# THE DESIGN OF THE MST REVERSED FIELD PINCH

(Poster (5T14) presented at the 29th Annual Meeting of the
Division of Plasma Physics of the American Physical Society
November 2-6, 1987, San Diego, CA)

A.F. Almagri
S. Assadi
J. Beckstead
G. Chartas
R.N. Dexter
D.J. Den Hartog
Y.L. Ho
D.W. Kerst
T.W. Lovell
S.C. Prager
J.S. Sarff
W. Shen
C. Spragins
J.C. Sprott

PLP 1022

November 1987

Plasma Studies

University of Wisconsin

# The Design of the
# MST Reversed Field Pinch*

A.F. ALMAGRI, S. ASSADI, J. BECKSTEAD, G. CHARTAS, R.N. DEXTER,
D.J. DEN HARTOG, Y.L. HO, D.W. KERST, T.W. LOVELL, S.C. PRAGER, J.S. SARFF,
W. SHEN, C. SPRAGINS and J.C. SPROTT

*University of Wisconsin-Madison*

The MST (Madison Symmetric Torus) experiment will soon begin operation. The vacuum vessel is 5 cm thick aluminum (R=1.5 m and a=52 cm). Most RFP devices employ a metallic liner to protect voltage gaps from plasma. MST is unconventional in that the vacuum vessel serves the function of liner, conducting shell and toroidal and equilibrium field coils. One implication of this design is that insulated gaps are exposed to plasma, thus a combination of low voltage startup and special gap protection is required to prevent arcing. To this end we have designed a gap protection scheme that is successfully tested in the prescence of plasma up to 300 volts. By employing large current feed flanges and using the vacuum vessel as the equilibrium field coils, field errors are reduced to small levels. In addition, two primary systems are used for the poloidal field to reduce field errors to extremely small levels. Also all portholes are limited to no greater than 3.2 cm in diameter. The first experiments will investigate shell proximity requirements using a movable limiter.

---

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

# INTRODUCTION

The Madison Symmetric Torus (MST) is a reversed field pinch device ($R_0$=150 cm , a=52 cm) designed for the dual purpose of exploring the basic physics of the RFP configuration and functioning as a key support experiment for ZT-H and RFX . The wealth of experience accumulated from past RFP devices and from past wisconsin machines has been incorporated into the MST design, which is unconventional in several ways. The dominant physics goal is to study the role of the boundary condition on RFP stability and confinement.

# SCIENTIFC GOALS

## 1) Boundary Condition Studies

To examine the effects of RFP boundary conditions on stability, fluctuations and confinement. The first experiment will be to vary the width of the vacuum region between plasma and the conducting wall using a movable toroidal limiter .

## 2) q Scaling Studies

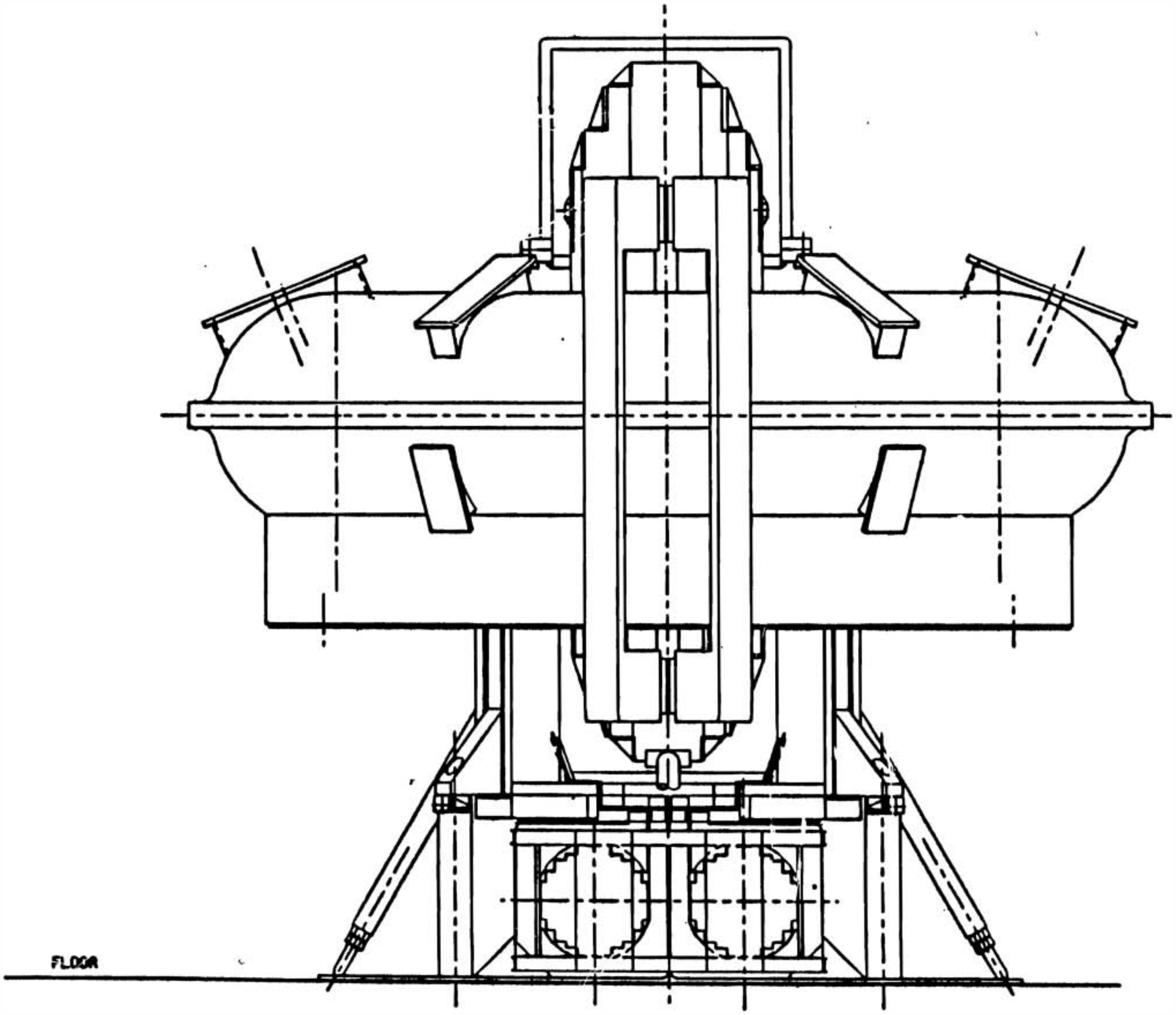
A future objective is to track stability and confinement as the plasma configuration is varied from RFP to tokamak.

# MACHINE DESCRIPTION

MST is designed with special attention payed to the minimization of magnetic field errors due to shell gaps , iron core winding and portholes. Ease of disassembly was also required for alteration of the boundary. The resulting machine design contains several unconventional features :

1) A thick (5cm) aluminum vacuum vessel that functions as $B_t$ field winding and conducting shell.
2) A gap protection scheme that protects the gap in the presence of plasma up to at least 300 volts
3) Flanged $B_t$ and $B_p$ gaps to reduce field errors
4) A continuity winding and guard core transformer to inhibit current from flowing on the outside surface of vacuum vessel
5) Small pumping and diagnostic portholes to reduce field errors
6) Three primary winding systems :

   One primary winding (magnetizing) to reduce the iron core stray flux. The second primary winding (poloidal field) to reduce the radial field in the $B_p$ gap. The third winding (d.c.bias) to reverse bias the iron core to obtain a 2 volt-sec flux swing.



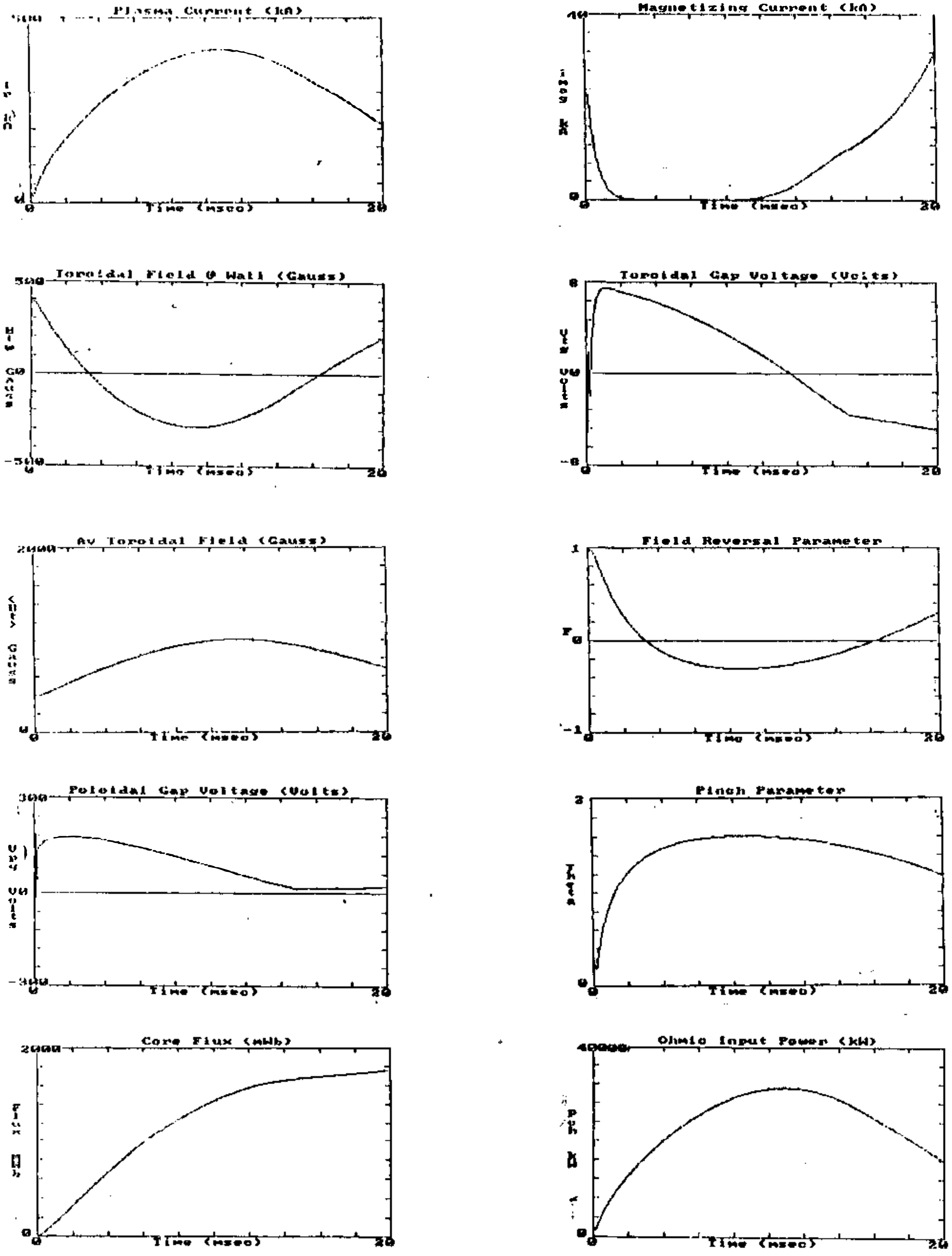
MST Device

# PROJECTED PLASMA PARAMETERS

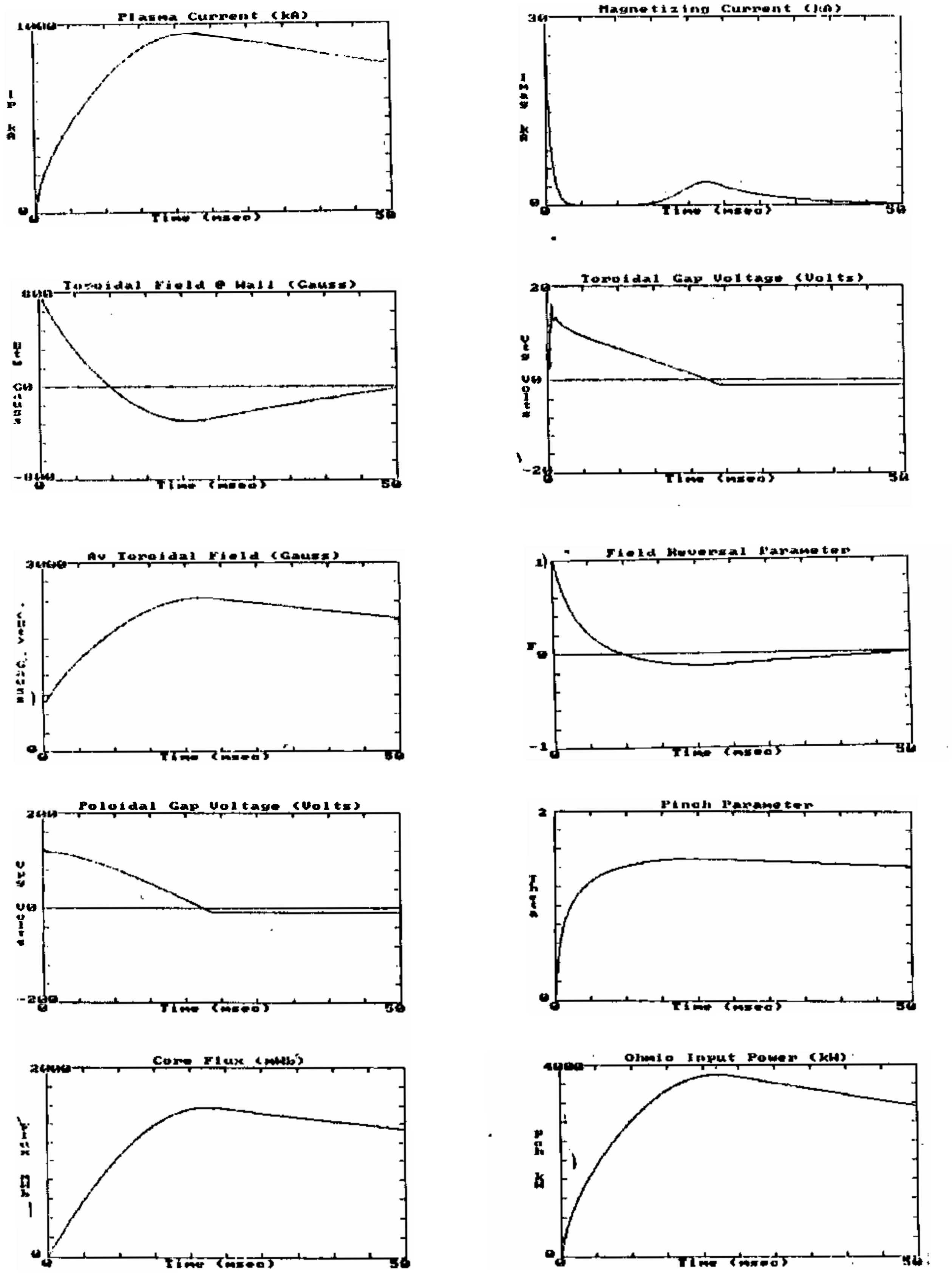
The projected plasma parameters for MST are determined by a combination of electrical circuit modeling, based on the modified bessel function model, and assumptions about the scaling of plasma parameters with plasma current and machine size. A range of possibilities that bracket the actual case have been examined. We are faily confident of achieving 400 kA discharges reversed for 10 msec (pessimistic), since these were achieved in the noncircular RFP tests. However the best we can expect is to obtain 1.0 MA discharges reversed for 40 msec (optimistic). Table # 1 gives plasma parameters for both pessimistic and optimistic limits.

TABLE # 1

| Parameter | Pessimistic | Optimistic |
|---|---|---|
| Major radius | 1.50 m | 1.50 m |
| Minor radius | 0.52 m | 0.52 m |
| Plasma current | 400.0 kA | 1.0 MA |
| Loop voltage | 75.0 V | 4.0 V |
| Average toroidal field | 1000.0 G | 2500.0 G |
| Toroidal field at wall | -300.0 G | -150.0 G |
| Poloidal flux swing | 1.8 V-s | 1.6 V-s |
| Electron temperature | 100.0 eV | 1000.0 eV |
| Average plasma density | $3\times10^{19}$ $m^{-3}$ | $4\times10^{19}$ $m^{-3}$ |
| Poloidal $\beta$ | 10% | 20% |
| Confinement time | 0.4 ms | 40.0 ms |
| Discharge duration | 10.0 ms | 40.0 ms |



Typical waveforms for a pessimistic, 400-kA, 10-ms discharge in MST.



Typical waveforms for an optimistic, 1-MA, 40-ms discharge in MST.

# TOROIDAL FIELD SYSTEM

The MST toroidal field system circumvents some of the problems associated with discrete toroidal field coil systems such as field ripples, loss of diagnostic access and disassembly. However, using the vacuum vessel as a one turn toroidal field winding requires the use of a step-up current transformer(48:1). The poloidal current is fed to the shell from the transformer via a long axisymmetric flange system to symmetrize the shell current. The flange system consists of a pair of annular horizontal disks which connect to a long coaxial cylindrical section . The cylinders are connected at four locations to the transformer secondary (see fig # 1).

The calculated toroidal field ripple is about 0.05% of the poloidal field with the dominant component being m=0 , n=4 , and the resultant magnetic island width of about 1 cm. This design allows virtually unlimited diagnostic access and easy maintenance of the vacuum vessel.

# POLOIDAL FIELD SYSTEM

The poloidal field system that produces the toroidal current and poloidal magnetic field consists of three major components, poloidal winding system, poloidal flange, and the continuity winding ( see fig # 2).

## 1) Poloidal Winding System

The poloidal field windings consist of three seperate windings, the d.c. bias winding, the magnetizing winding, and the poloidal field winding .

### A) Bias Winding

The bias winding is used to reverse bias the iron core to accomplish a 2.0 volt-second flux swing . This 40 turn winding will carry 24 kA-turns for 3 to 10 seconds . Since the biasing field is a d.c. field, it is very critical that the winding be distributed around the iron core properly to minimize flux leakage into the plasma volume. This winding distribution has been empirically determined and the stray field within the plasma region was reduced to a value less than 1.0 gauss everywhere (see fig # 3).

### B) Magnetizing Winding

The magnetizing winding is used to carry the magnetizing current that is required for a finite permeability transformer. This 40 turn winding is distributed around the core so as to minimize the leakage flux in the plasma region. The desired distribution was empirically determined for a magnetizing current of 400 kA-turns. The residual field was reduced to less than 5.0 gauss at the shell poloidal gap and will only arise late in the discharge as the core saturates. This winding consists of aluminum straps wrapped around the iron core and designed to carry a magnetizing current up to about 0.5 MA and a stand-off voltage of 20.0 kV (see fig * 4).

### C) Poloidal Field Winding

The poloidal field winding is used to force the surface (plasma image) current in the poloidal flange to flow in the radial direction as it crosses the poloidal gap. This is accomplished by threading these windings through holes in the poloidal flange. The total amp-turns in these windings must equal the plasma current. To accomplish that, a set of current transformers is used. The poloidal distribution of the toroidal current density in the wall will be measured prior to placement of this winding.

## 2) Poloidal Flange

The flange is used to reduce the field errors that result from the imperfect matching of the poloidal field winding distribution to that of the surface current distribution in the shell wall, due to using a finite number of turns (40). This "flange effect" arises because the poloidal component of the surface current, resulting from imperfect matching, will not be localized at the gap but will be distributed over the entire flange. As a result, the radial field will be weaker at the plasma edge .

## 3) Continuity Winding

The return current on the exterior surface of the shell would have a different distribution from that on the inner surface of the shell (plasma image current). Hence, if this current is allowed to flow on the exterior surface, a poloidal component of the current would exist at the gap to connect the two distributions, thereby producing a large m=1 magnetic field at the gap(see fig # 5).

To avoid this field error, a continuity winding is used to inhibit return currents from flowing on the exterior surface of the shell. A field error of smaller magnitude would still exist if the poloidal distribution of current in the continuity winding does not match the distribution of shell wall current. To eliminate these errors the poloidal field winding , which is distributed to match the wall current distribution, is used to impose the right current

# Summary

To facilitate the boundary condition studies, MST was designed to be relatively free of magnetic field errors so that the magnetic integrity of the boundary layer and the core region is unquestionable. Field error minimization was a driving criterion for design of the toroidal and poloidal magnetic field systems, and the vacuum pumping system. Field errors are minimized by

1) Using the conducting vacuum vessel as the $B_t$ winding
2) Using flanges for $B_t$ and $B_p$ gaps
3) Using continuity winding
4) Using separate primary system for the magnetizing current
5) Using small porthols properly placed, for daignostic and vacuum pumping

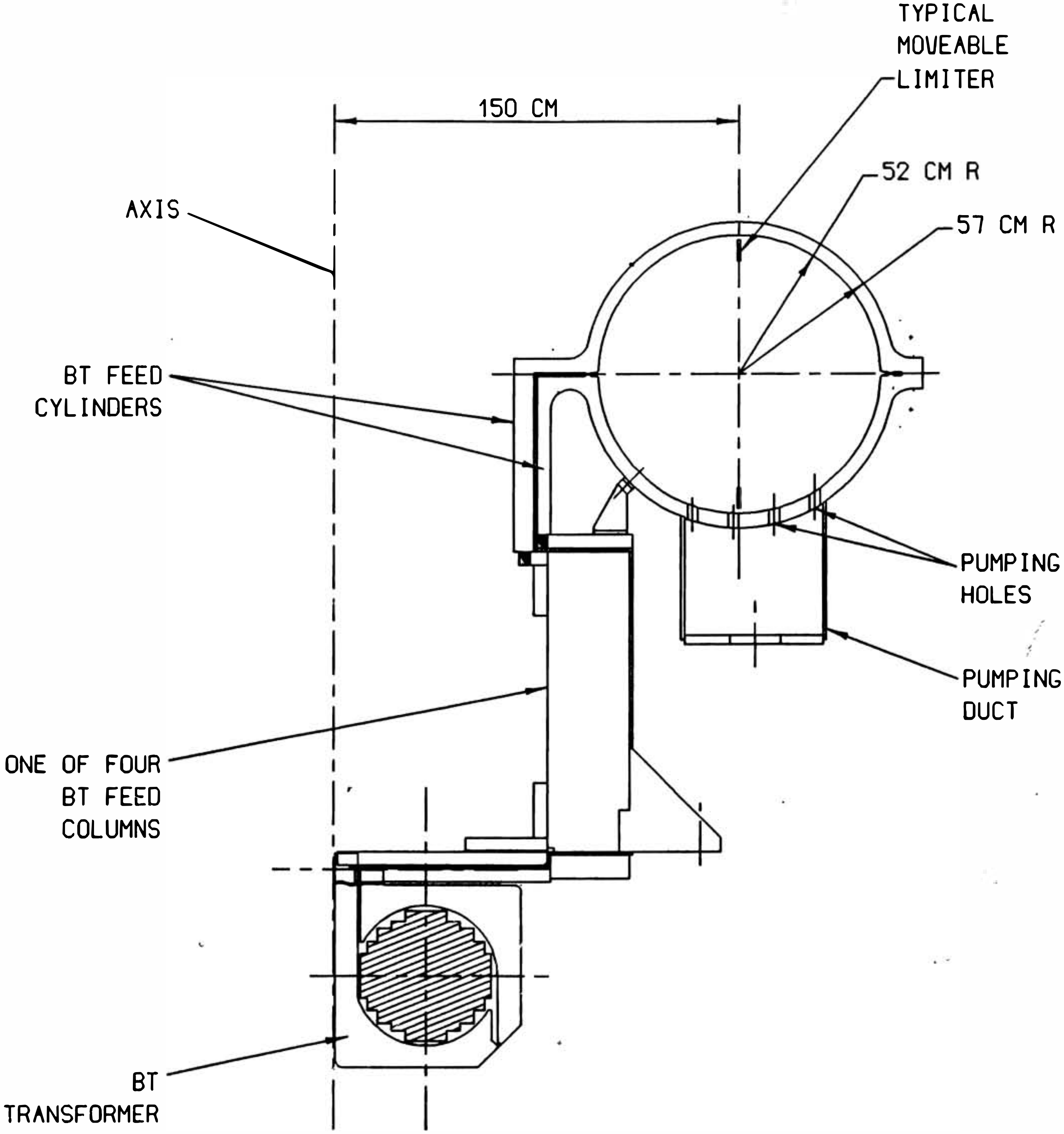


Figure 1: Schematic illustration of toroidal field system

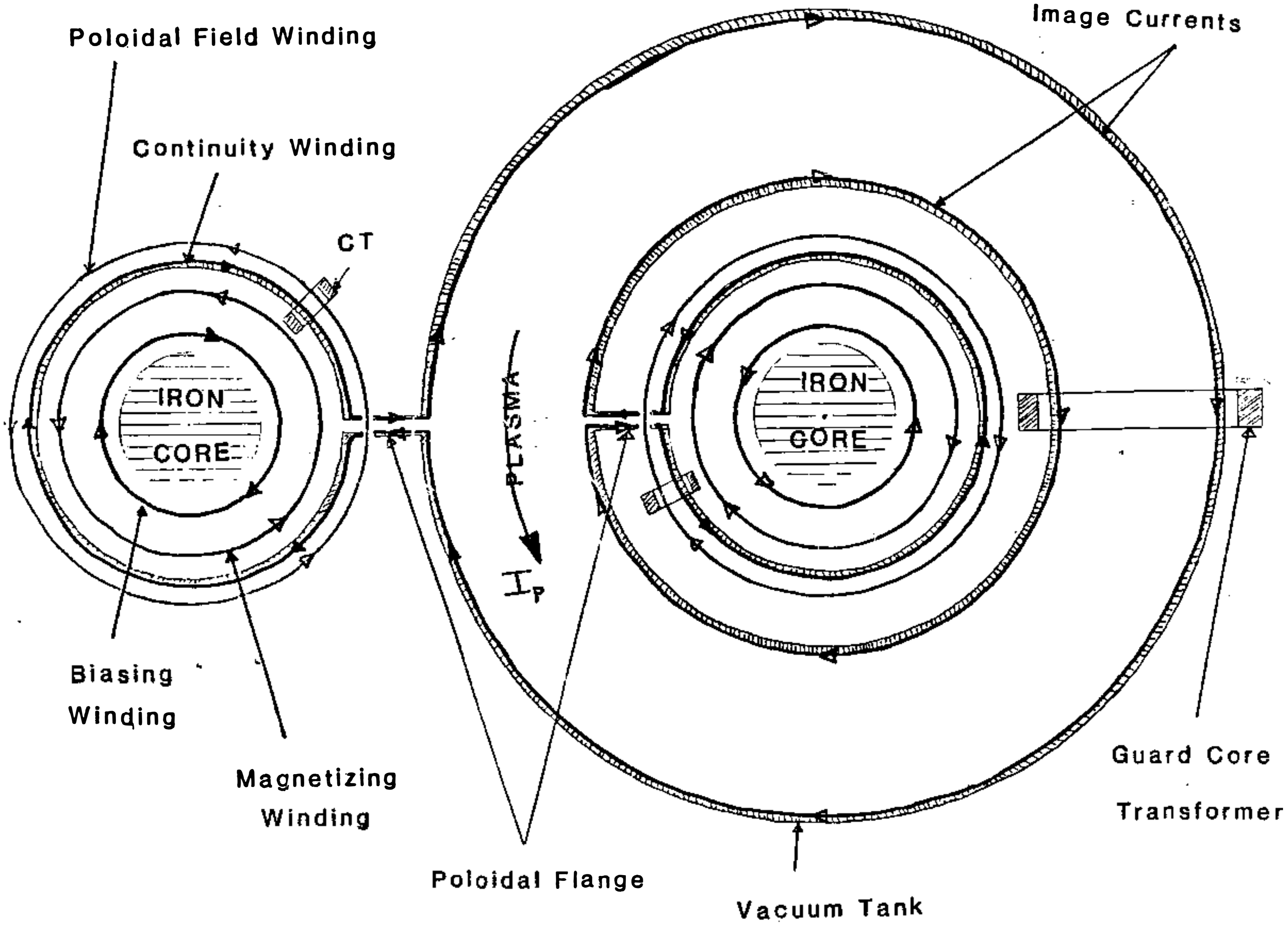


Figure 2: Schematic illustration of poloidal field system

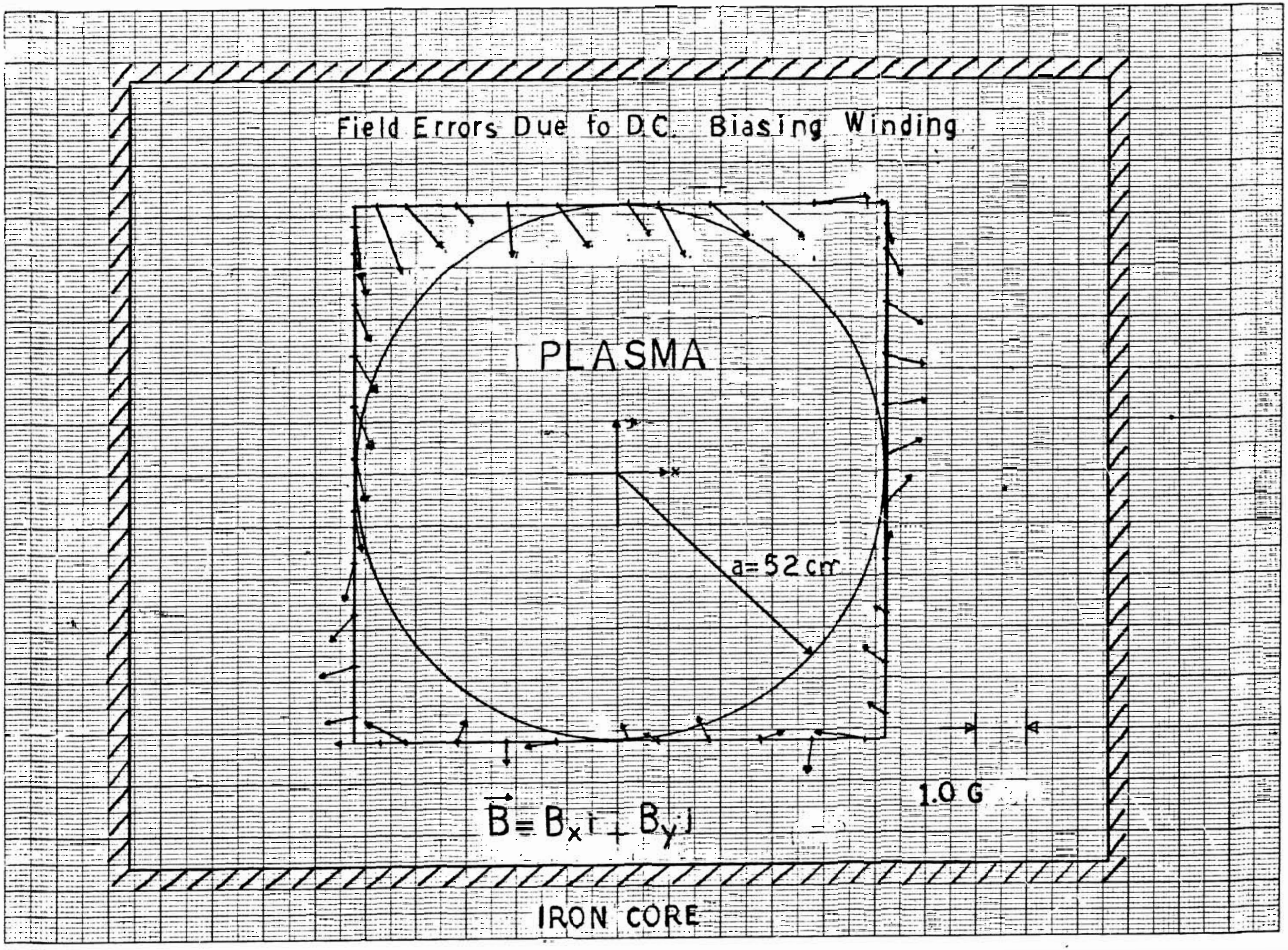

Field Errors Due to D.C. Biasing Winding
PLASMA
y
x
a=52 cm
1.0 G
$\vec{B} = B_x i + B_y j$
IRON CORE

Figure 3

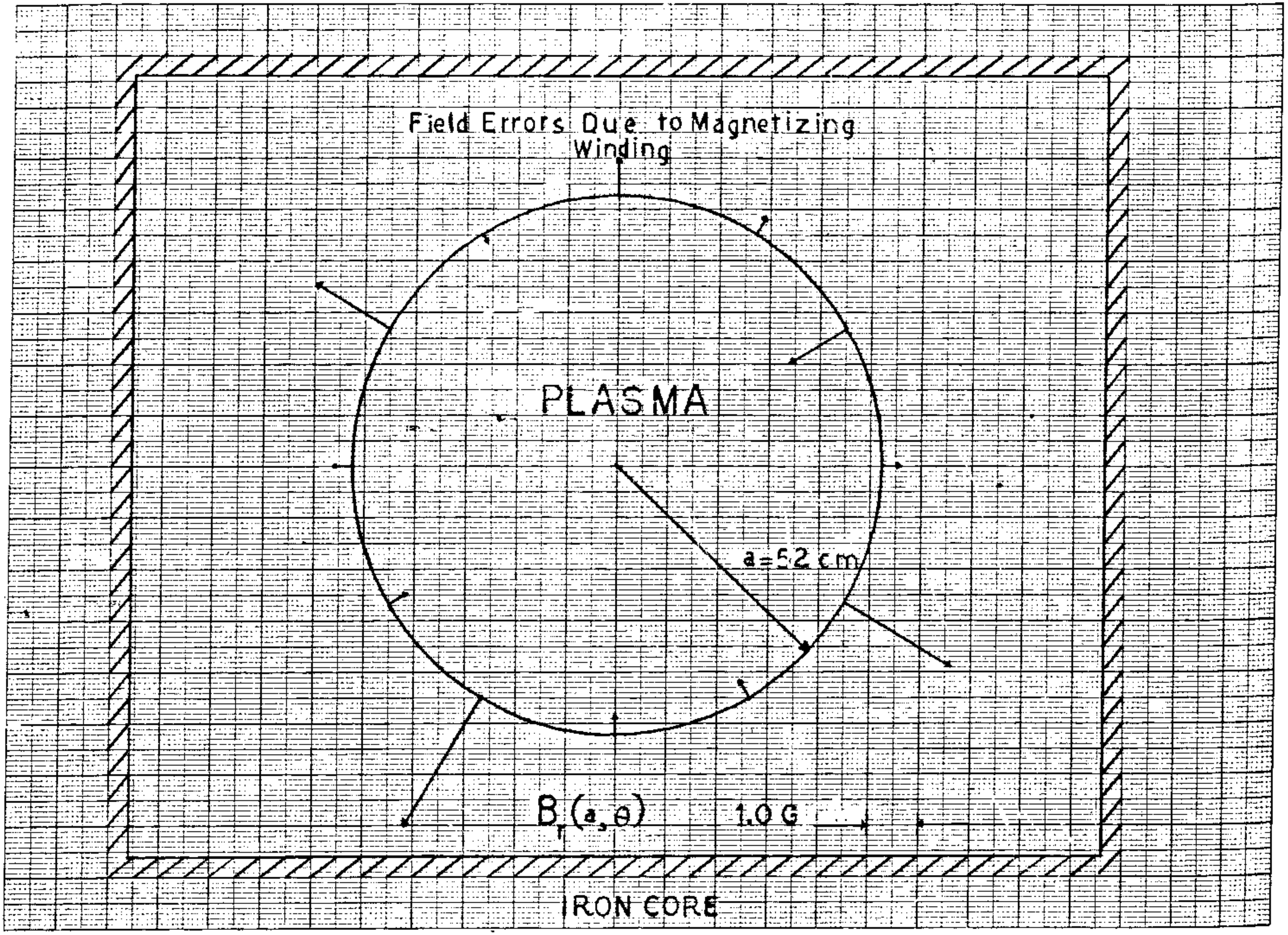

Field Errors Due to Magnetizing Winding
PLASMA
a=52 cm
$B_r(a,\theta)$
1.0 G
IRON CORE

Figure 4-a

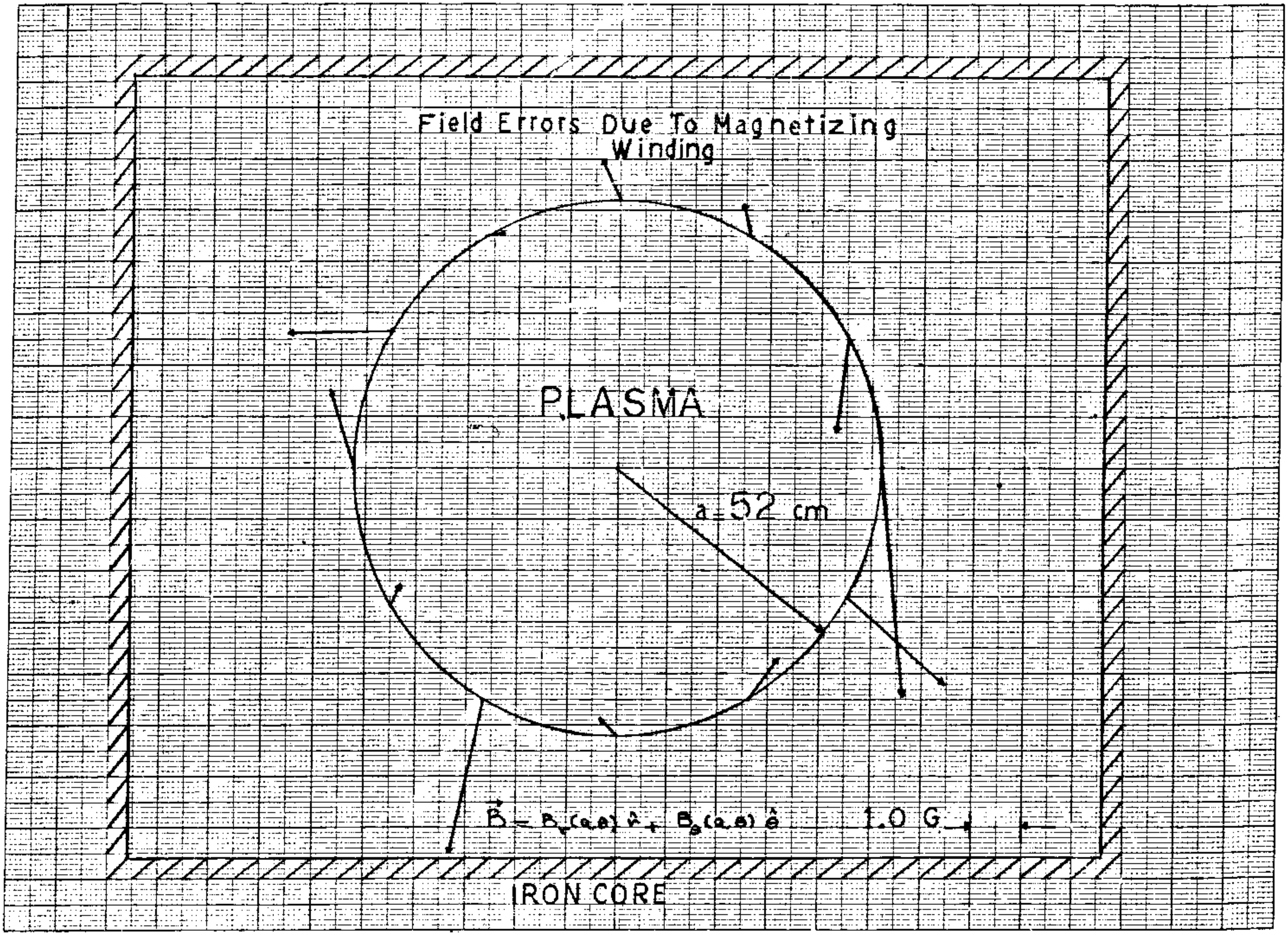

Field Errors Due To Magnetizing Winding
PLASMA
a = 52 cm
$\vec{B} = B_r(a,\theta)\hat{r} + B_\theta(a,\theta)\hat{\theta}$
1.0 G
IRON CORE

Figure 4-b

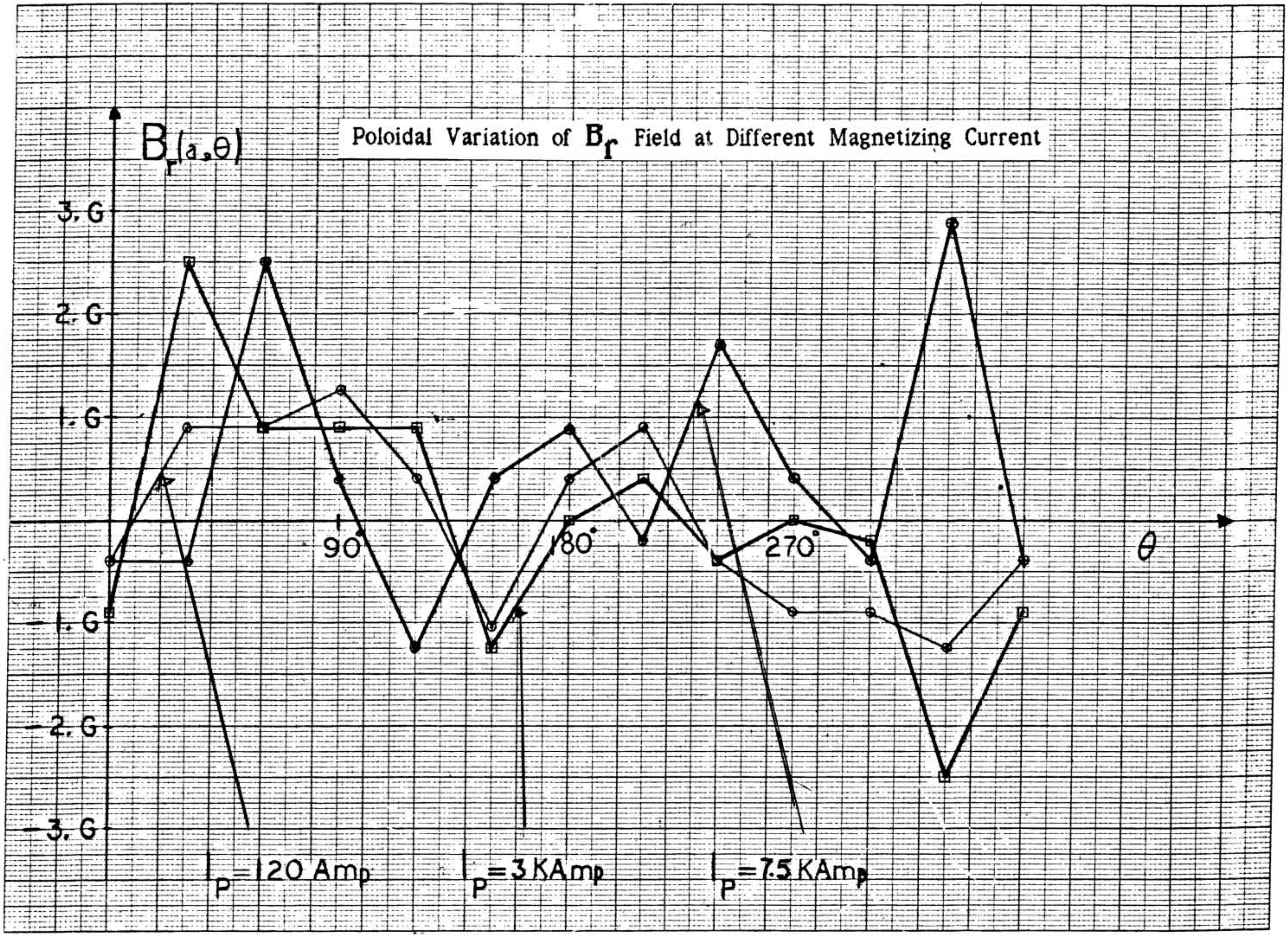
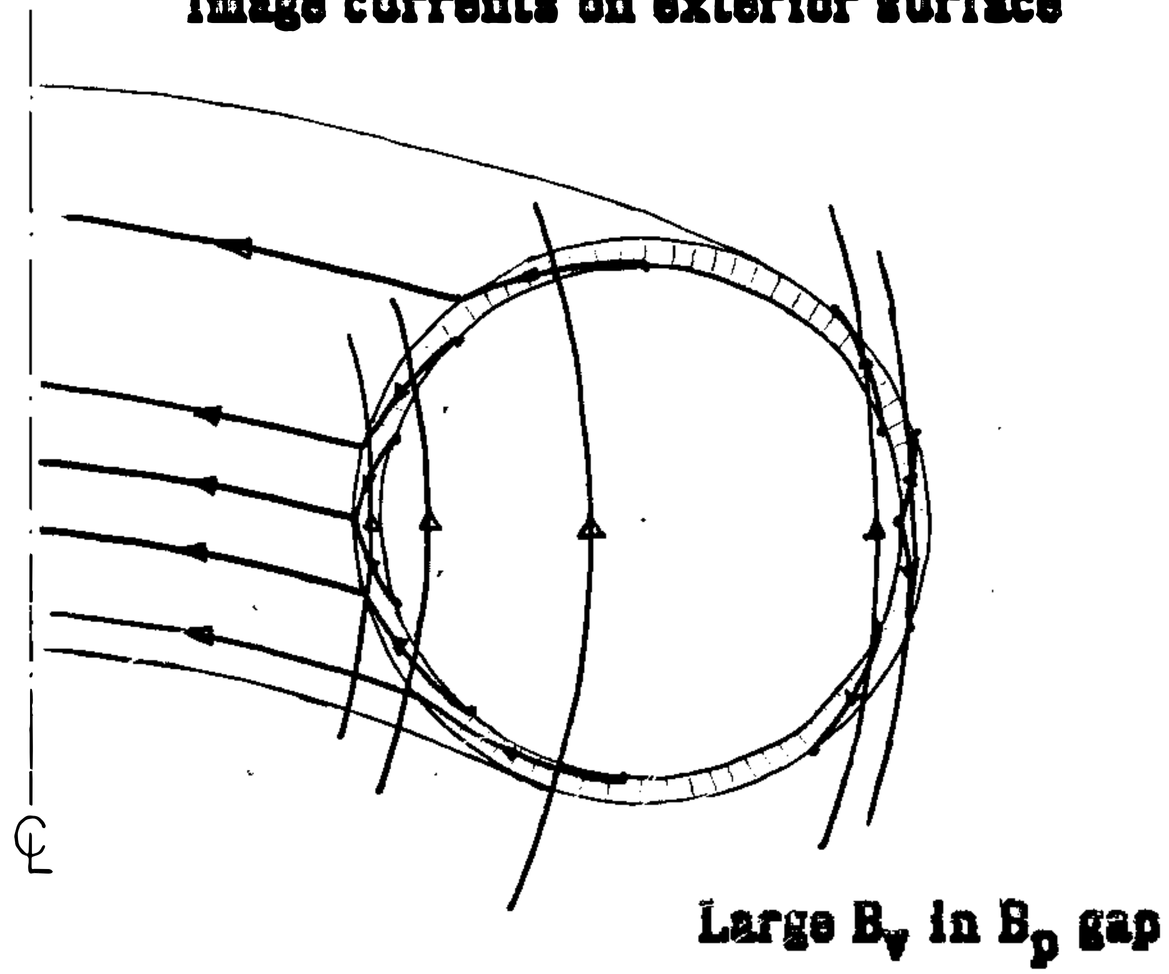

Poloidal Variation of $B_r$ Field at Different Magnetizing Current

Figure 4-c

**Image currents on exterior surface**



m=1 error field results from image current

$J_\theta$ flowing around the $B_p$ gap

Figure 5