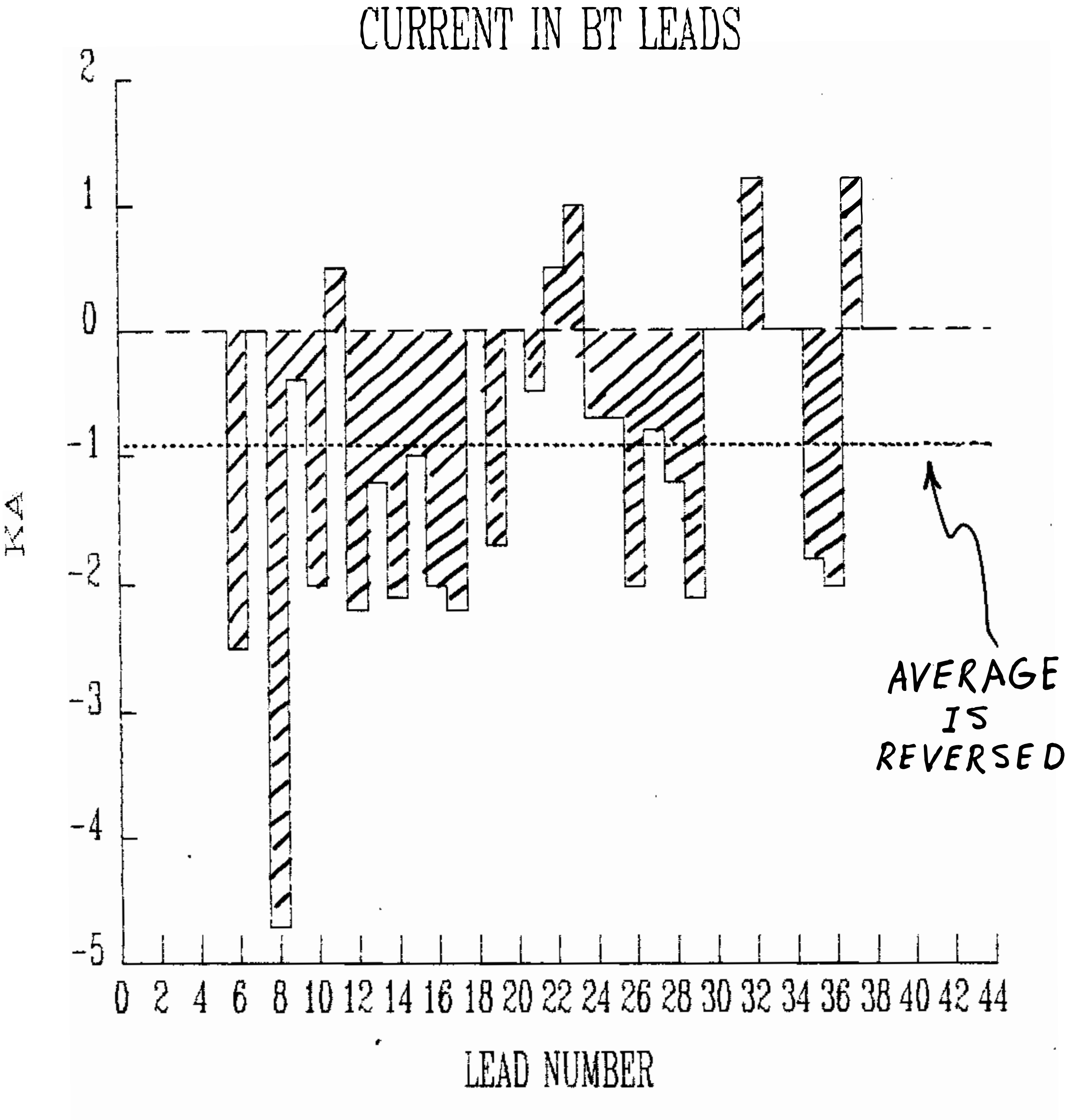
FOURIER AMPLITUDES OF THE ERROR FLUX AT THE POLOIDAL GAP

USING THE t=0 WIDTH OF THE GAP
THE ERROR FIELD IS COMPARABLE
TO THE EQUILIBRIUM TANGENTIAL FIELD



The toroidal field is produced by driving the aluminum vacuum vessel wall with 44 lead pairs connected uniformly around the toroidal gap.

CURRENT IN THE BT LEADS IS NON-UNIFORM TOROIDALLY. DATA TAKEN BELOW ARE DURING REVERSAL.



AVERAGE IS REVERSED

SUMMARY OF DIVERTOR RFP

1. REVERSED-FIELD PLASMAS ARE OBTAINED USING 'AIDED-REVERSAL' FIELD PROGRAMMING WITH REVERSAL TIME $\lesssim$ 1.5 MSEC. THE BASIC PLASMA PARAMETERS FOR A TYPICAL I_p = 135 kA DISCHARGE ARE

   $n_e \sim (1-2) \times 10^{13}$ cm^{-3}

   $T_e \sim 100$ eV (THOMPSON SCATTERING)

2. LARGE SCALE GLOBAL ASYMMETRY IS OBSERVED IN THE EQUILIBRIUM MAGNETIC FIELD:

   a) THE POLOIDAL STRUCTURE APPEARS TO BE DOMINANTLY m=1.

   b) THE ASYMMETRY VARIES RAPIDLY IN THE TOROIDAL DIRECTION SUGGESTING A LARGE n STRUCTURE, BUT NO SINGLE n VALUE FITS THE DATA WELL.

   c) THE LOW q TOKAMAK IS SYMMETRIC AS ARE THE VACUUM FIELDS.

3. LARGE FIELD ERRORS ARE PRESENT AT BOTH THE TOROIDAL AND POLOIDAL GAPS.

CONCLUSIONS

IT IS CLEAR THE ASYMMETRY IS ASSOCIATED WITH ATTEMPTING TO LOWER THE TOROIDAL FIELD.

IS THE ASYMMETRY ASSOCIATED WITH A LARGE FIELD ERROR OR IS THERE MORE FUNDAMENTAL PHYSICS AT WORK?

WE HAVE NO EVIDENCE AT THIS POINT WHICH ANSWERS THIS QUESTION. IT IS PROBABLY NECESSARY TO SIGNIFICANTLY REDUCE THE FIELD ERRORS BEFORE THE ANSWER BECOMES APPARENT.

ATTEMPTS WERE MADE TO FIX THE FIELD ERRORS, BUT ONLY SLIGHT IMPROVEMENT RESULTED AND THE ASYMMETRY PERSISTED.