BNL-105107-2014-TECH

Booster Technical Note No. 60;BNL-105107-2014-IR

Booster Parameter List

Z. Parsa

October 1986

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

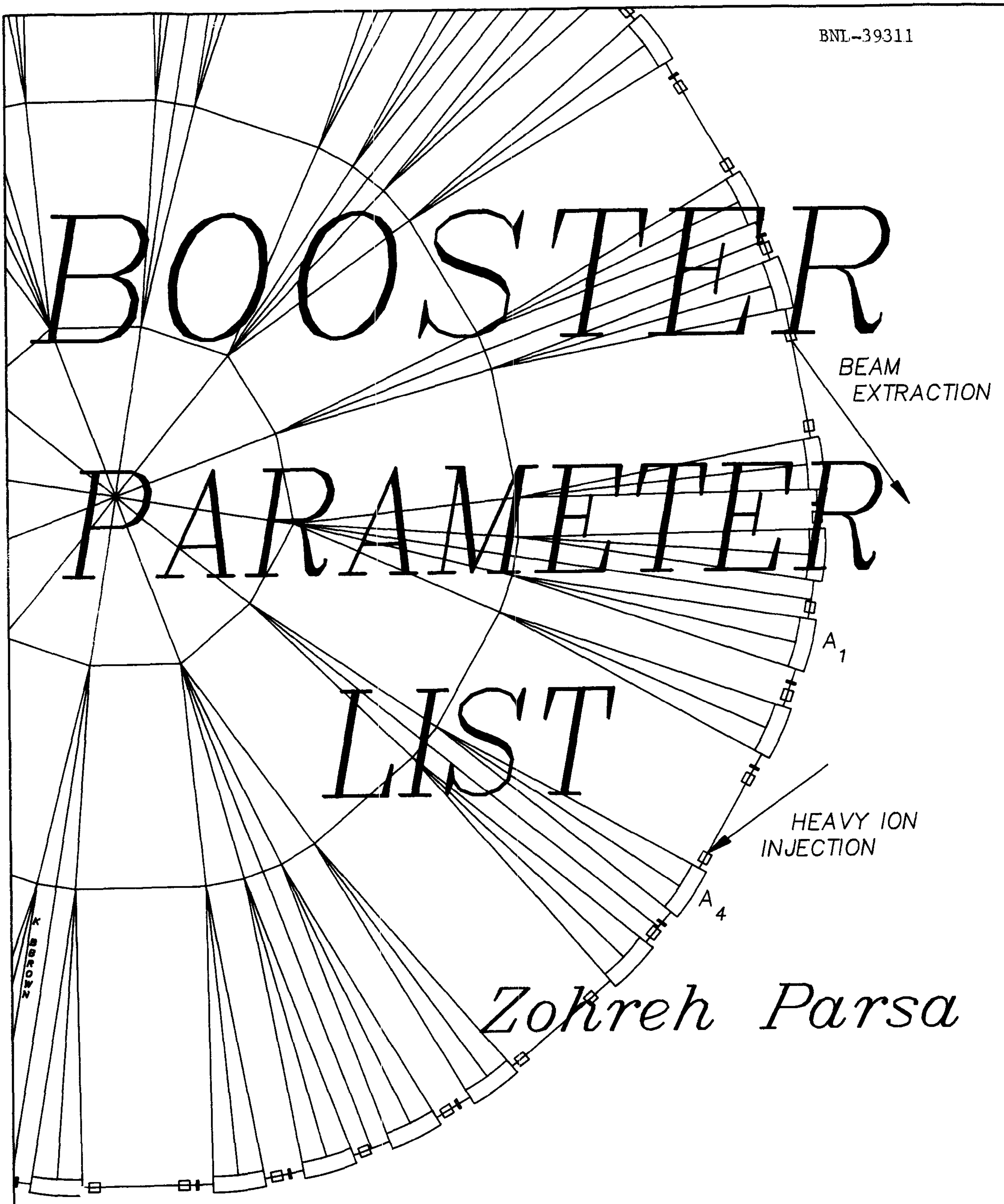
USDOE Office of Science (SC)

DISCLAIMER

BNL-39311

BOOSTER PARAMETER LIST

Zohreh Parsa



ACCELERATOR DEVELOPMENT DEPARTMENT
Brookhaven National Laboratory
Upton, N.Y. 11973

OCTOBER 1986

BOOSTER PARAMETER LIST

1. Introduction

The AGS Booster is designed to be an intermediate synchrotron injector for the AGS, capable of accelerating protons from 200 MeV, the linac operating energy, to 1.5 GeV, (with the possibility of an upgrade to 2.5 GeV), at a repetition rate of 7.5 Hz, and capable of accelerating heavy ions to a magnetic rigidity equal to 17.52 Tesla-meters at a 1 Hz repetition rate.

As presently designed, the Booster will have: A circumference equal to one quarter that of AGS; with six identical superperiods. It will have a FODO lattice with bending magnets missing in some cells in order to accommodate the space needed for RF acceleration, injection, ejection and abort system without otherwise interrupting the periodicity. The dipoles of the proposed lattice have an aperture of 3.25" x 10" and an injection field of about 1.6 kG (0.7 kG for heavy ions).

In total, the Booster will have 36 dipoles, each of 2.4 meter magnetic length, and 48 quadrupoles which have 0.50375 meter magnetic length. We have chosen a "separated function" structure with quadrupoles and zero-gradient dipoles. Furthermore, for maximum tuning versatility the dipoles and the quadrupoles will be independently powered.

This note describes the parameter list of the AGS-Booster. The chromaticity correction sextupole configuration is 1,2,4,7 and the eddy current sextupole strengths are taken to be 0.12 Tesla per meter square [4]. A schematic layout of the Booster lattice and its superperiods are also included [1,6,17]. The present values of the Booster parameters are tabulated below. (Note that, the values listed are for theoretical calculations.)

This new expanded format of the parameter list includes items (more detailed) that were not present in the previous lists. Some of these items will be completed as the information become available. For convenience, we have included additional Figures describing many aspects of the AGS - Booster. This updates the Booster Parameter List. Furthermore, these changes will be reflected in the Booster Design Manual [II].

A brief overview of the parameters is given in the AGS-Booster Parameter List Table (next page).

QUICK REFERENCE
AGS BOOSTER PARAMETER LIST

	Protons	Polarized Protons	Heavy Ions
Energy			
Injection	200 MeV	200 MeV	$>$ 1 MeV/nucleon
Ejection	1.5 GeV	1.5 GeV	$p = 5.25\ Q/A$ (GeV/c)/nucleon
No. of Particles/Pulse	$\sim 10^{12}$	1.5 - 3 $\times 10^{13}$	15 $\times 10^9$ (S), 3 $\times 10^9$ (Au)
Lattice			
Circumference		201.78 m (1/4 AGS)	
Magnetic bend radius		13.75099 m	
Periodicity		6	
Number of cells		24 FODO	
Cell length		8.4075 m	
Phase advance/cell		72.3°/72.45°	
ν_x/ν_y (nominal)		4.82/4.83	
β_y max/min		13.6/3.7 m	
x_p max		2.95 m	
transition γ		4.88	
RF System			
Number of stations	2	2	2
Harmonic number	3	3	3
Frequency range (MHz)	2.5 — 4.11	2.5 — 4.11	0.200 — 2.5
Peak RF voltage	90	90	17
Acceleration time (ms)	62	62	500
Reptition rate	7.5 Hz (4/AGS pulse)	1 Hz (1/AGS)	1 Hz (1/AGS)
Dipoles			
Number		36	
Length (magnetic)		2.4 m	
Gap		82.55 mm	
Vacuum chamber aperture		66 mm	
Good field region ($< 10^{-4}$)		16 $\times$ 6.6 cm	
Injection field (kG)	1.56	1.56	0.108 A/Q
Ejection field	5.46	5.46	12.74
Quadrupoles			
Number		48	
Length (magnetic)		50.375 cm	
Aperture		16.5 cm	
Vacuum chamber aperture		15.25 cm	
Injection pole tip field (kG)	1.02	1.02	0.068 A/Q
Ejection pole tipe filed (kG)	3.6	3.6	8.3
Field Quality 6/2		0.0	
All other harmonics		$< 10^{-4}$	
Chromaticity Sextupoles			
Number		2 $\times$ 12	
Length (magnetic)		10 cm	
Max. pole tip field (kG)		3.0	
Max. Vacuum Pressure		3 $\times 10^{-11}$ torr	

BOOSTER PARAMETER SUMMARY

type of machine	synchrotron for protons and heavy ions polarized proton accumulator
beam energy, max	

	p	d	C	S	Cu	I	Au	
	1.50	1.93	11.60	30.95	53.81	74.62	68.95	GeV
	1.500	0.963	0.967	0.967	0.854	0.588	0.350	GeV/nucleon

circumference	201.78 m (1/4 AGS)
straight-section use	RF, h=3, A6 and E6 RF, h=1, B3 and B6 heavy ion inj. kickers, A5 and F8 heavy ion inj. septum, A3 ejection kicker, F3 ejection septum, F6 absorber blocks, D3
bunch separation, no. of bunches	
no. of particles/pulse	protons, 1 — 3 $\times 10^{13}$ polarized protons, $\sim 10^{12}$

C	S	Cu	I	Au	
54	~15	~10	~6.6	~3.2	x 10^9 ions

beam current

p	p↑	d	C	S	Cu	I	Au	
								mA pk
								mA avg

beam energy, max

p	p↑	d	C	S	Cu	I	Au	
								kJ

transverse emittance, inj., (90% area/π)	50 mm-mrad
rms fractional energy spread, inj - ejec	bunched to 1.5 eV-s, protons bunched to 0.05 eV-s/nucleon, heavy ions
longitudinal emittance, inj - ejec (rms area/π)	
lattice, total no. of cells	FODO, 8.4075-m cells, 24
betatron tune, x,y	4.82, 4.83
β_x max, min	13.865/3.5754 m

β_y max, min	13.644/3.7033 m
horizontal dispersion, max, min	2.9515/0.5400 m
magnet type	iron-dominated, Cu conductor
magnetic field, dipole, ejec.	protons, 0.546 T; heavy ions, 1.274 T, max
magnetic radius of curvature	13.75099 m
magnetic gradient, quad, ejec.	Gf: protons, 1.20 T/m
	heavy ions, T/m
	Gd: protons −1.24 T/m
	heavy ions, T/m
dipole length (magnetic/physical)	2.4/2.34 m, excl. coils
quad length (magnetic/physical)	0.50375/0.472 m, excl. coils
number of dipole and quadrupole magnets	36 dipoles, 48 quads
dipole excitation current, max	protons, 2220 A
	heavy ions A
quad excitation current, max	protons, 2220
	heavy ions A
vacuum chamber, dimen.	70 × 152 mm, dipoles
	152.4 mm (circular), quads
RF: harmonic number	3
RF: frequency	

	p	d	C	S	Cu	I	Au	
inj.	2.523	0.788	0.562	0.446	0.349	0.265	0.213	MHz
ejec.	4.114	3.877	3.884	3.885	3.804	3.522	3.061	MHz

acceleration period — 62 ms, protons; 500 ms (max), heavy ions

energy gain per turn

p	d	C	S	Cu	I	Au	
							kV

peak RF voltage, total RF power

p	d	C	S	Cu	I	Au	
							kV
							kW

RF system length, per cavity system

rms bunch length, inj - ejec

	p	d	C	S	Cu	I	Au	
inj.								cm
ejec.								cm

synchrotron period, inj - ejec

	p	d	C	S	Cu	I	Au	
inj.								ms
ejec.								ms

Injector system — 200 MeV linac, protons; Tandem Van de Graaff, heavy ions

TABLE 1. Isotopes, Charge States, and Ionic Masses.

	Q	Z	A	Ionic Rest Mass (u)	Ionic Rest Mass Energy (GeV/nucleon)
p	+1	1	1	1.00728	0.93828
d	+1	1	2	2.01355	0.93781
C	+6	6	12	11.99671	0.93125
S	+14	16	32	31.96439	0.93047
Cu	+21	29	63	62.91808	0.93029
I	+29	53	127	126.88857	0.93068
Au	+33	79	197	196.94846	0.93126

TABLE 2. Injection Energies and Fields

	v/c	f	p	E_{inj}		B_{inj}
		(MHz)	(GeV/c)	(MeV)	(MeV/nucleon)	(kG)
p	0.5662	2.5235	0.6444	200.0	200.000	1.563
d	0.1767	0.7878	0.3368	30.0	15.000	0.817
C	0.1262	0.5623	1.4211	90.0	7.500	0.575
S	0.1000	0.4457	2.9925	150.0	4.688	0.519
Cu	0.0782	0.3485	4.5969	180.0	2.857	0.531
I	0.0595	0.2653	7.0489	210.0	1.654	0.590
Au	0.0478	0.2131	8.7805	210.0	1.066	0.645

TABLE 3. Ejection Energies and Fields — $B_{max} = 12.74$ kG

	v/c	f	p	E_{ejec}		B_{ejec}
		(MHz)	(GeV/c)	(GeV)	(GeV/nucleon)	(kG)
p	0.9230	4.114	2.251	1.500	1.5000	5.459
d	0.8699	3.877	3.308	1.927	0.9635	8.024
C	0.8714	3.884	19.847	11.602	0.9668	8.024
S	0.8716	3.885	52.926	30.952	0.9672	9.170
Cu	0.8534	3.804	95.932	53.810	0.8541	11.081
I	0.7900	3.522	152.345	74.623	0.5880	12.743
Au	0.6868	3.061	173.358	68.950	0.3500	12.743

2. Beam and Operational Parameters

injected particles — protons, polarized protons, heavy ions (through gold)

injection momenta

p	d	C	S	Cu	I	Au	
0.6444	0.3368	1.4211	2.9925	4.5969	7.0489	8.7805	GeV/c

$B\rho$, at injection

p	d	C	S	Cu	I	Au	
2.1496	1.1235	0.7901	0.7130	0.7302	0.8108	0.8875	T-m

output momenta

p	d	C	S	Cu	I	Au	
2.251	3.308	19.847	52.926	95.932	152.345	173.358	GeV/c

$B\rho$, at ejection

p	d	C	S	Cu	I	Au	
7.507	11.034	11.034	12.610	15.238	17.523	17.523	T-m

output kinetic energy

p	d	C	S	Cu	I	Au	
1.500	1.927	11.602	30.952	53.810	74.623	68.950	GeV
1.5000	0.9635	0.9668	0.9672	0.8541	0.5876	0.3500	GeV/nucleon

radio frequency

	p	d	C	S	Cu	I	Au	
inj.	2.523	0.788	0.562	0.446	0.349	0.265	0.213	MHz
ejec.	4.114	3.877	3.884	3.885	3.804	3.522	3.061	MHz

bunch spacing
  center to center
  free, between bunches
avg. beam current (at max energy)
no. of particles/pulse — protons, 1 - 3 $\times 10^{13}$; polarized protons, $\sim 10^{12}$

C	S	Cu	I	Au	
54	~15	~10	~6.6	~3.2	x 10^9 ions

bunches per pulse
rms bunch length, ejec.
beam energy

space-charge tune shift, inj.	~.7
acceleration time	62 ms, protons & polarized protons 500 ms (max.) heavy ions
repetition rate	7.5 Hz (4 pulses/AGS pulse), protons 1 Hz (1 pulse/AGS pulse), polarized protons 1 Hz (1 pulse/AGS pulse), heavy ions
peak RF voltage	90 kV, protons & polarized protons 17 kV, heavy ions
synchronous phase angle	30°, average
circumference	201.78 m (1/4 AGS)
avg. radius	32.114 m
magnetic bend radius	13.75099
magnetic field, dipole	

	p	d	C	S	Cu	I	Au	
inj.	0.1563	0.0817	0.0575	0.0519	0.0531	0.0590	0.0645	T
ejec.	0.5459	0.8024	0.8024	0.9170	1.1081	1.2743	1.2743	T

horiz. tune	4.82
vert. tune	4.83
transition γ	4.8812
natural chromaticity, horiz.	-4.92970
natural chromaticity, vert.	-5.26488
space-charge tune shift	
lattice type	separated function, FODO
superperiodicity	6
max β	14 m
max dispersion	3 m
no. of dipoles	36
dipole length	2.4 m (magnetic)
dipole field, max	1.2743 T
full good-field aperture, horiz.	152.4 mm
no. of standard quads	48
standard quad length	0.50375 m (magnetic)
standard quad strength, max	1.24 T/m
full good-field aperture	152.4 mm
no. of sextupoles	24 (12 SF + 12 SD)
no. of families	2
location	1,7 (SF), 2,4 (SD)
sextupole strength ($B'' L$)	

rms fractional energy spread, inj
rms fract. energy spread, ejec
long. emittance, inj., rms
long. emittance, ejec., rms

Note 1: rms longitudinal emittance = $\sigma_E \sigma_t$

3.
Lattice Parameters

circumference	201.78 m (1/4 AGS)
revolution time	

	p	d	C	S	Cu	I	Au	
inj.	1.1888	3.8082	5.3353	6.7307	8.6076	11.3061	14.0791	μs
ejec.	0.7292	0.7737	0.7724	0.7723	0.7887	0.8519	0.9800	μs

straight-sections (8 total)
- RF, h=3, A6 and E6
- RF, h=1, B3 and B6
- heavy ion inj. kickers, A5 and F8
- heavy ion inj. septum, A3
- ejection kicker, F3
- ejection septum, F6
- absorber blocks, D3

ring — 6 superperiods, 4 cells/superperiod

cell lattice

B CT SF QF | B CT SD QD | n CT QF | B CT SD QD | B CT QF | n CT QD | B CT SF QF | B CT QD

B	dipole bend magnets, horiz., 1.2743 T
CT	correction and trim coil assembly
SF, SD	sextupoles
QF, QD	quads
magnetic rigidity, ejec	7.507 T-m, protons & polarized protons
	17.523 T-m (max), heavy ions
magnetic radius	13.75099 m
lengths:	
superperiod	33.63 m
cell	8.4075 m
B	240 cm (magnetic)
CT	10 cm (magnetic)
SF, SD	10 cm (magnetic)
QF, QD	50.375 cm (magnetic)

Note 1: Component sequences are listed in the clockwise (CW) direction as seen from above.

Lattice Optics

phase shift per cell, x,y	72.3, 72.45 degrees
betatron tune, x,y	4.82, 4.83
tuning range, x,y	$\pm$ 1
transition γ	4.8812

natural chromaticity, x,y   -4.9297, -5.2649

zero-chrom. sext. $B'' L/B\rho$, F,D : F = 0.13607, D = -0.81060 m^{-2}
with eddy currents

4.1.
Ring Dipole Magnets

number of horiz. bends	36
magnetic field	1.2743 T, max
length, magnetic	2.40 m
length, plate to plate	2.34 m (center arc)
length, coil-end to coil-end	2.66 m (center arc)
gap	82.55 mm
inductance	3.2 mH
transfer function	0.2436 T/kA, injection
	0.2320 T/kA, ejection
current at ejection	2240 A, protons
	5490 A, heavy ions
mass	
aperture	152 × 70 mm
coil dimensions, pancake	266.1 × 26.8 × 9.46 cm
turns per pole	8 (4 × 2 pancakes)
conductor dimensions	25.4 × 50.8 mm
conductor length	
insulation thickness	
iron lamination dimensions	76.2 × 59.7 cm
lamination material	
lamination thickness	0.6 mm — 1.0 mm
weight of iron	

4.2.
Ring Quadrupole Magnets

number of quads	48
B'	+1.2000 T/m, focusing
	–1.2369 T/m, defocusing
$B' B\rho$	
length, magnetic	50.375 cm
length, plate to plate	47.2 cm
length, coil end to coil end	66.1 cm
inductance	350 μH
transfer function	T/m per kA, inj.
	T/m per kA, ejec.
current at ejec	2240 A, protons
	5490 A, heavy ions
mass	
aperture	152.4 mm (circular)
pole tip radius	82.55 mm
pole tip field	

	p	d	C	S	Cu	I	Au	
inj., f	0.0990							T
inj., d	0.1020							T
ejec., f	0.3457					0.8071	0.8701	T
ejec., d	0.3564					0.8308	0.8308	T

coil dimensions	26.76 × 66.07 × 9.46 cm
turns per pole	5
conductor length	
conductor mass	
maximum field	
conductor dimensions	31.75 × 31.75 cm
quadrupole width, max	59.1 cm
iron lamination dimensions	
lamination material	
lamination thickness	0.6 — 1.0 mm
iron weight	

4.3.
Ring Sextupole Magnets

number of sextupoles	24 (12 SF + 12 SD)
number of families	2
location	1,7 (SF), 2,4 (SD)
sextupole strength ($B''L$)	
B''	+ T/m^2, focusing
	– T/m^2, defocusing
$B''B$	
length, magnetic	cm
length, plate to plate	10.0 cm
length, coil end to coil end	$\sim$ 20 cm
inductance	μH
transfer function, at inj	T/m^2-kA
current at ejec	A, protons
	A, heavy ions
mass	
aperture	152.4 mm (circular)
pole tip radius	mm
pole tip field, mag.	3.0 kG

	p	d	C	S	Cu	I	Au	
inj., f	0.04576							T
inj., d								T
ejec., f								T
ejec., d								T

coil dimensions	× × cm
turns per pole	
conductor length	
conductor mass	
maximum field	
inter-coil insulation thickness	
conductor dimensions	× cm
sextupole width, max	
iron lamination dimensions	
lamination material	
lamination thickness	0.6 — 1.0 mm
iron weight	

4.4.
Correction and Trim Magnets

Special Devices/Correction and Trim Coil Assembly

assembly length (CT)	10 cm

Assembly Complements:

Primary Package:

Element	*Inner Radius*	*Outer Radius*	*Turns/ Pole*	*Induct.*	*BL (1 cm) (100 A)*
dipole	mm	mm		H	T-m
sextupole					
quadrupole					

In various Secondary Packages:
quadrupole
skew shell
normal shell
sextupole
octupole

Note 1: zero-chromaticity sext. strengths ($B'' L/B\rho$) SF, SD = + . /– . m^{-2}

4.5.
Injection Magnets

H^- Injection Line

<u>External</u>	
Injection Dipoles (Horizontal-Bend)	
number	8 main bending dipoles
magnetic field	0.901 T (8 main dipoles)
length, magnetic	0.600 m
Injection Trim Magnets	
number	2 horiz. trim dipoles 2 vert. trim dipoles
magnetic field	200 G-m
length, magnetic	
length, slot	
Injection Quads	
number	6
magnetic field	0.224 T/m, max
length, magnetic	0.30 m
<u>In ring</u>	
Injection kicker magnets	
type	
field strength	
magnet gap	
eff. length of module	
total length of module	
bend angle, direction	
rise time	
flat top	
fall time	
voltage	
current	
flat top uniformity	
no. of modules	
Injection slow orbit-bump magnets	
number	3

Heavy Ion Injection Line

External

Injection Dipoles (Horizontal-Bend)

number	14 main bending dipoles
magnetic field	
length, magnetic	

Injection Pitching and Steering Magnets

number	
number	4 pitching dipoles 2 steering dipoles
magnetic field	
length, magnetic	

Injection Quads

number	26
magnetic field	
length, magnetic	

In ring

Injection kicker magnets

type	
field strength	
magnet gap	
eff. length of module	
total length of module	
bend angle, direction	
rise time	
flat top	
fall time	
voltage	
current	
flat top uniformity	
no. of modules	

Injection slow orbit-bump magnets

number	3

4.6.
Ejection Magnets

External

Ejection Dipoles (Horizontal-Bend)	
number	3 combined-function dipoles
Ejection Vertical-Bend Magnets	
number	
magnetic field	
length, magnetic	
length, slot	
Ejection Quads	
number	12
magnetic field	
length, magnetic	0.50 m

In ring

Ejection kicker magnets	
type	
field strength	
magnet gap	
eff. length of module	
total length of module	
bend angle, direction	
rise time	
flat top	
fall time	
voltage	
current	
flat top uniformity	
no. of modules	
Ejection septum magnet	
Ejection slow orbit-bump magnets	
number	4

4.7.
Magnet Errors

DIPOLE ERRORS

a_n and b_n are the skew & regular coefficients of the 2(n+1) pole.

Units are 10^{-4} of dipole field at 1 cm.

Calculated Systematic Errors

	b_2	b_4	b_6	b_8	b_{10}	b_{12}	b_{14}
Geometric, at inj							
Geometric, ejec							

Calculated Random Errors

	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
rms-geom											

	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
rms-geom											

QUADRUPOLE ERRORS

Units are 10^{-4} of the quadrupole field at 1 cm.

Calculated Systematic Errors

	b_5	b_9	b_{13}	b_{17}
geometric				

Calculated Random Errors

	a_1	a_2	a_3	a_4	a_5	a_6
geometric, skew						

	b_1	b_2	b_3	b_4	b_5	b_6
geometric, regular						

Magnet Alignment and Uniformity Tolerances

Dipole
Δx-rms
pitch
roll
Δy-rms
$\Delta \phi$-rms
$\Delta(BL)/BL$, rms

Quad
Δx-rms
pitch
roll
Δy-rms
$\Delta \phi$-rms
$\Delta(B'L)/B'L$, rms

Correction and Trim Assembly
Δx-rms
Δy-rms
$\Delta \phi$-rms

Beam-position monitor relative to quad
Δx-rms
Δy-rms

5.
Vacuum System

beam tube lengths	
shaped, in dipole	
circular	
beam-tube material	
beam-tube dimensions	
shaped, in dipole	
circular	
beam-tube conductance	
pressure required, avg.	3×10^{-11} torr, avg.
normal pumping	
ion pumps	
isolation valves	
roughing	
flanges and bellows	
pumpdown hand valves	
bake-out temperature	
beam-tube insulation	
pump-down time	

6.
Main Power Supply

current, ejec
current regulation
inductance, ring dipoles
stored energy, ring dipoles
inductance, ring quadrupoles
stored energy, ring quadrupoles
voltage during ramp
voltage during de-ramp

7.
Tuning and Correction Power Supplies

	BL (I_{max}) (T-m, 1 cm)	*Range (T-m)*	*Tolerance (T-m)*	*No. of Families*	*No. Elements/ Family*
primary package					
dipole, H,V					
quad, QF, QD					
sext, SF,SD					
secondary packages					
quad, Q1,—,Q4					
skew quad, SQ1,—,SQ4					
sextupole, S1,—,S4					
skew sext.,SS1,—,SS4					
octupole, O1,—,O4					
skew octupole, SO1					
tuning power supplies					

correction element supplies

	BL (I_{max}) (T-m, 1 cm)	*Range (T-m)*	*Tolerance (T-m)*	*No. Families*	*No. Elements/ Family*
primary package					
dipole, H,V					
quad, QF, QD					
sext, SF,SD					
special packages					
dipoles, H					
dipoles, V					
dipoles, H & V					
skew quad, SQ					

8.
Radio Frequency Acceleration System

radio frequency

	p	d	C	S	Cu	I	Au	
inj.	2.523	0.788	0.562	0.446	0.349	0.265	0.213	MHz
ejec.	4.114	3.877	3.884	3.885	3.804	3.522	3.061	MHz

revolution time

	p	d	C	S	Cu	I	Au	
inj.	1.1888	3.8082	5.3353	6.7307	8.6076	11.3061	14.0791	μs
ejec.	0.7292	0.7737	0.7724	0.7723	0.7887	0.8519	0.9800	μs

harmonic	3
acceleration time	62 ms, protons 500 ms, heavy ions
repetition rate	7.5 Hz (4 pulses/AGS pulse), protons 1 Hz (1 pulse/AGS pulse), polarized protons 1 Hz (1 pulse/AGS pulse), heavy ions
energy gain	
no. of stations	4 total 2 for protons 2 for heavy ions
vacuum aperture	

	Inj		Ejec		
	protons	hvy ions	protons	hvy ions	
peak voltage	90	17	90	17	kV
synchronous phase					
long. emitt.					eV-s
bucket/bunch area ratio					
bucket half height, $\Delta E/E$					x 10^{-4}
energy spread (σ_E/E)					x 10^{-4}
rms bunch length					cm
synch. tune (f_s/f_o)					x 10^{-3}
total RF power					kW

9. Booster Injection System

Transfer line from linac

length (from __ to __)

magnet sequence

dipole parameters

field

bend angle

length, effective

magnet gap

current

resistance

current regulation

number

quadrupole parameters

gradient

length, effective

pole-tip diameter

current

resistance

number

vacuum required

Proton injection fast-kicker magnets

number

type

field strength

magnet gap

eff. length of module

total length of module

bend angle, direction

rise time

flat top

fall time

voltage
current
flat top uniformity

Proton injection slow orbit-bump magnets

number
type
field strength
bend angle, direction
rise time
flat top
fall time
voltage
current
flat top uniformity

Transfer line from tandem

length (from __ to __)

magnet sequence

dipole parameters

- field
- bend angle
- length, effective
- magnet gap
- current
- resistance
- current regulation
- number

quadrupole parameters

- gradient
- length, effective
- pole-tip diameter
- current
- resistance
- number

vacuum required

Heavy-ion injection fast-kicker magnets

number
type
field strength
magnet gap
eff. length of module
total length of module
bend angle, direction
rise time
flat top
fall time
voltage
current
flat top uniformity

Heavy-ion injection electrostatic septum

number
type
electric field strength
electrostatic gap
eff. length of module
total length of module
deflection angle, direction
rise time
flat top
fall time
voltage
flat top uniformity

Heavy-ion injection slow orbit-bump magnets

number
type
field strength
bend angle, direction
rise time
flat top
fall time
voltage
current
flat top uniformity

10. Booster Ejection System

Transfer line to AGS

length (from __ to __)

magnet sequence

dipole parameters
- field
- bend angle
- length, effective
- magnet gap
- current
- resistance
- current regulation
- septum thickness, eff.
- number

quadrupole parameters
- gradient
- length, effective
- pole-tip diameter
- current
- resistance
- number

stripper

vacuum required

Ejection fast-kicker magnets

number

type

field strength

magnet gap

eff. length of module

total length of module

bend angle, direction

rise time
flat top
fall time
voltage
current
flat top uniformity

Ejection septum magnet
number
type
field strength
magnet gap
eff. length of module
total length of module
bend angle, direction
rise time
flat top
fall time
current
voltage
flat top uniformity

Ejection slow orbit-bump magnets
number
type
field strength
bend angle, direction
rise time
flat top
fall time
voltage
current
flat top uniformity

11. Abort Systems

Absorber Blocks

location

absorber block section

- beam energy into absorber blocks
- material
- dimensions
- max temp. rise

Beam Dump System

location

component sequence

kicker magnets

- type
- field strength
- length, effective
- no. modules
- wave shape
- rise time
- characteristic period
- duration
- peak current
- voltage

beam dump

- beam energy into dump
- material
- dimensions
- max temp. rise

12. Instrumentation

Beam-Monitoring System

beam-position monitors

resolution at 10^8 protons/bunch

resolution at 10^8 protons/bunch

resolution at 10^{10} protons/bunch

length

number, x an y

mechanical position accuracy

beam-loss monitors

sensitivity

number

dynamic range

Schottky pickup station

beam-motion sensitivity

number of stations per ring

beam-profile monitors

wire

wire speed

number per ring

resolution

beam-current monitors

sensitivity

resolution

number per ring

Feedback System

transverse instability damping system

operating frequency

length of 50-ohm terminated strip line

system bandwidth

total power

number of systems, per ring

13. Control System

Computer System

host computer characteristics:
- CPU's
- RAM
- disk storage
- magnetic tape
- high speed bus
- communication
- no. terminals
- floor space
- ac power

Booster Ring Communication Links:
- cable bandwidth

- cable assignments

(Fiber-optic links probably cannot be used in the tunnel because of their vulnerability to radiation damage.)

Control and Monitor Points

beam position monitors
beam loss monitors
beam profile

vacuum pump status and current
vacuum gauge current
gate valves

PS voltage taps
dipole corrector status,
  readback, and reference
other correctors
energy dumps
miscellaneous
  tunnel environment

  totals

14. Conventional Facilities

tunnel	
type	helical (corrugated) steel pipe
length	675 feet
mean radius, from Booster center	107.5 feet
cross-section	diameter, 10 feet
	height from concrete floor, 8 feet at center
shielding	
power supply stations, no.	
area	
RF station alcoves, number	
area	
height	

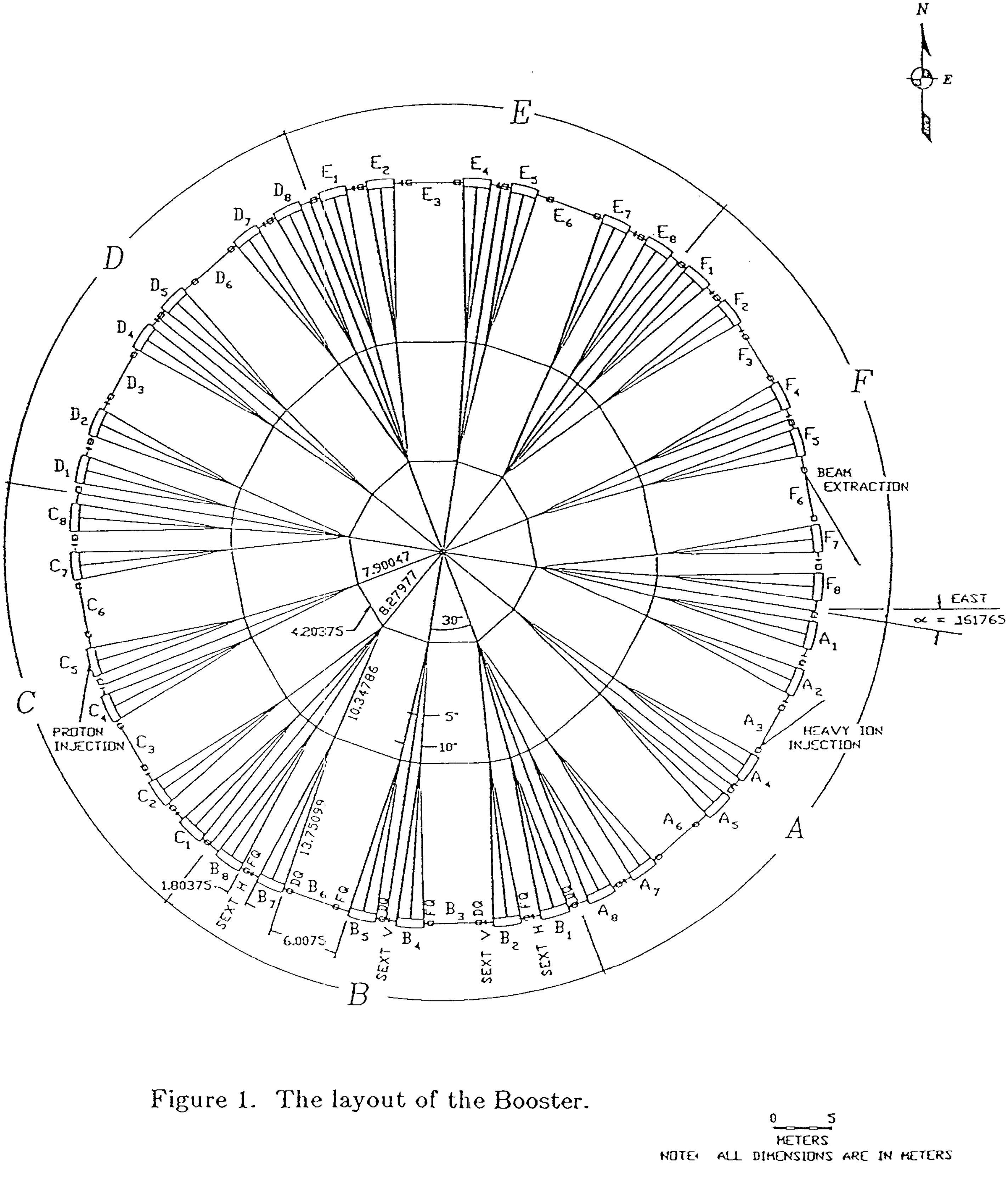


Figure 1. The layout of the Booster.

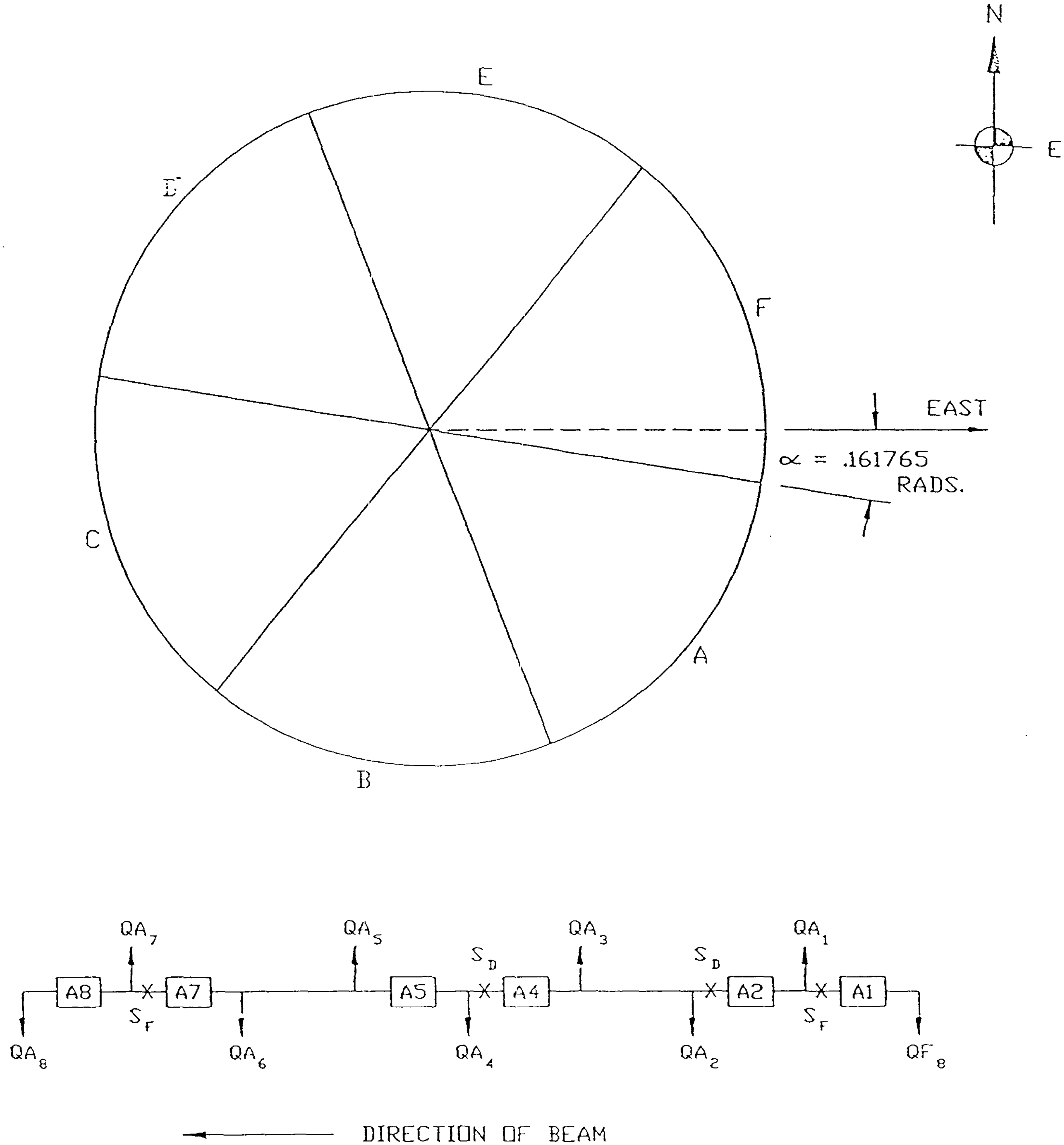
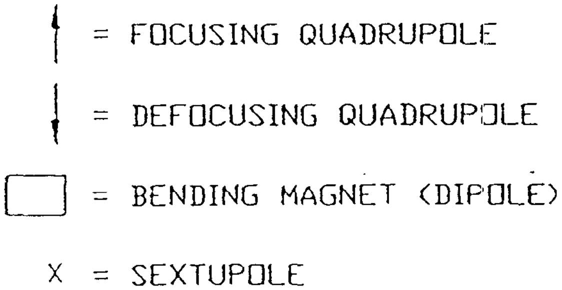


Figure 2. The booster lattice and components of a superperiod.



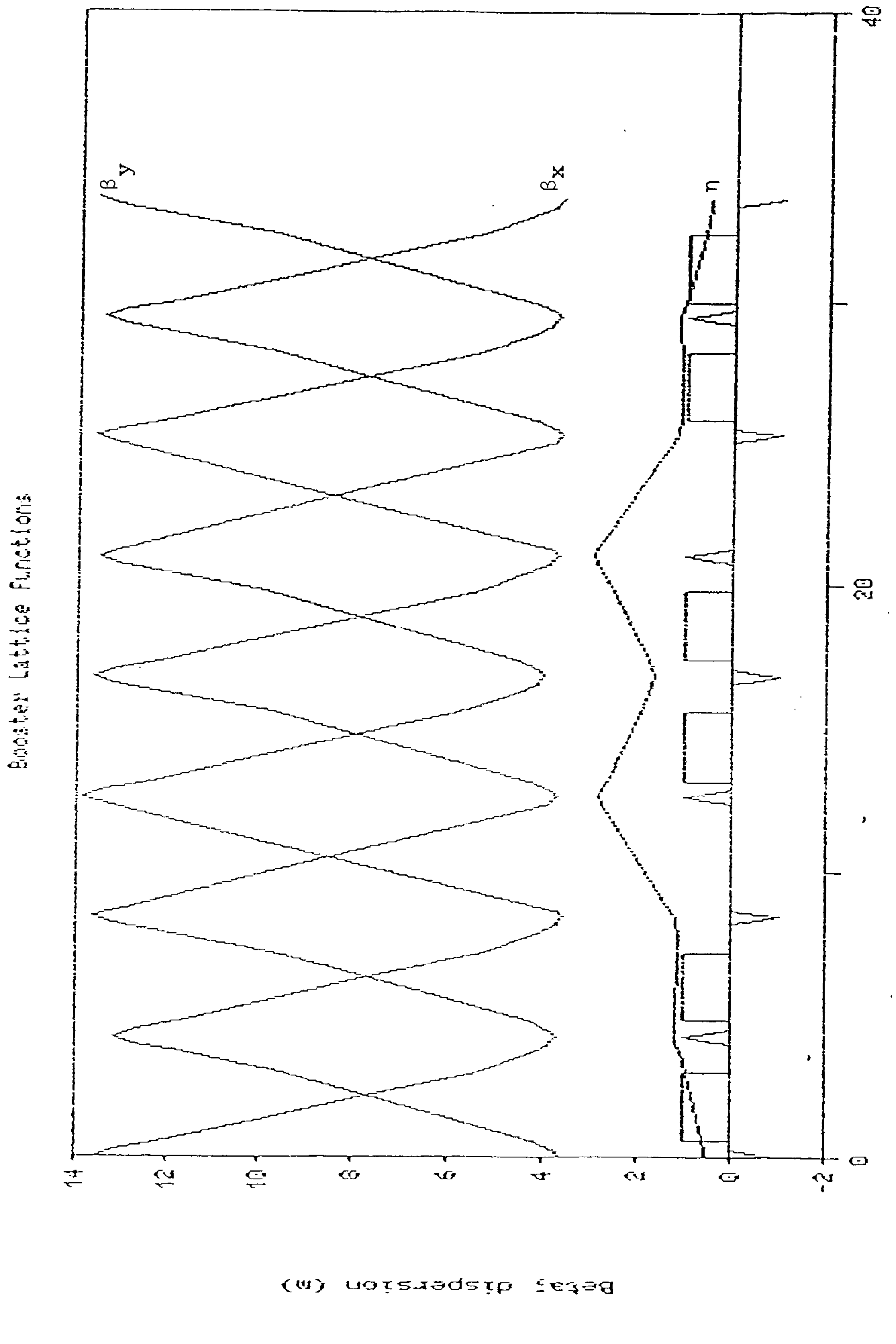


Figure 3. Amplitude and dispersion functions for the Booster lattice.

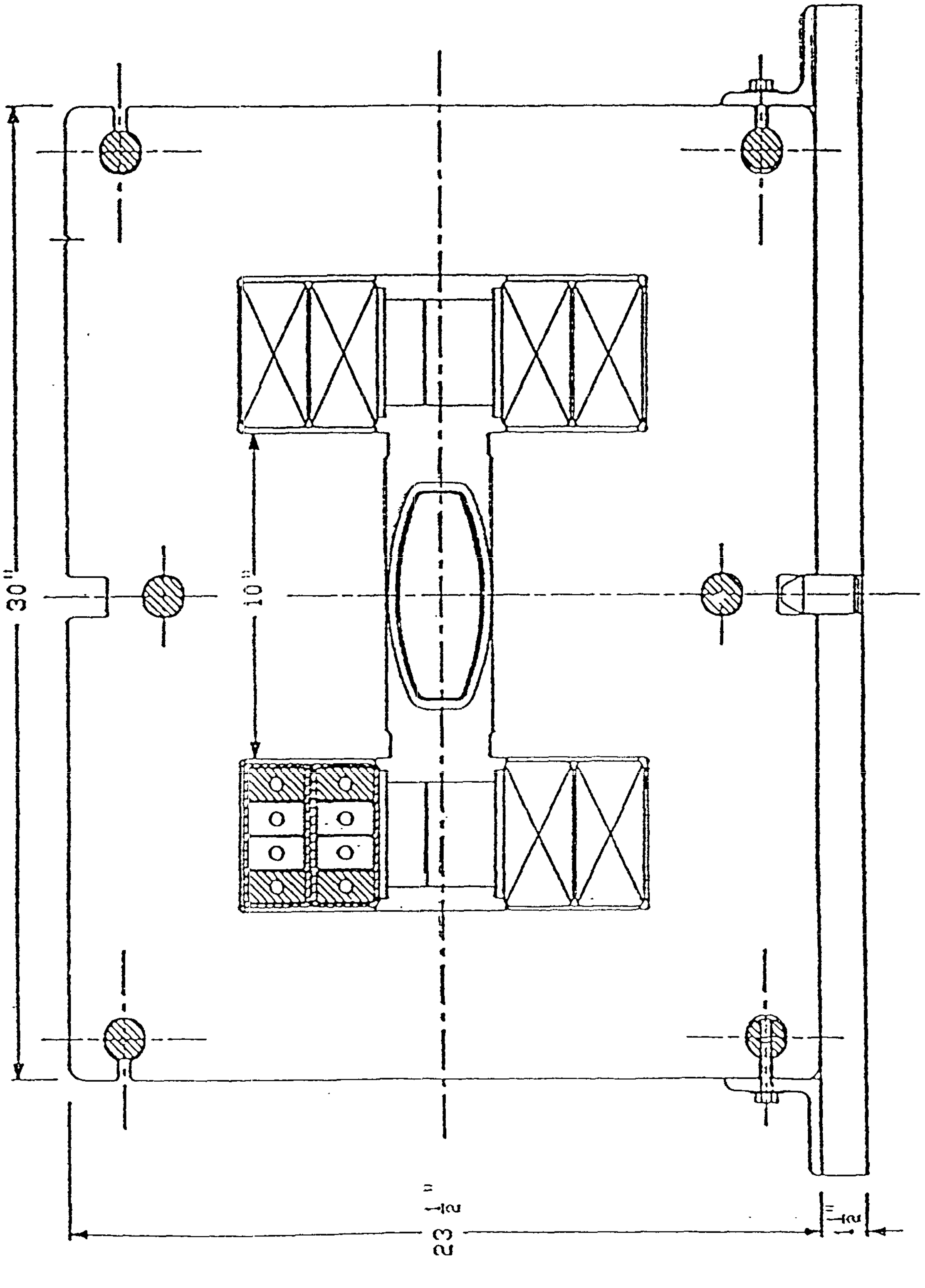


Figure 4. Dipole magnet, cross-section.

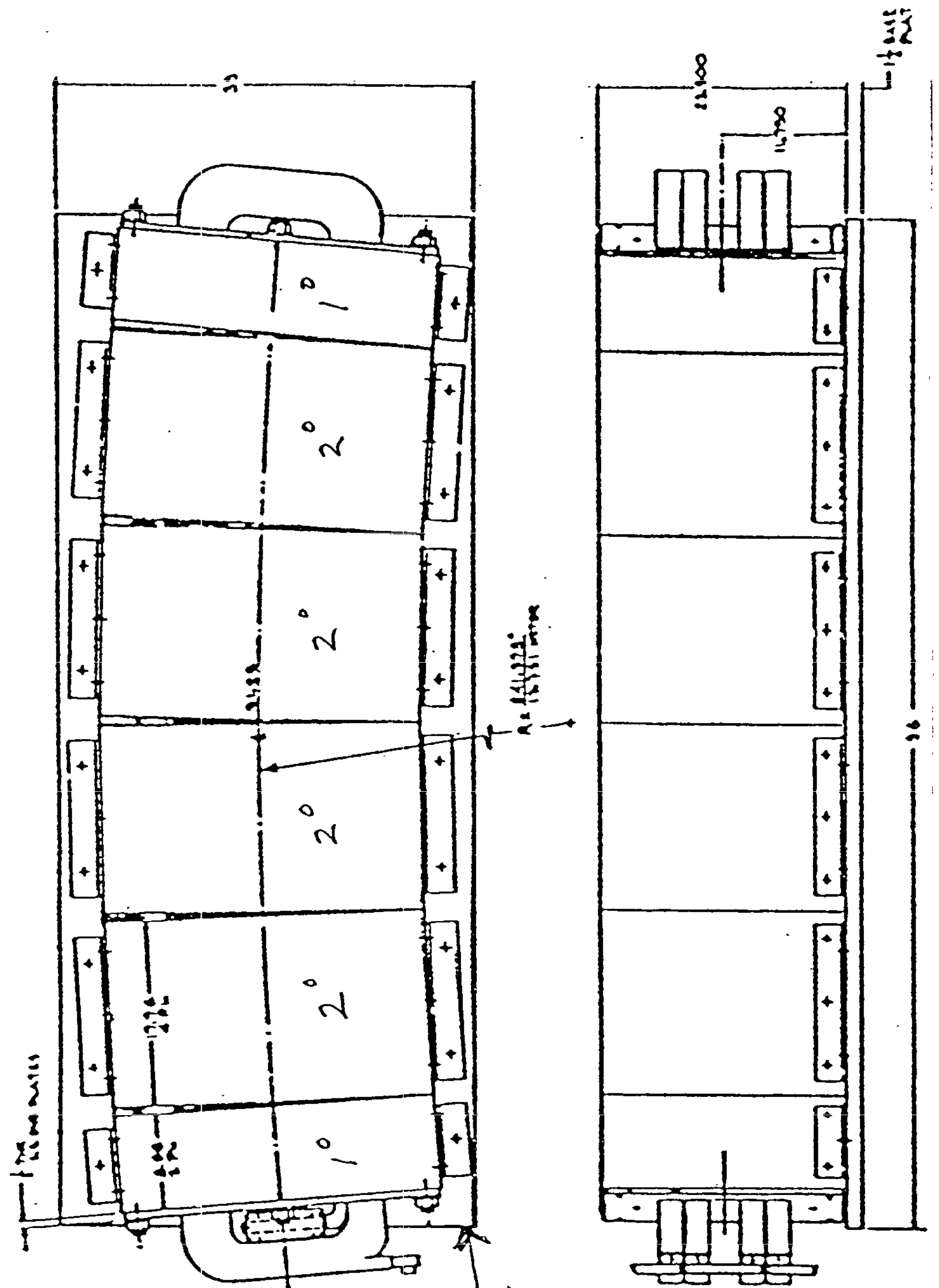


Figure 5. Dipole magnet, top view.

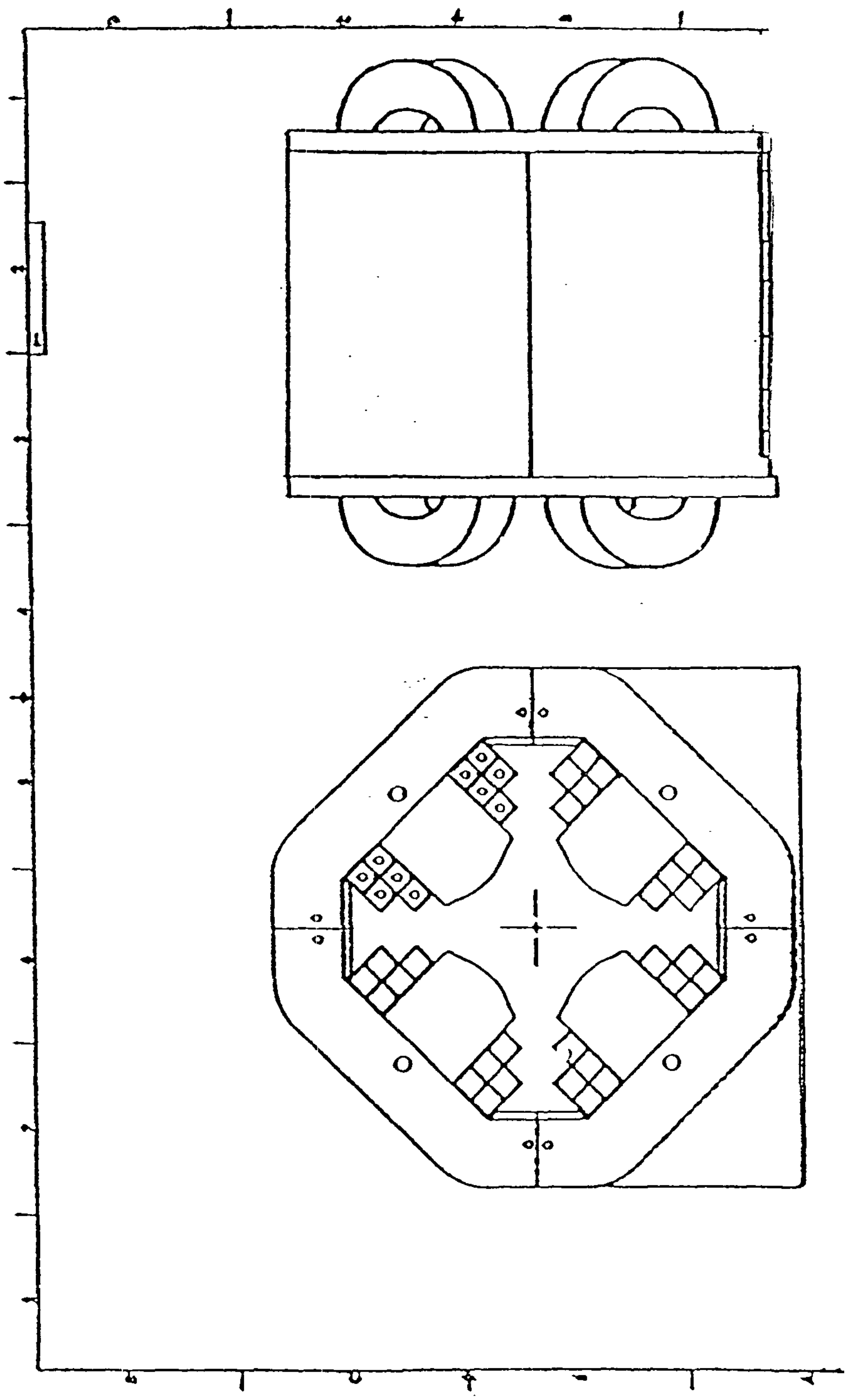


Figure 6. Quadrupole magnet.

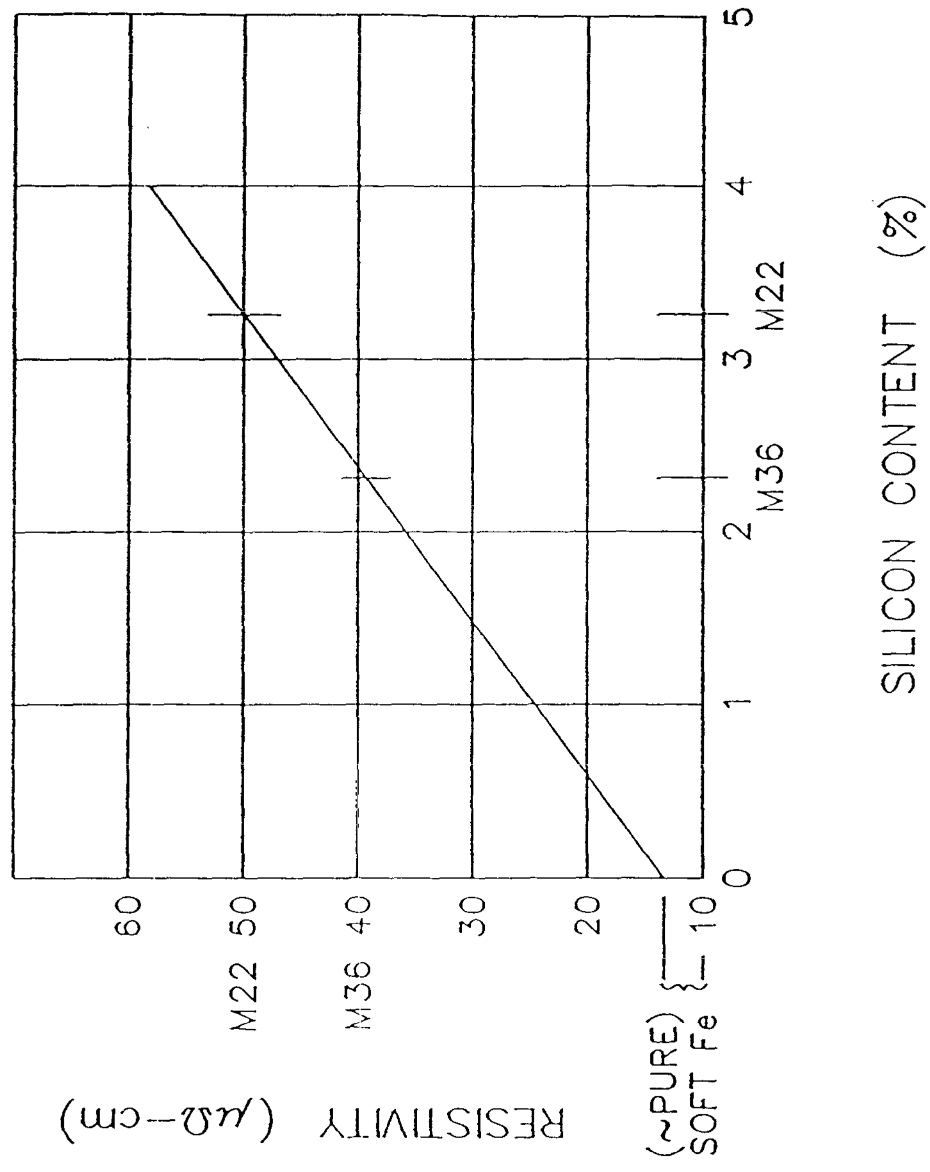


Figure 7. The effect of silicon content on the resistivity of the lamination steel.

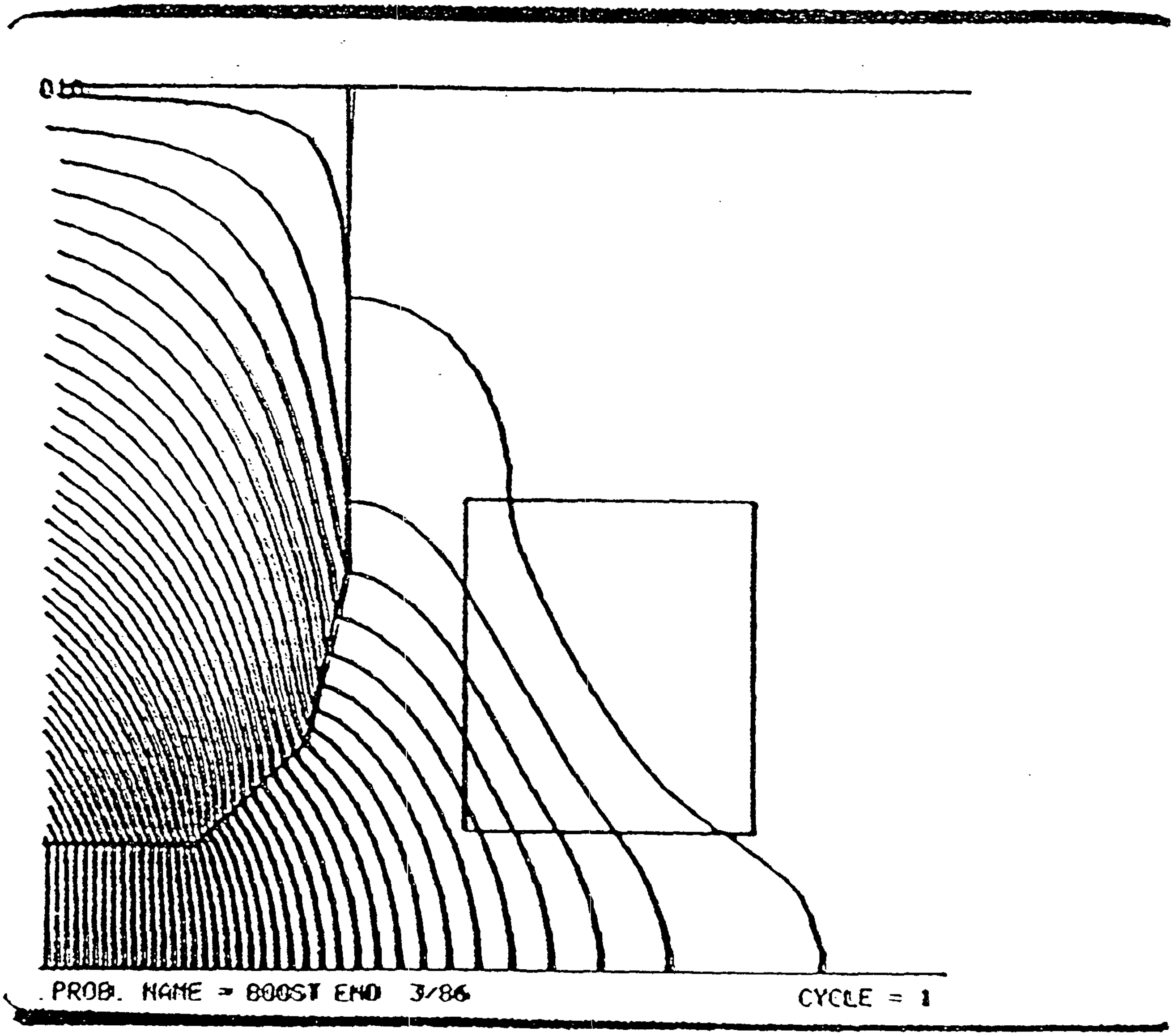


Figure 8. Beveled ends to ameliorate end effects.

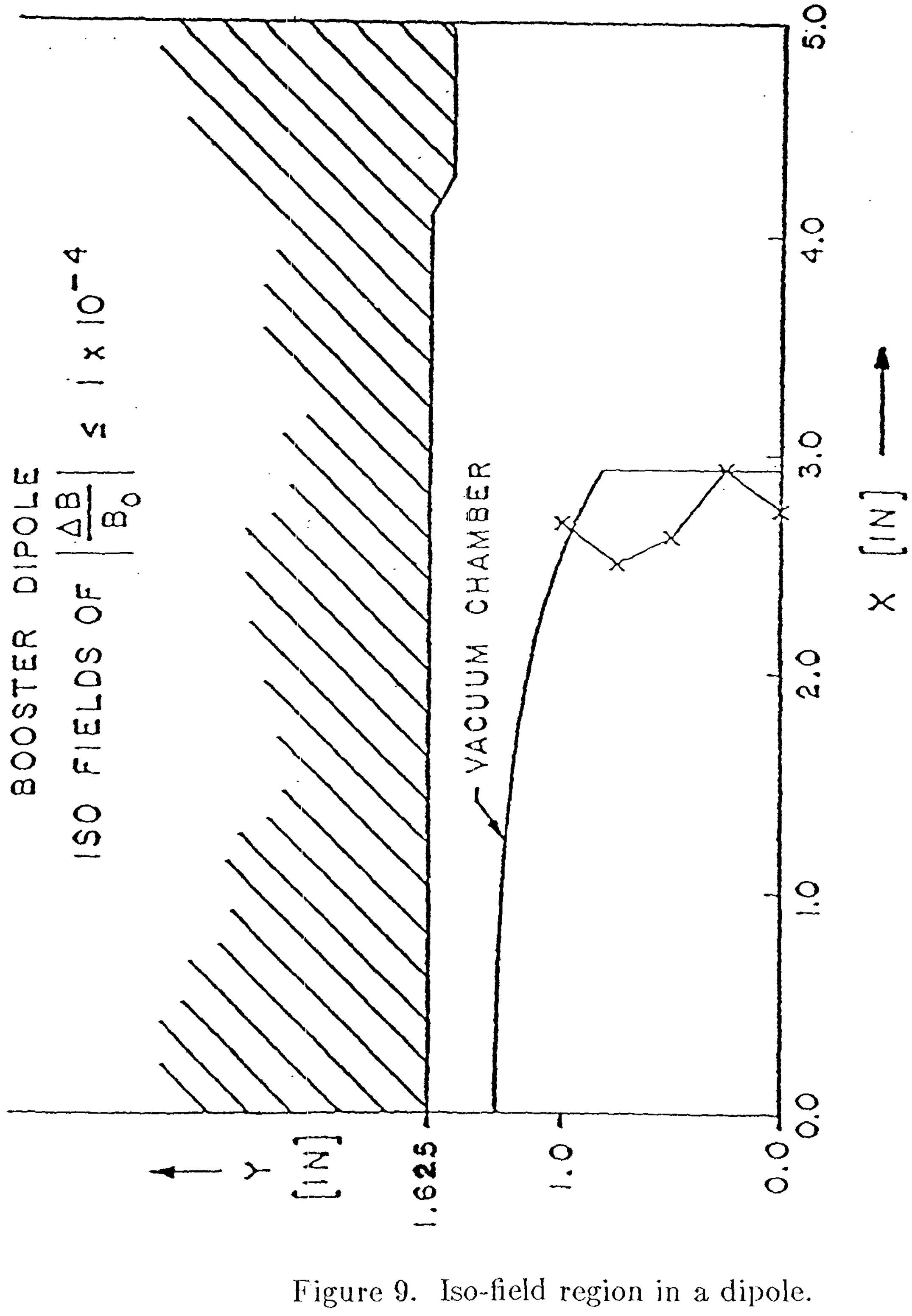


Figure 9. Iso-field region in a dipole.

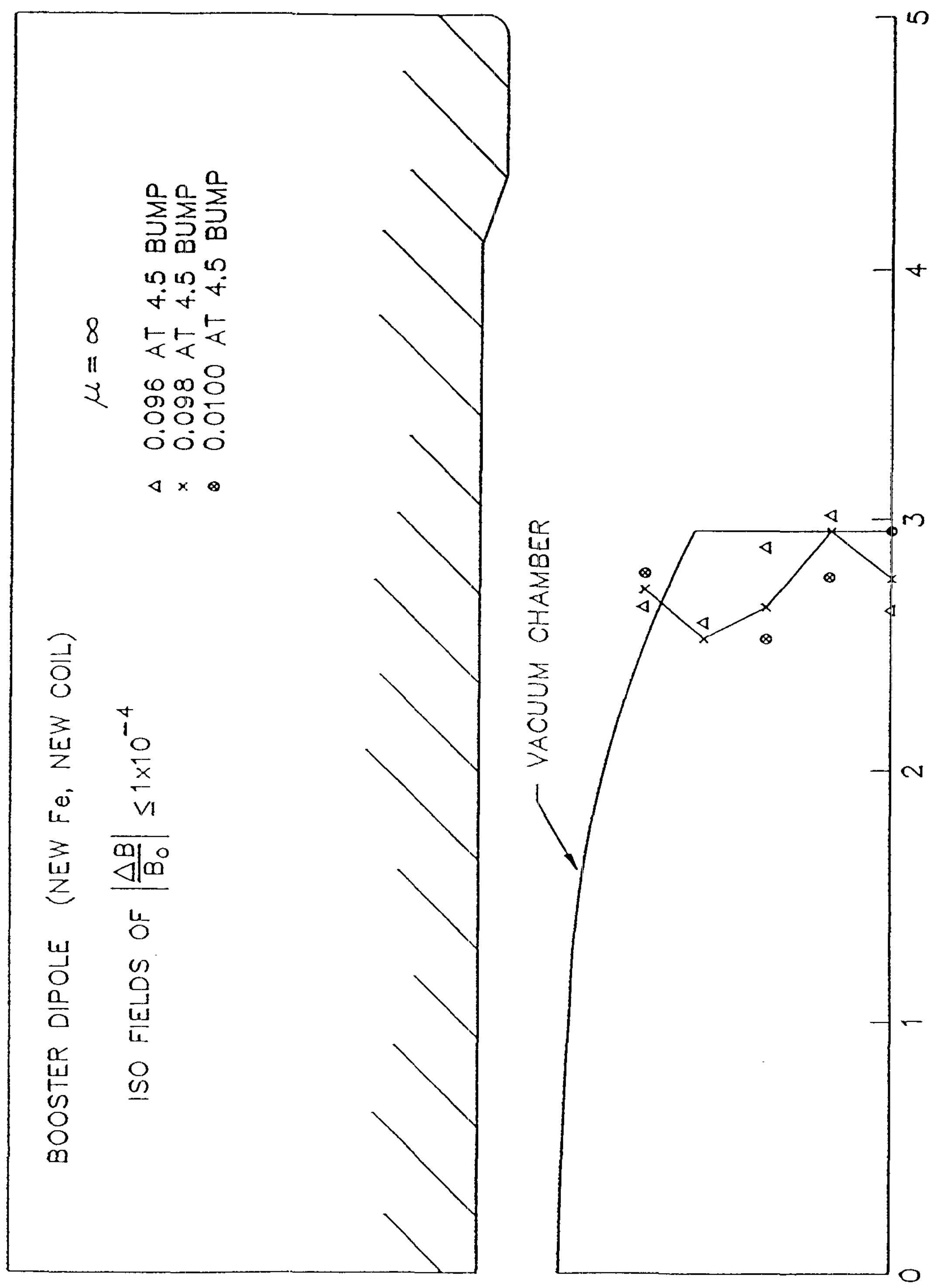


Figure 10. Movement of the iso-field boundary for 2-mil error in bump height.

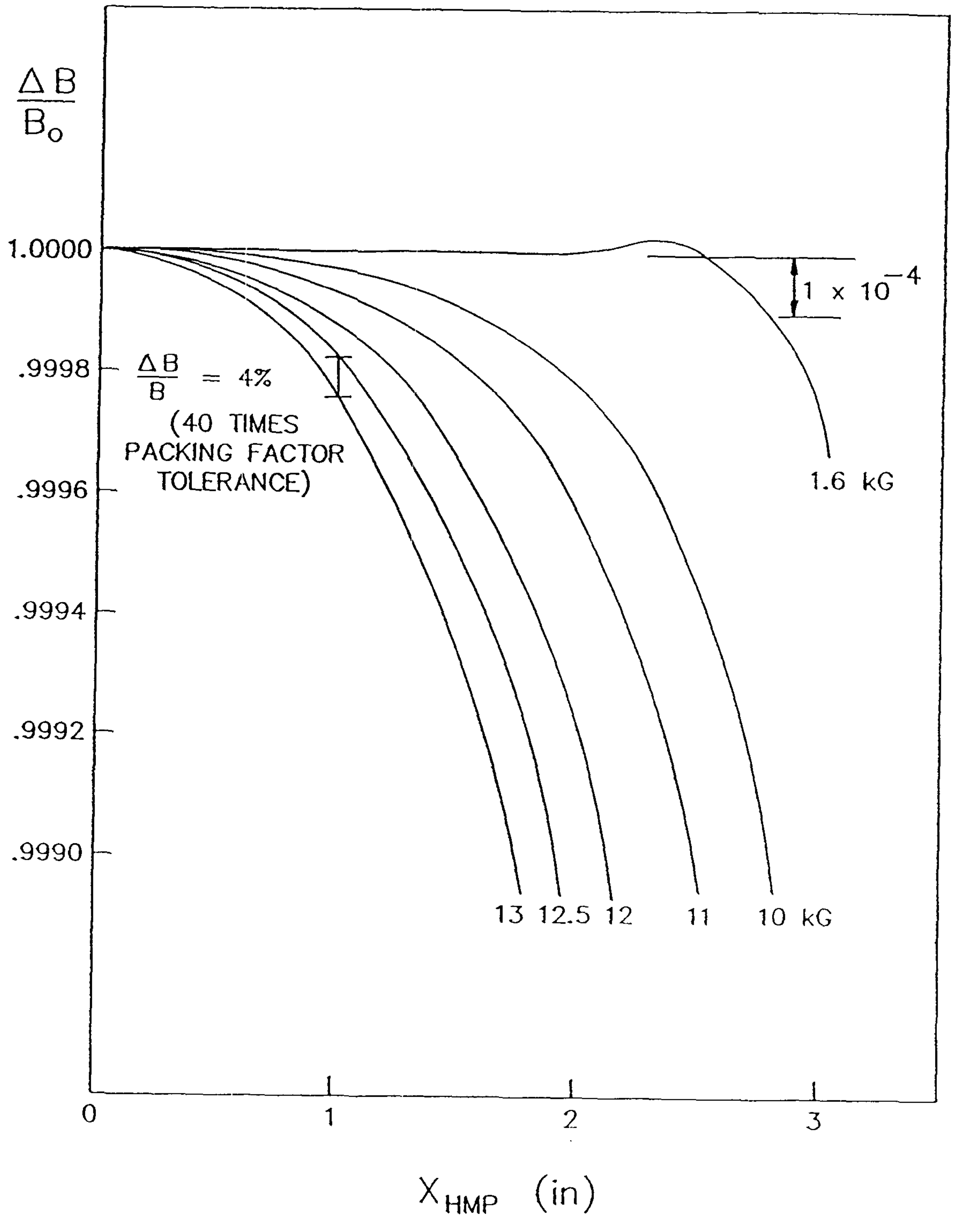


Figure 11. Shrinkage of good field region with increase in B.

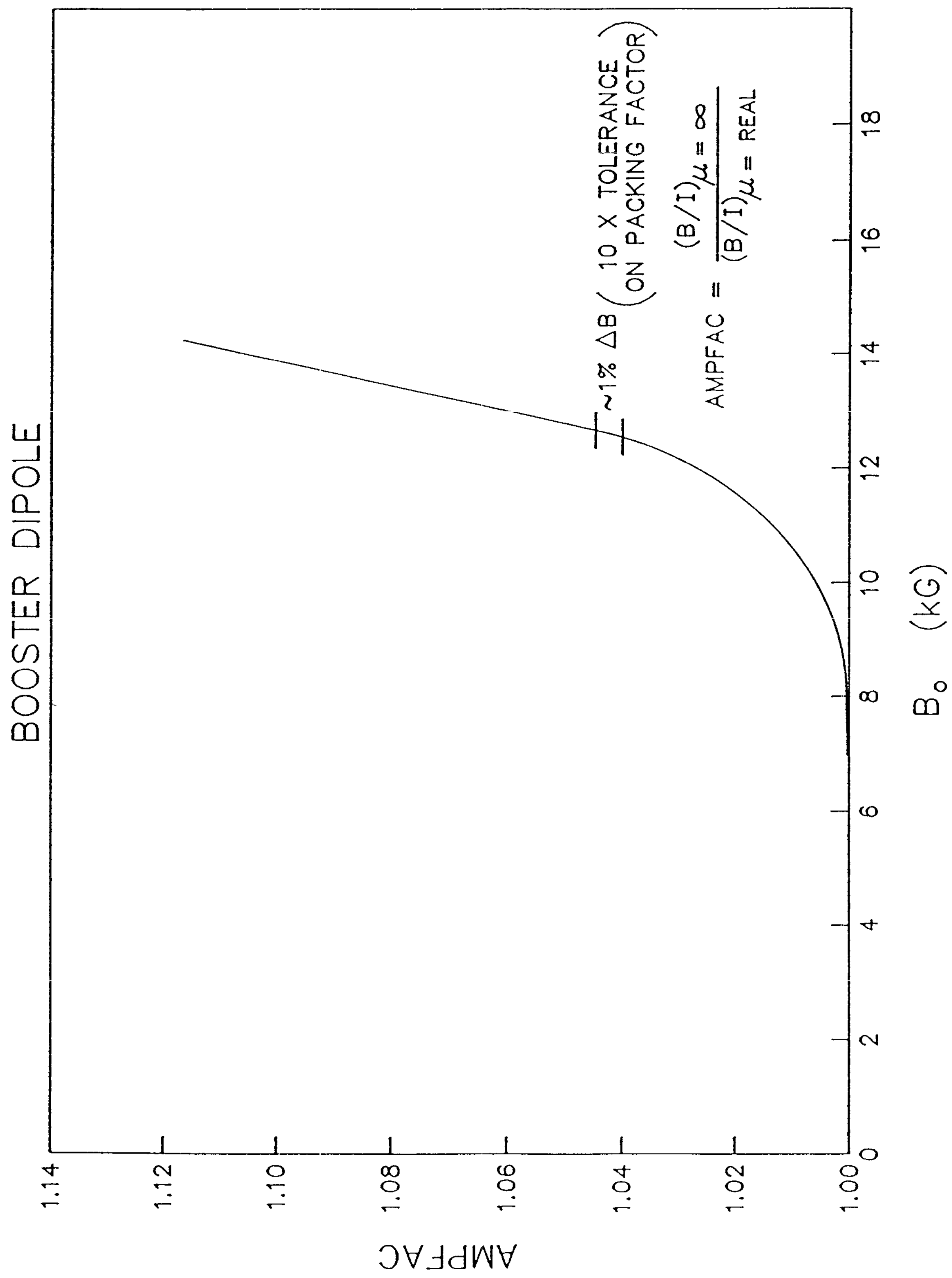


Figure 12. Saturation effects on field linearity.

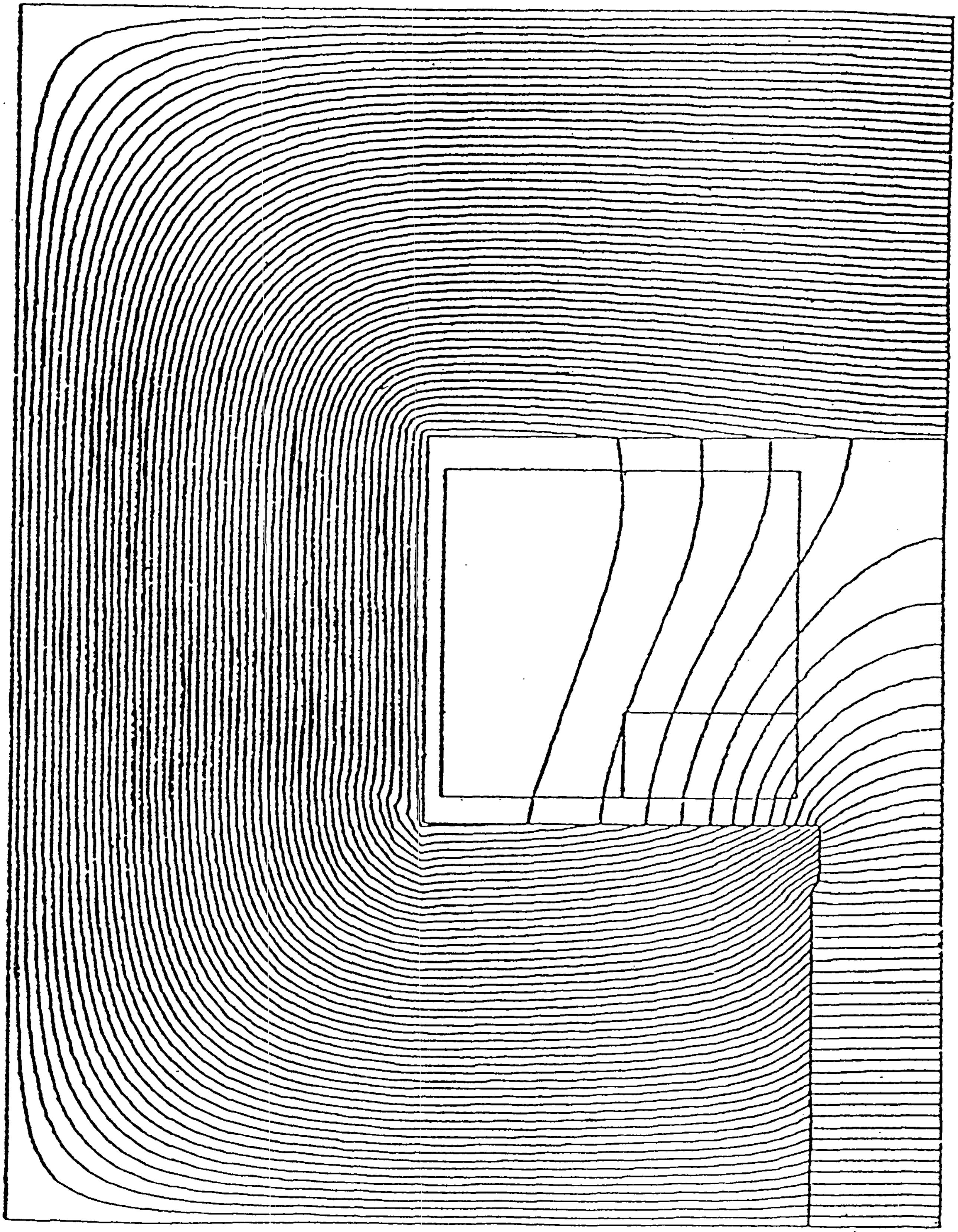


Figure 13. Flux pattern in the region of the coil.

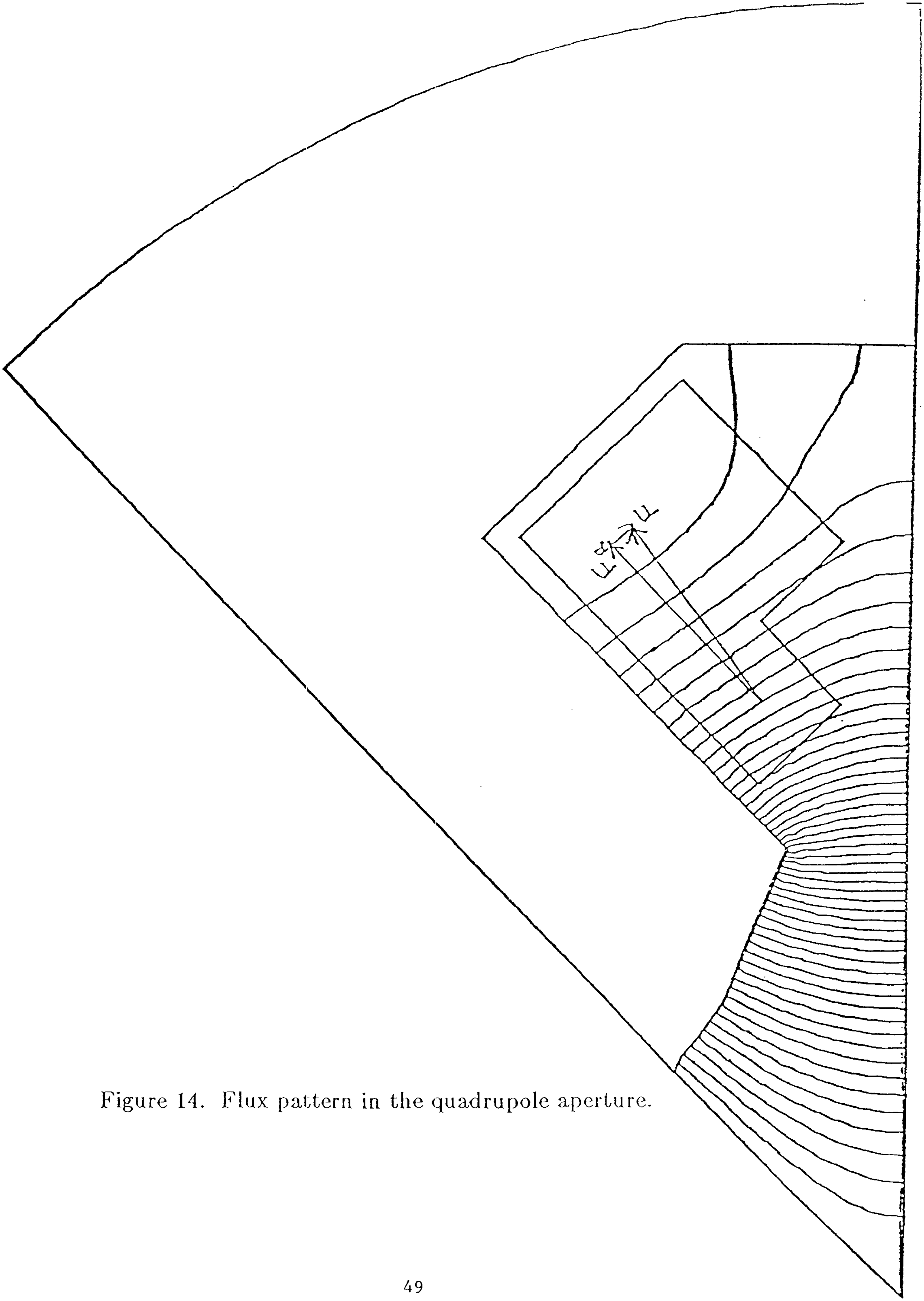


Figure 14. Flux pattern in the quadrupole aperture.

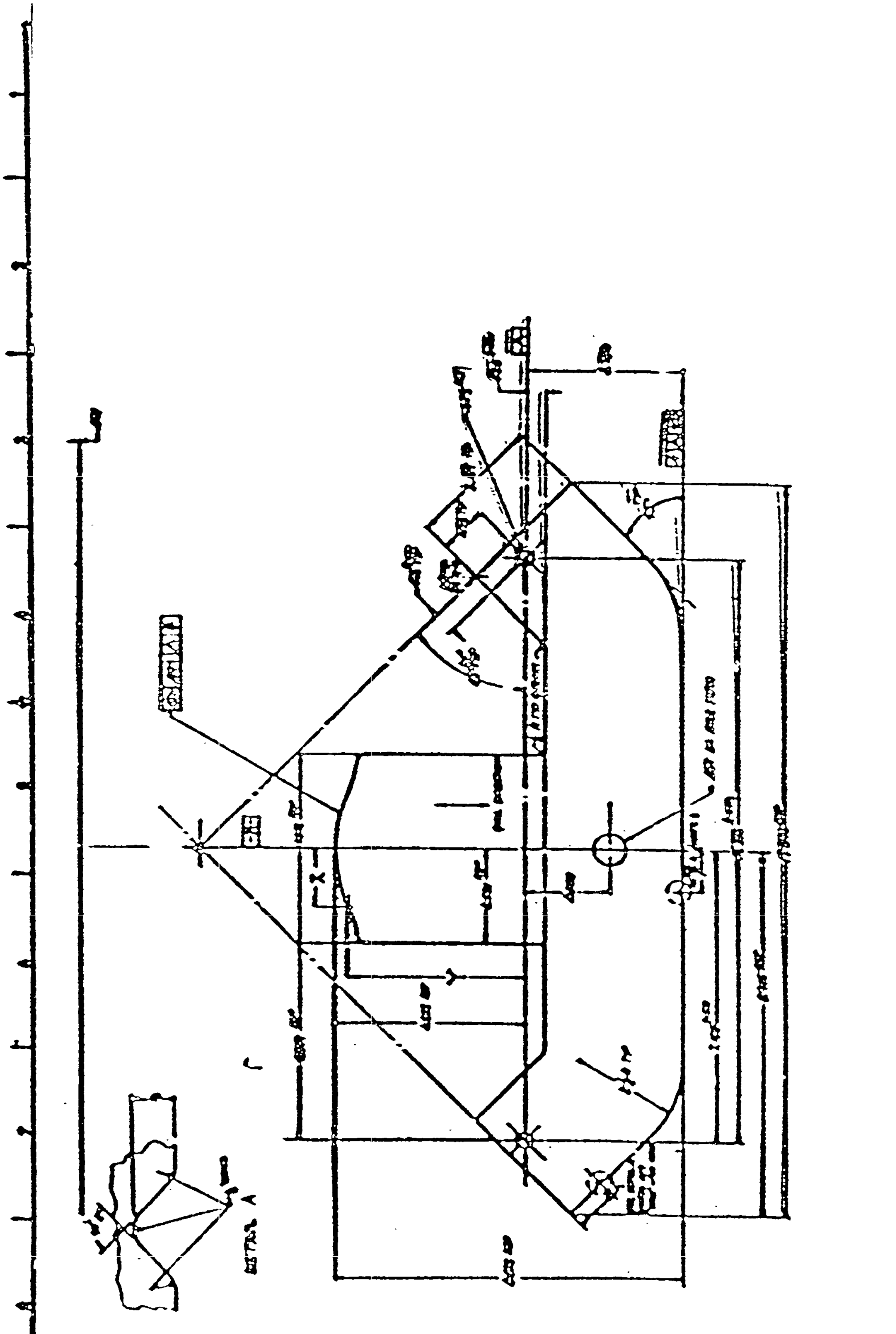


Figure 15. Quadrupole lamination.

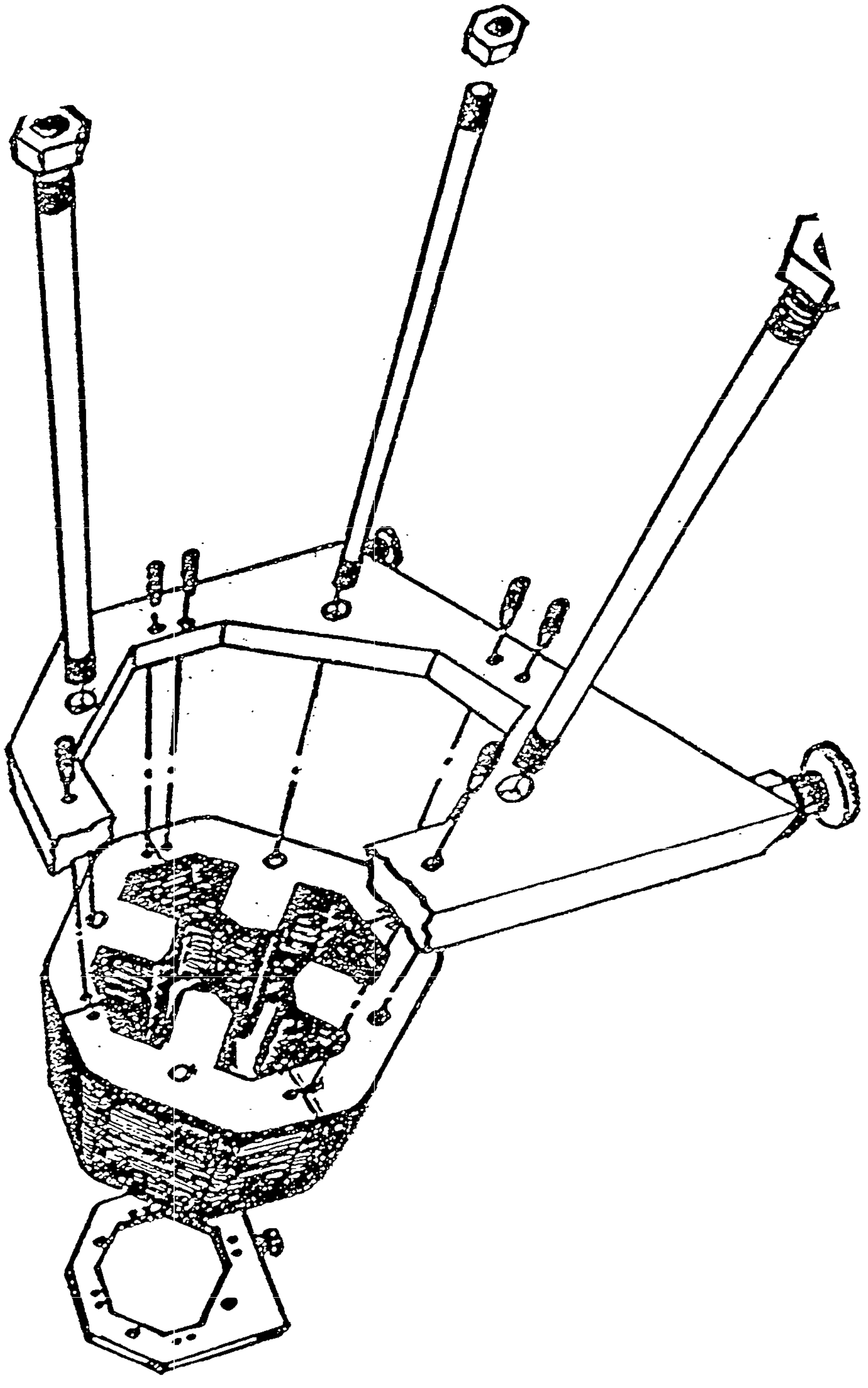
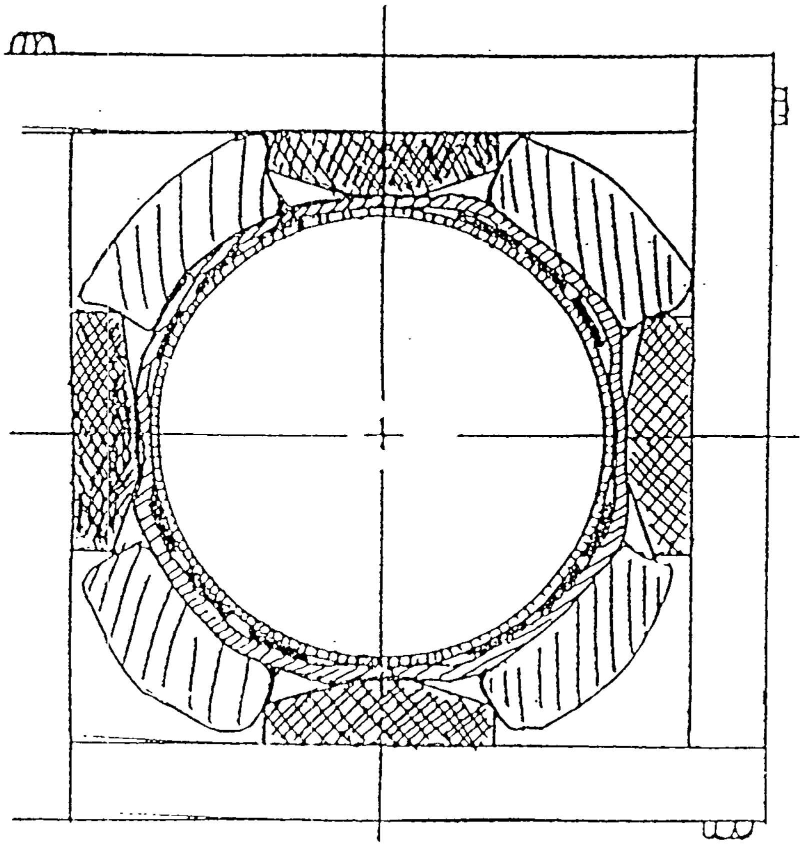


Figure 16. Quadrupole assembly.

TRIAL	INSULATION (WRAPPED)	POWER INPUT (WATTS)	TEMP. °F POLE TIP	TEMP. °F INSIDE
1	.04" FIBERGLASS TAPE	150	140	251
2	.04" FIBERGLASS + AL KAPTON + .01 FIBERGLASS	150	140	300
3	.05" FIBERGLASS + AL. KAPTON	150	130	275
4	.09" FIBERGLASS + 2 AL. KAPTON	150	125	303
5	.09" FIBERGLASS + 2 AL KAPTON	250	156	387
6	.120" FIBERGLASS + 3 AL KAPTON	250	160	401



LENGTH = 18"

Figure 17. Bake-out experiment with quadrupole.

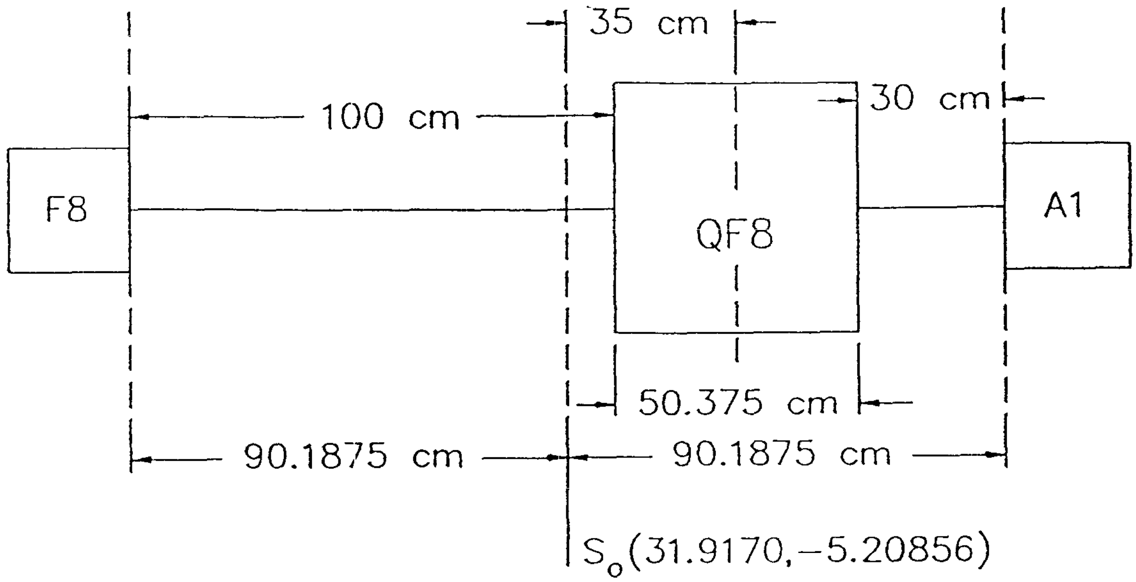


Figure 18. Relationship between quadrupole at F8 and dipole at A1.

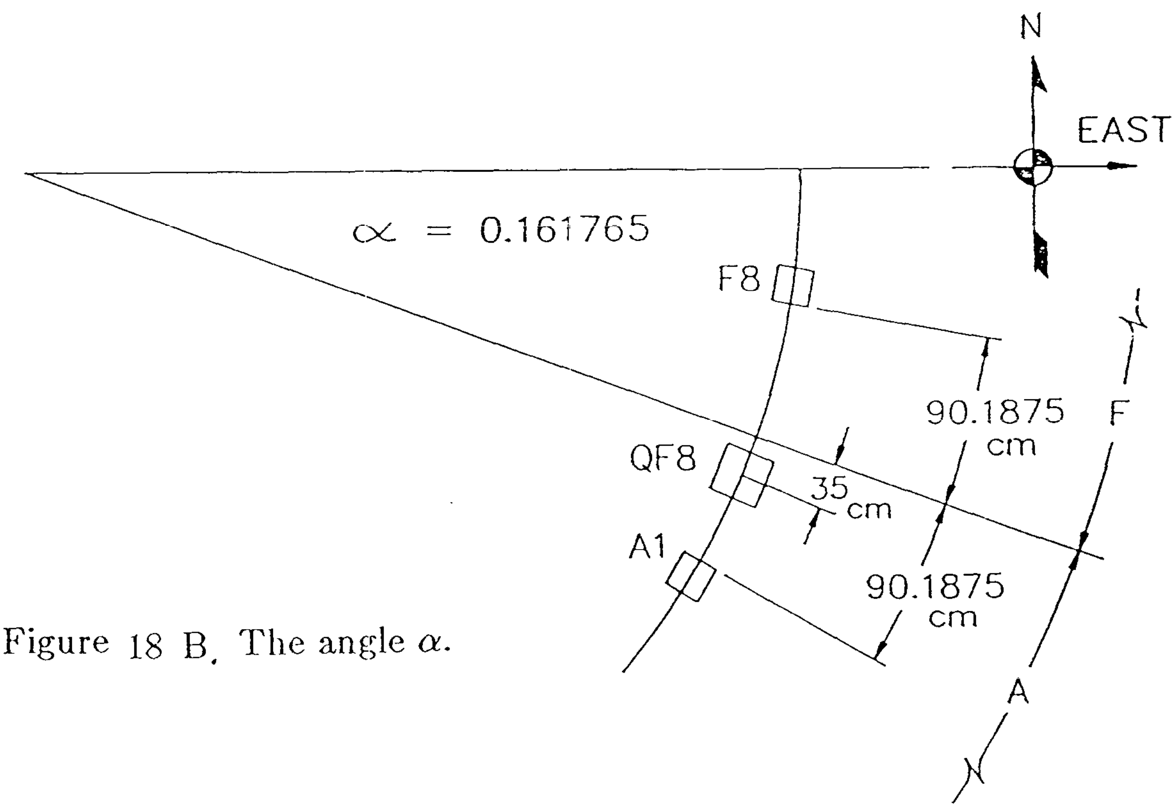


Figure 18 B. The angle α.

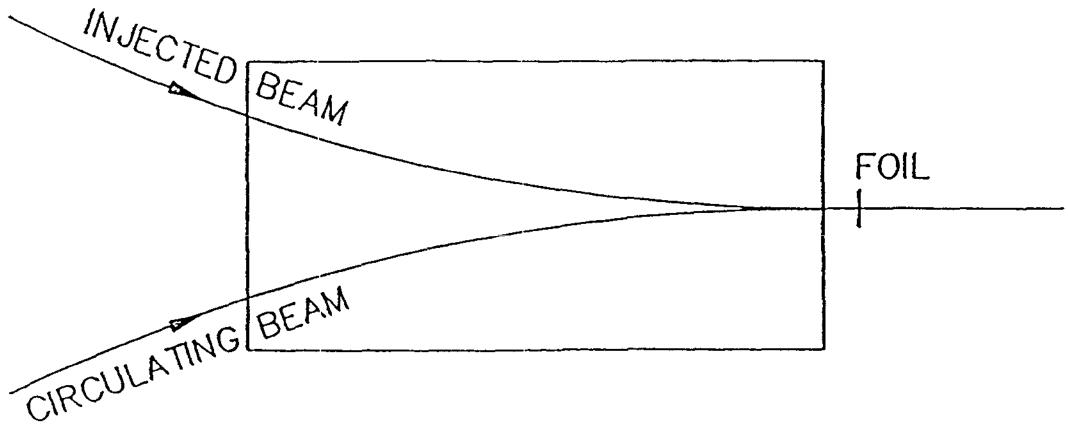


Figure 19. Foil location downstream of dipole.

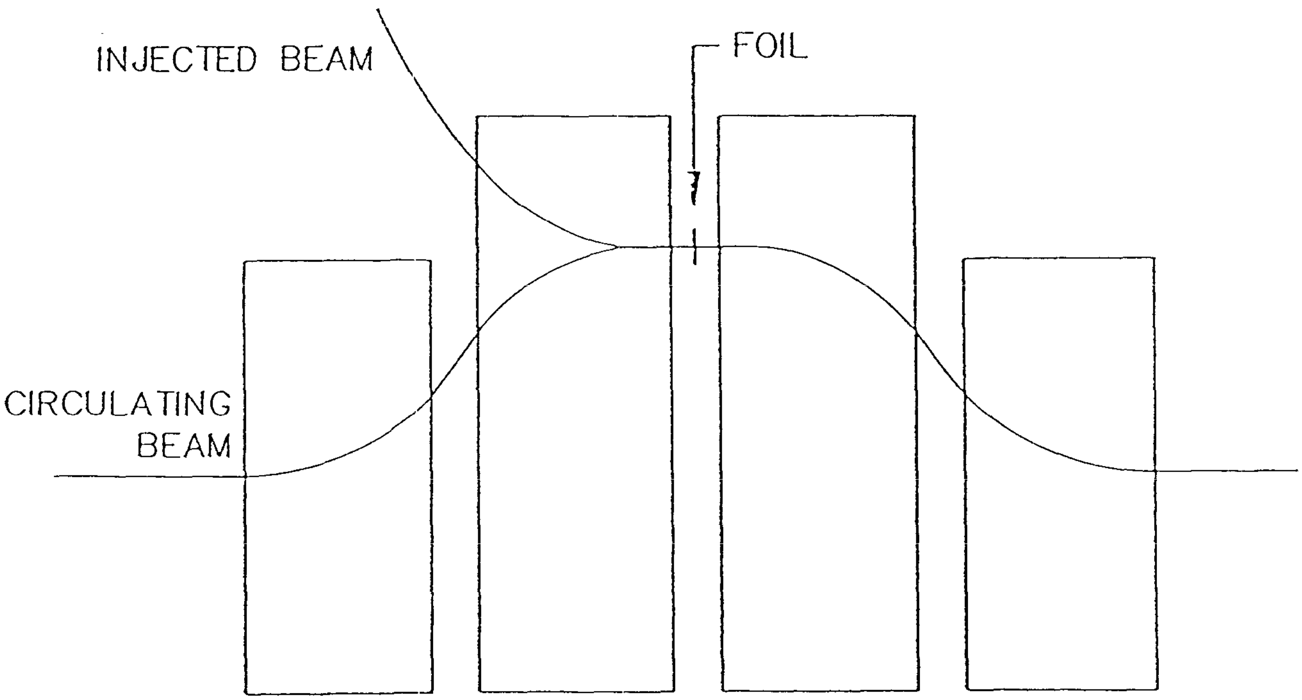


Figure 20. Bump in the circulating beam at injection.

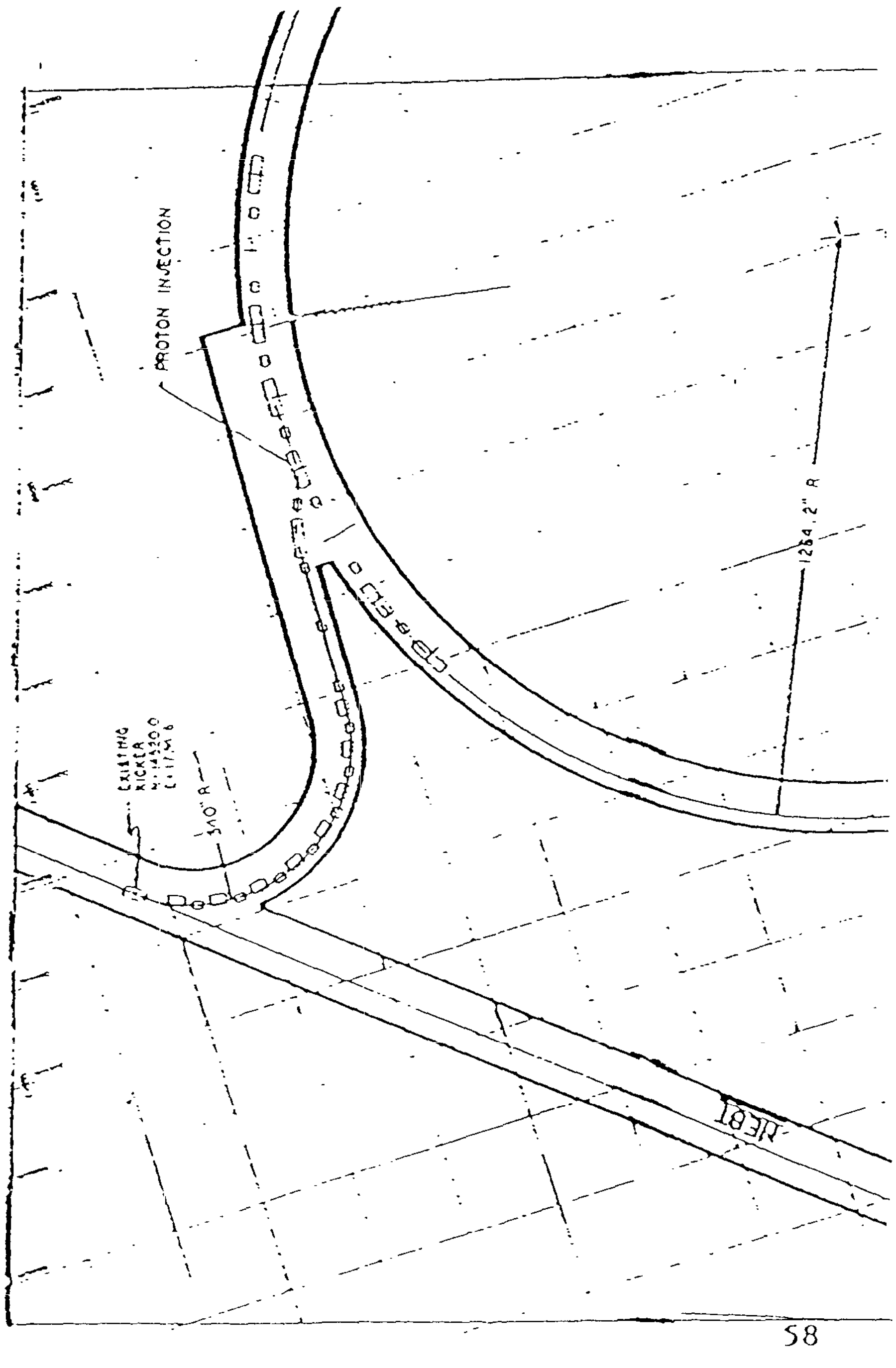
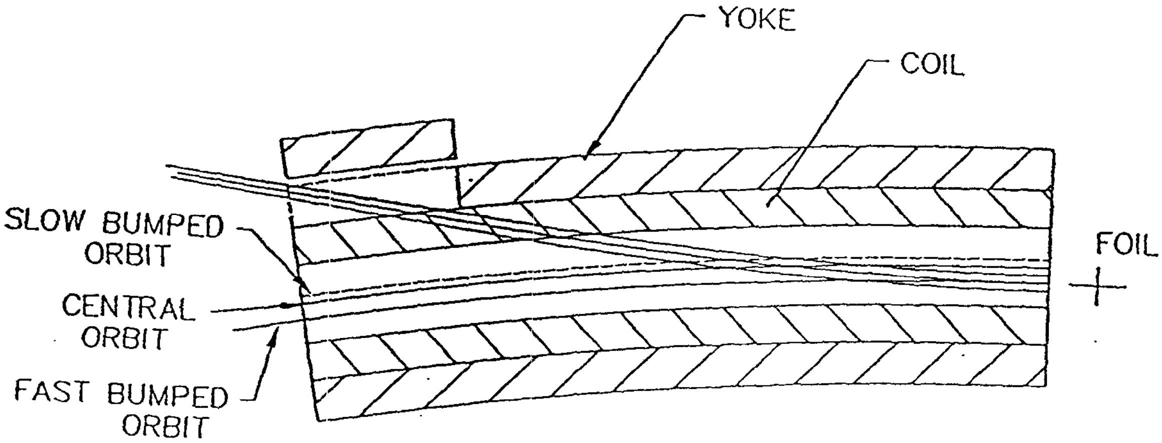


Figure 21. Linac to Booster Injection Line.



INJECTION TRAJECTORIES (CD5)

Figure 22. Injection trajectory in dipole magnet MDC5.

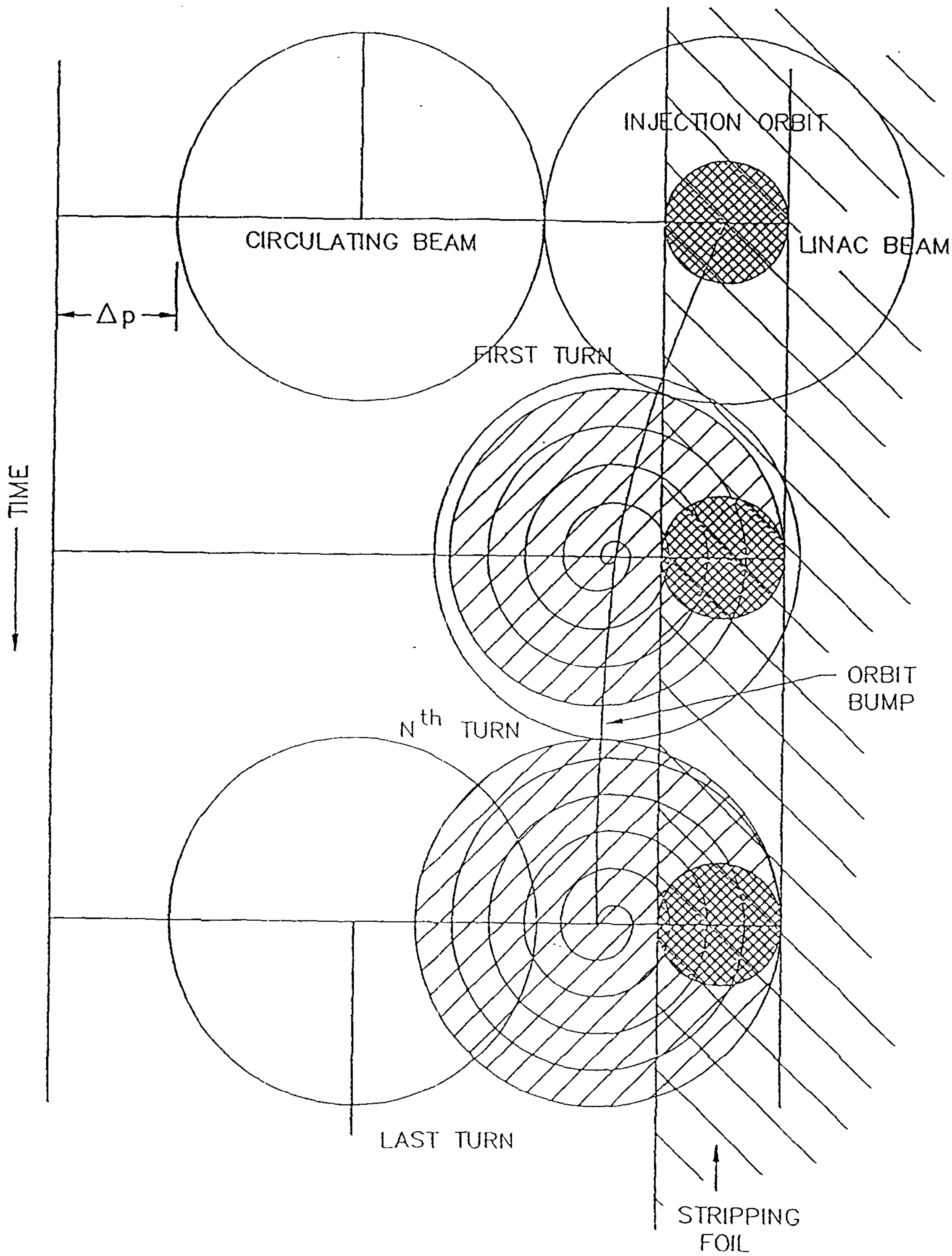


Figure 23. Populating the phase space with the injected beam.

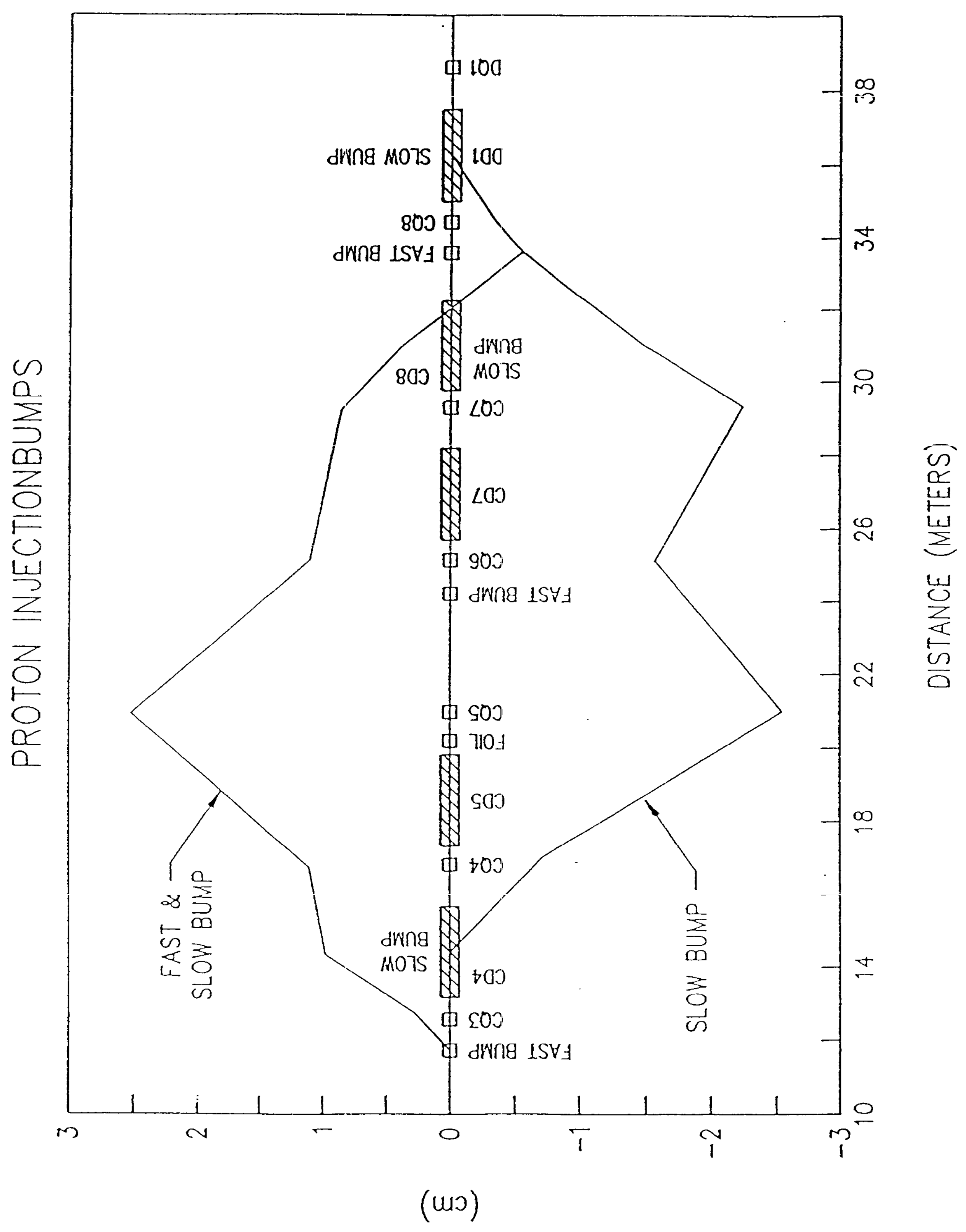


Figure 24. Location of the bump in the ring lattice.

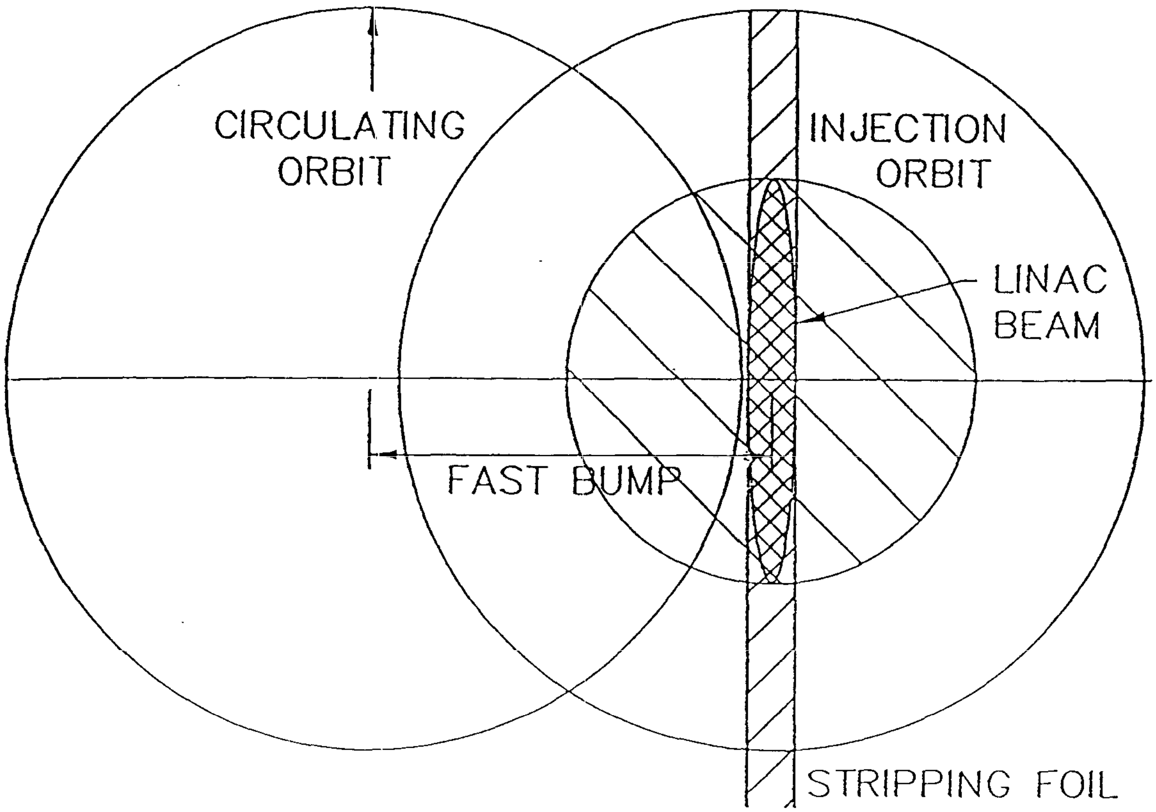


Figure 25. Injected and circulating polarized proton beams.

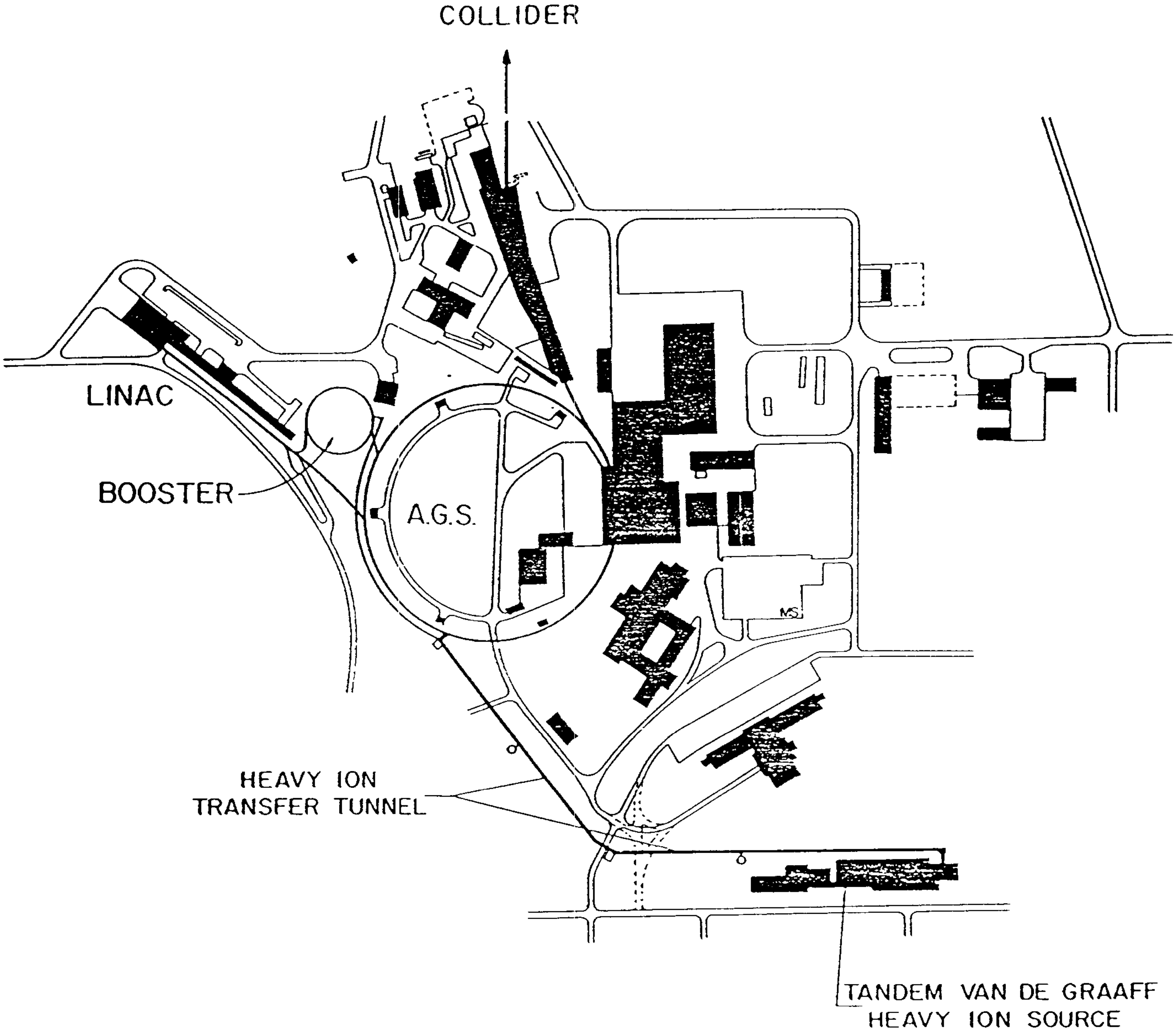


Figure 26. Heavy-ion transfer and injection line to the Booster.

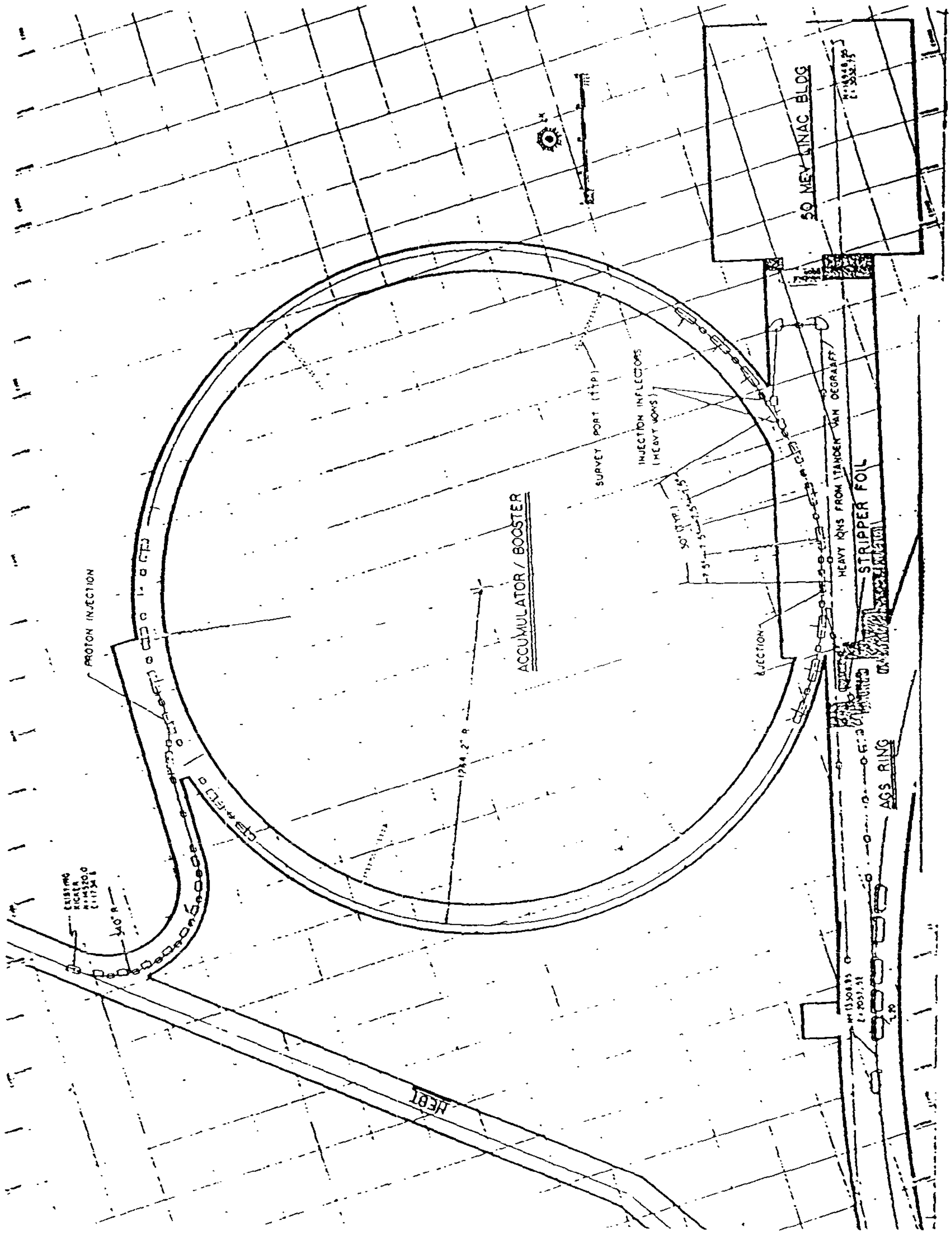


Figure 27. Booster ejection line to the AGS.

Half-Cell 1

CT Assembly = Correction and Trim Assembly

PUE = Pick-Up Electrodes

T = Transition from elliptical to circular beam pipe

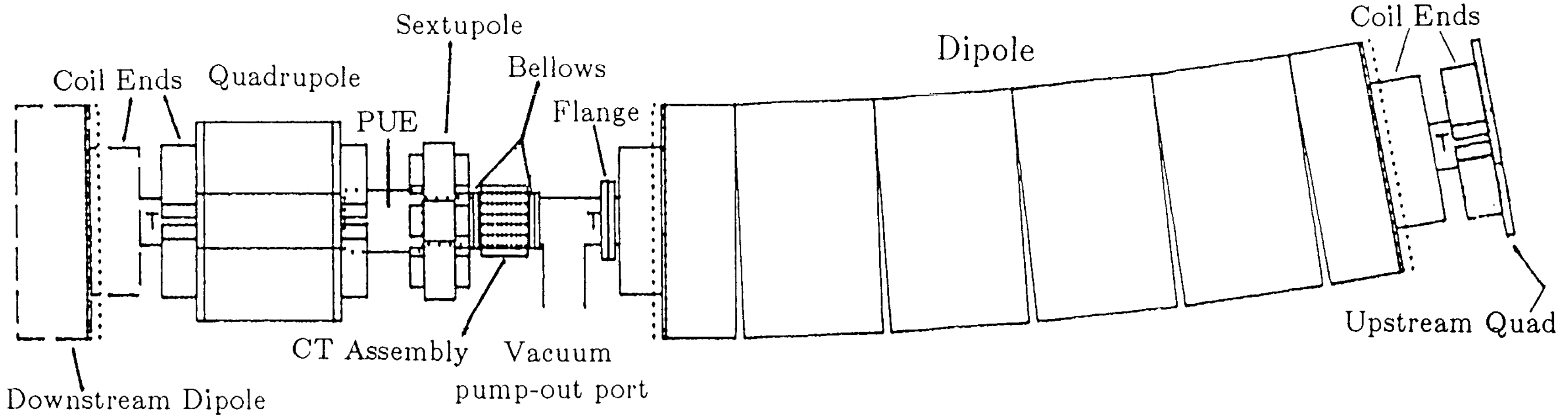


Figure 28. The first half-cell of each superperiod has, in general, a sextupole and a CT assembly in addition to the dipole and quadrupole. This half-cell is identical to half-cells 4 and 7 and differs from half-cell 2 only in its being followed by another dipole instead of being followed by a straight section.

Half-Cell 2

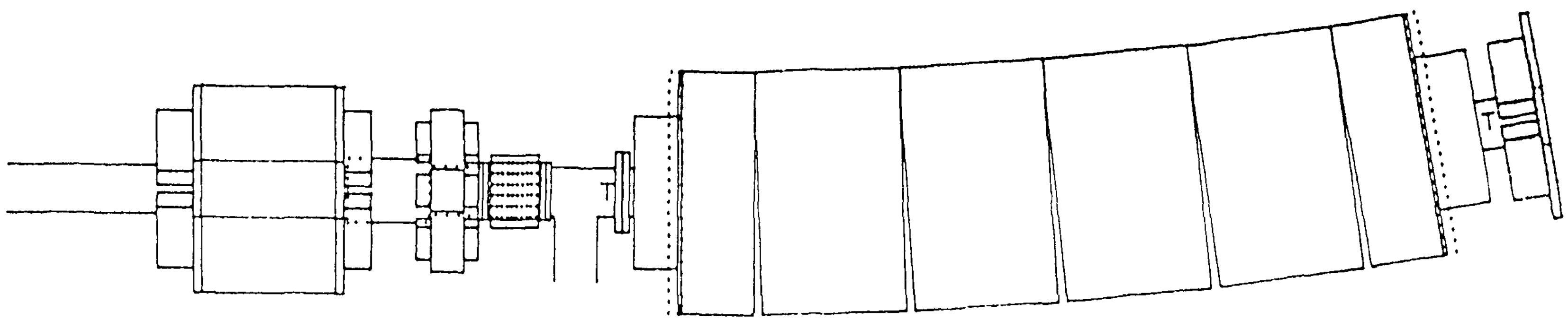


Figure 29. Half-cell 2 is followed by a straight section, thus no transition piece is required for the beam pipe downstream of the quadrupole.

Half-Cell 3

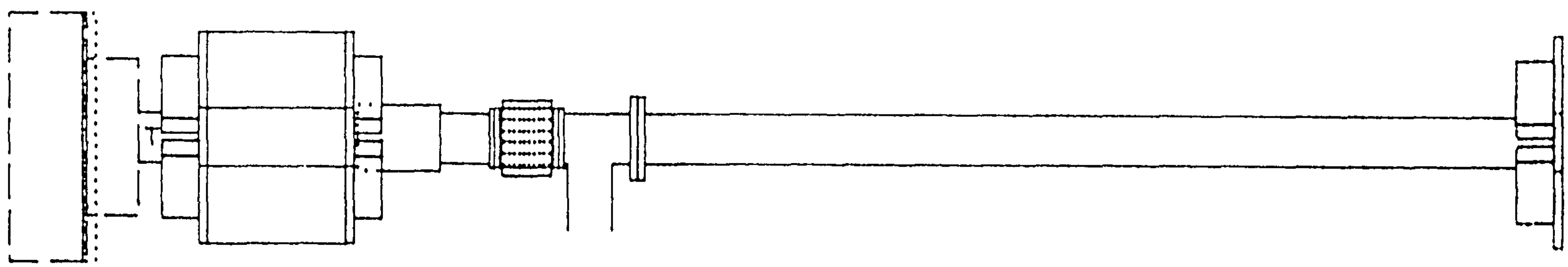


Figure 30. Half-cell 3 is identical to half-cell 6. In superperiod F, the CT Assemby is omitted in half-cell 3.

Half-Cell 5

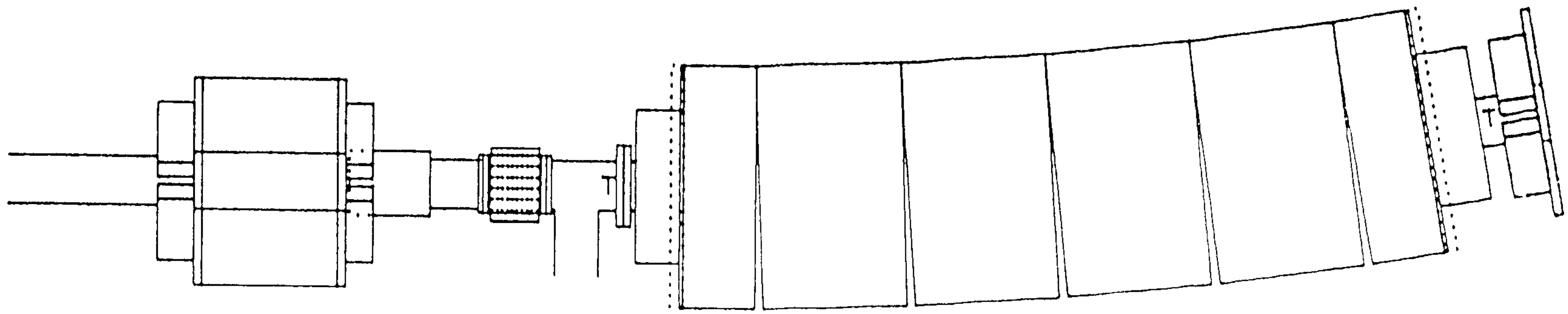


Figure 32. Half-cell 5, like half-cell 2, is followed by a straight section, but it does not contain a sextupole. In superperiod C, the CT assembly is omitted and a carbon foil is present for H^- stripping. The CT assembly is also eliminated in this half-cell in superperiod A.

Half-Cell 4

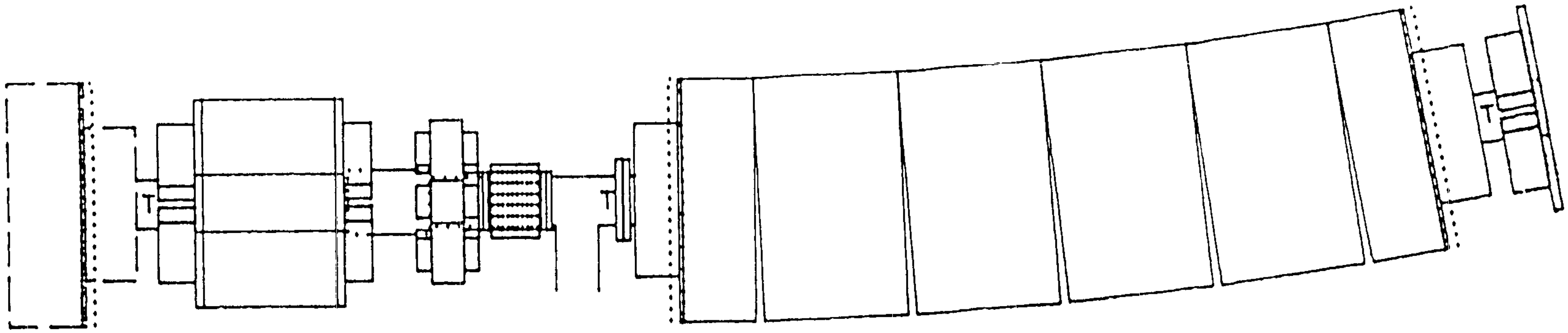


Figure 31. Half-cell 4 is identical to half-cell 1.

Half-Cell 6

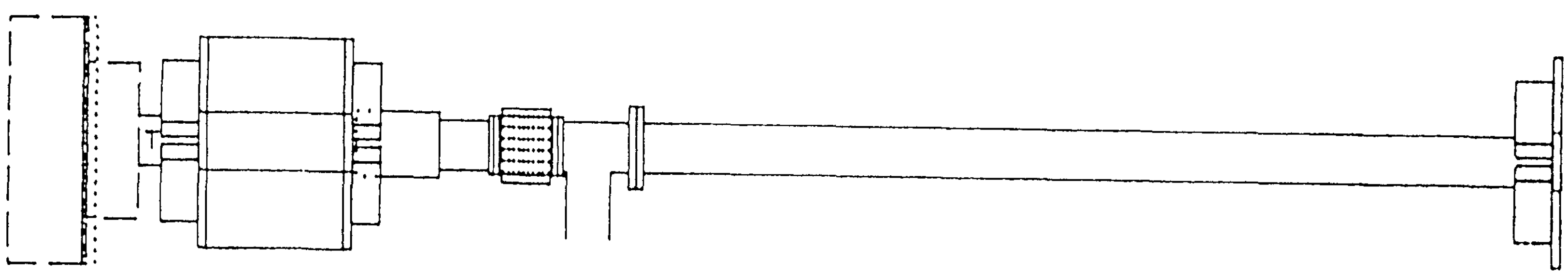


Figure 33. Half-cell 6 is identical to half-cell 3. In superperiod F, the CT assembly is omitted.

Half-Cell 7

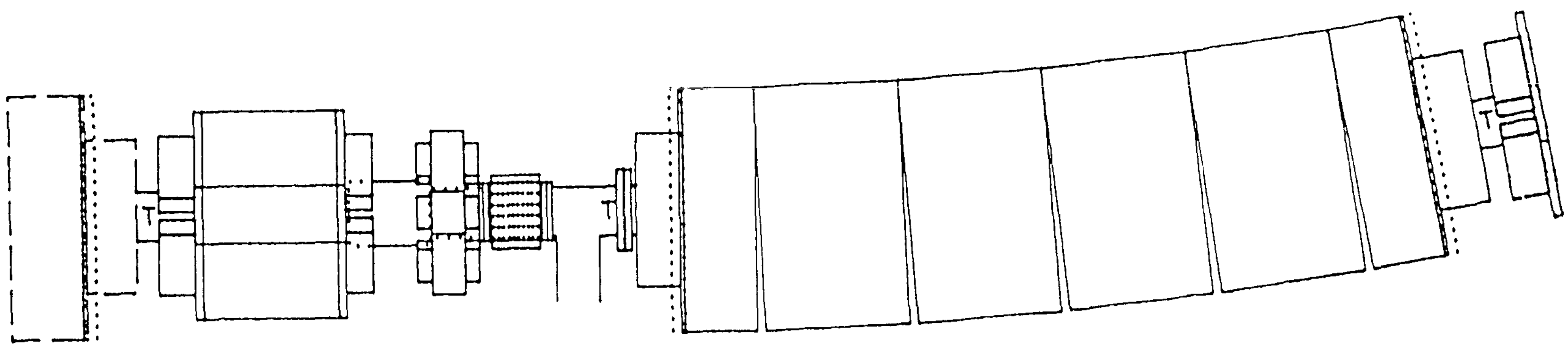


Figure 34. Half-cell 7 is identical to half-cell 1.

Half-Cell 8

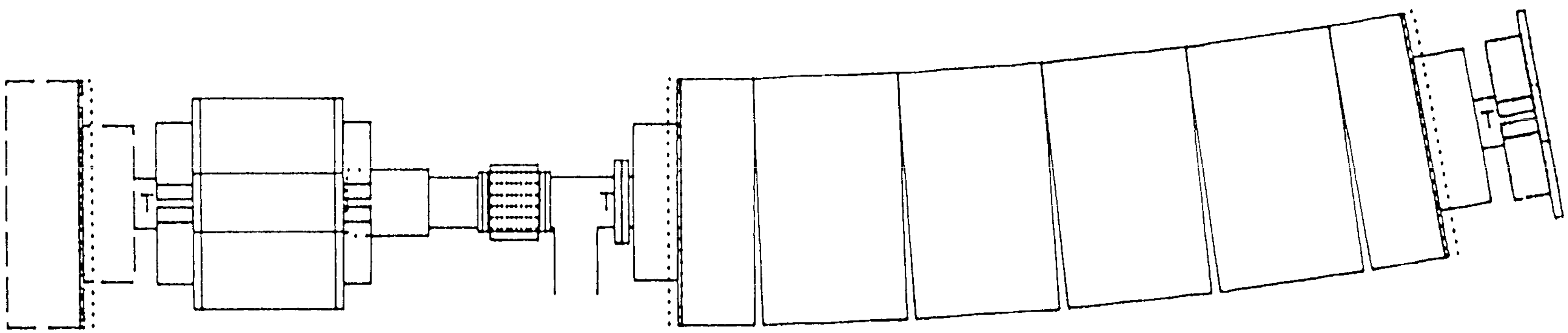


Figure 35. Half-cell 8 differs from half-cells 1, 4, and 7 only in its not having a sextupole. The CT assembly is omitted in this half-cell in superperiods C and F.

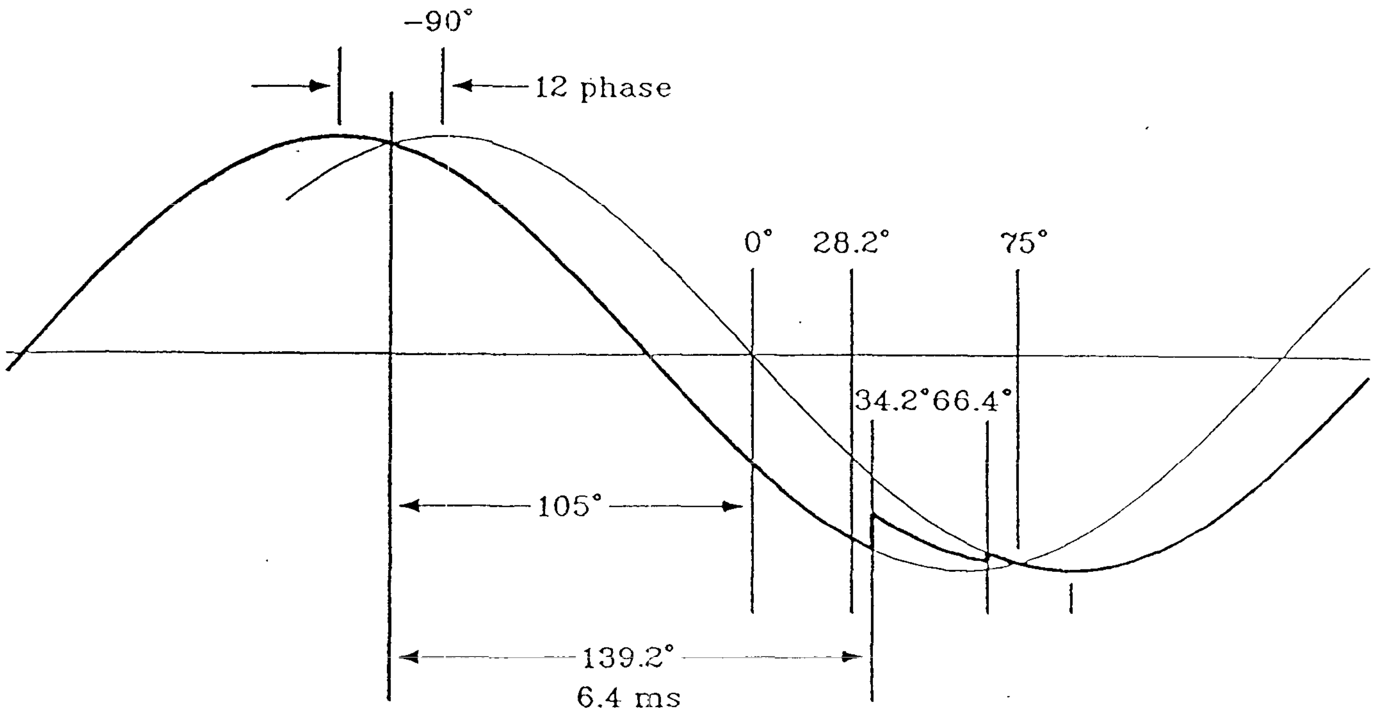


Figure 36. Commutation overlap.

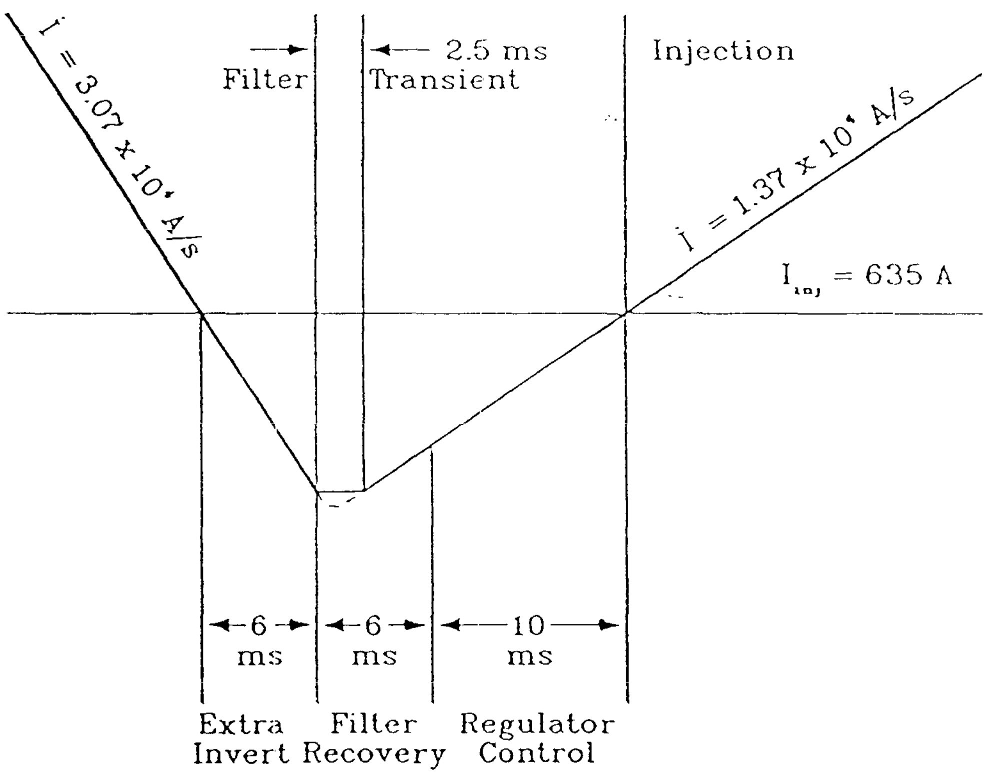


Figure 37. Injection undershoot process.

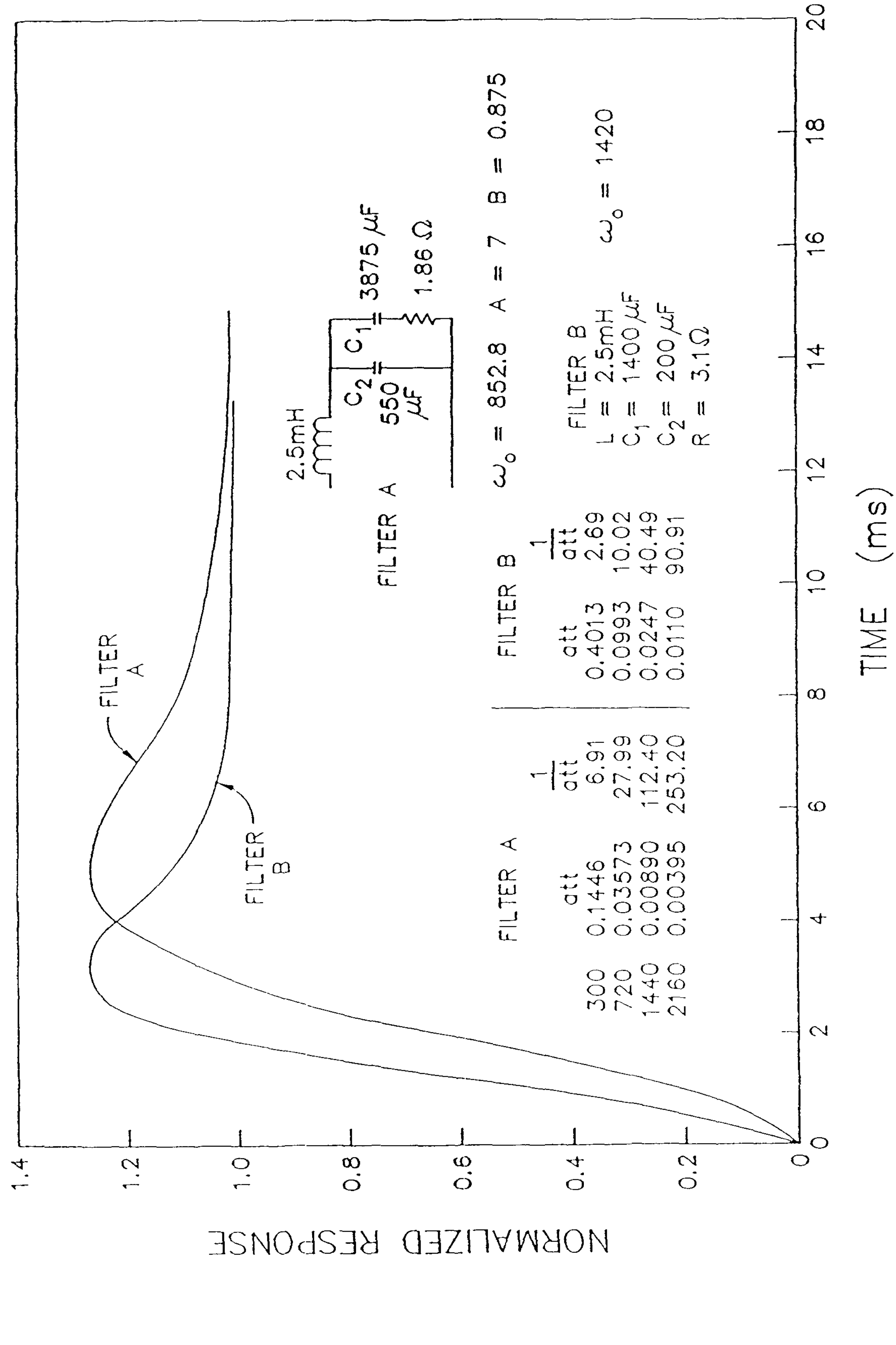


Figure 38. Filter designs for the dipole rectifier system.

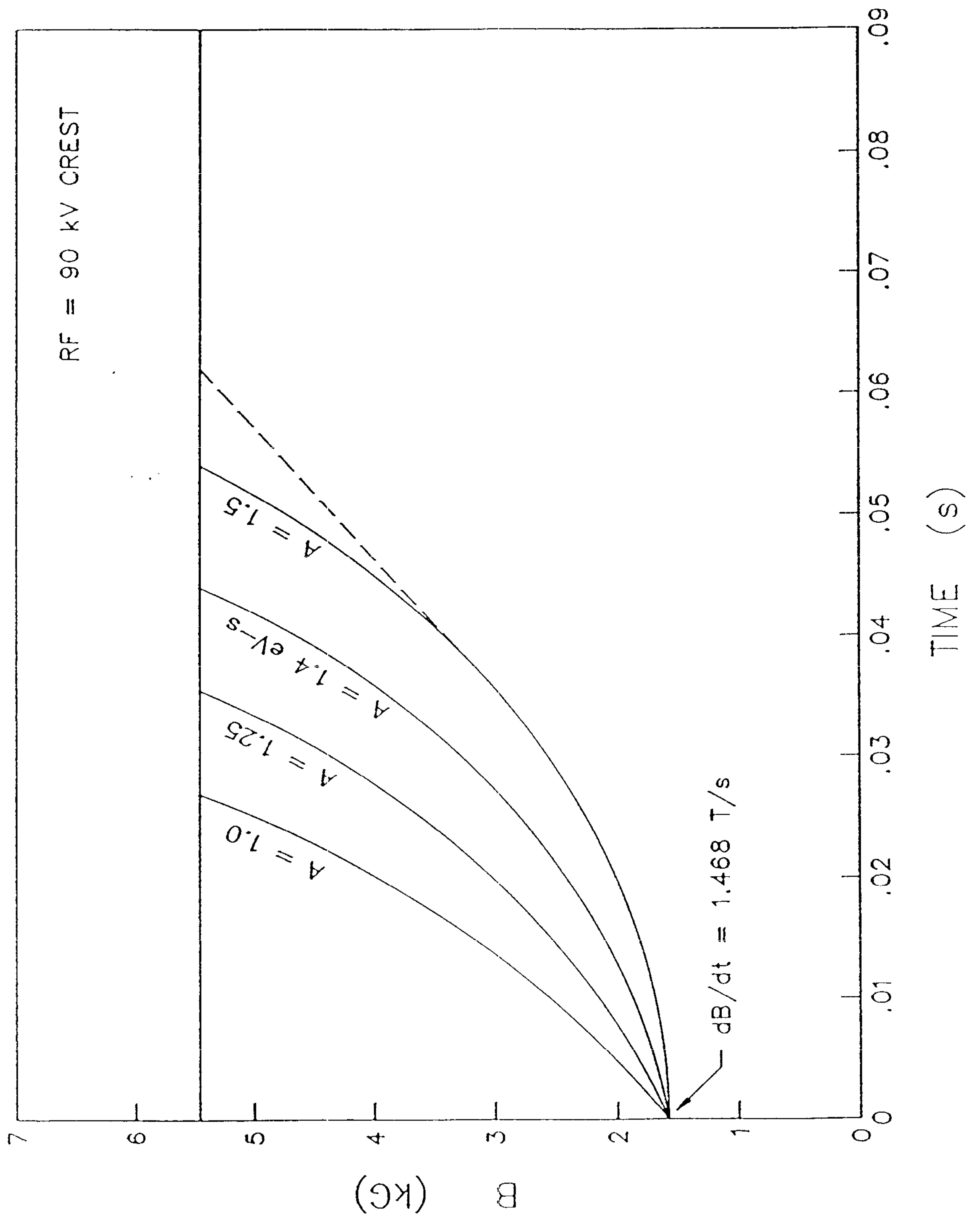


Figure 39. Dipole field versus time for different accelerating bucket areas.

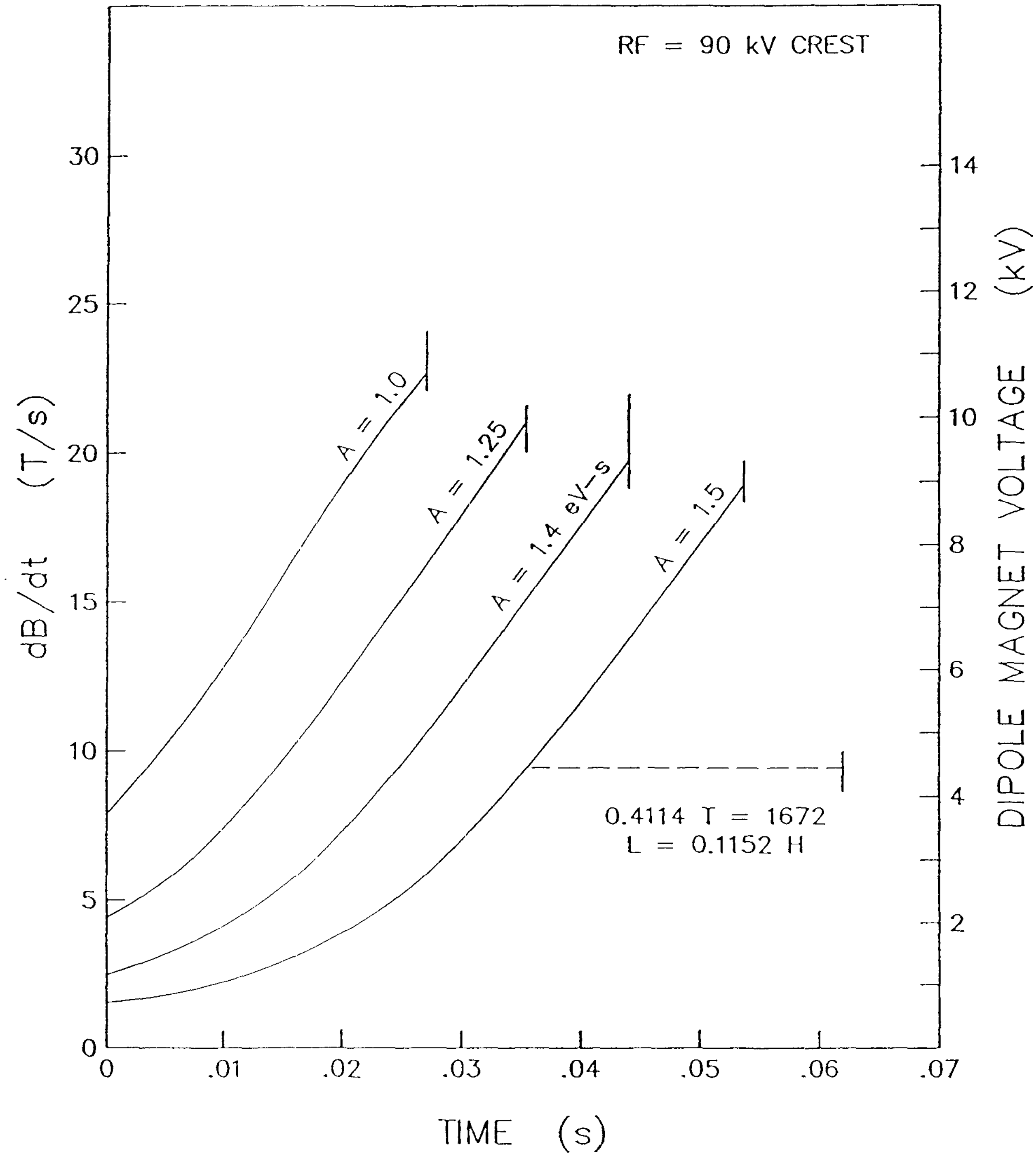


Figure 40, dB/dt and dipole voltage versus time.

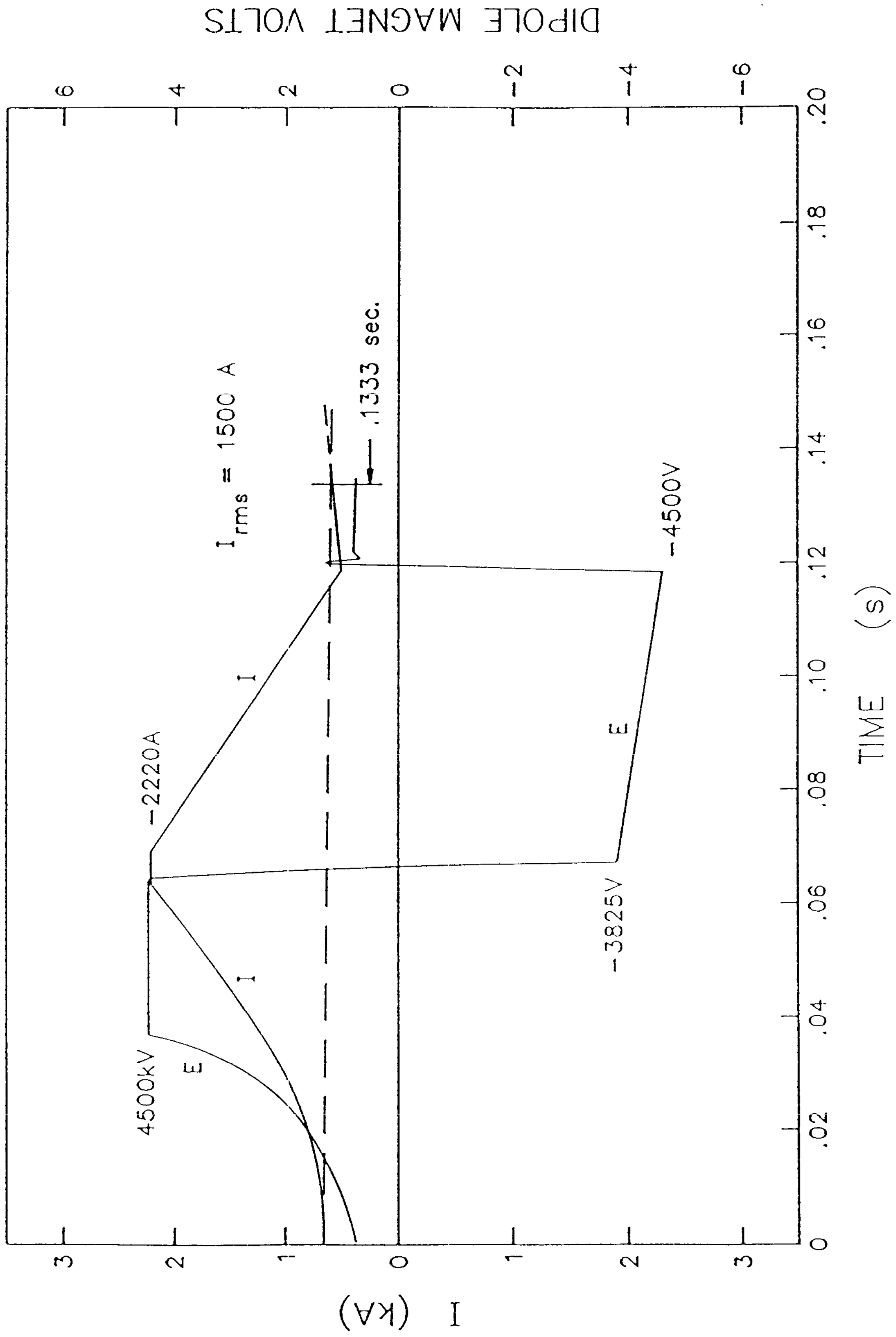


Figure 41. Proton accelerating cycle.

Acknowledgement:

We thank E. Courant, G. Cottingham, R. Thomas and other members of the Booster Task Force for their assistance.

REFERENCES

BST/TN*

1. E. Courant, Z. Parsa, The Booster Lattice, (1/15/86).
2. Z. Parsa, Booster Parameter List, (1/16/86).
3. Z. Parsa, F. Dell, Booster Coordinates, (1/17/86).
4. G. Morgan, S. Kahn, Calculation of Eddy Current in the Beam Tube, (1/28/86).
5. G. Danby, J. Jackson, Booster Dipole Field Computations, (1/10/86).
6. Z. Parsa, Booster Coordinates, (1/28/86).
7. R. Gupta, Y. Y. Lee, The Heavy Ion Injection Line for the AGS Booster, (2/06/86).
8. G. Morgan, Selection of Magnet Lamination Material and Thickness on the Basis of Eddy Current, (2/12/86).
9. Y. Y. Lee, Requirement for the AGS Booster Correction Elements, (2/12/86).
10. Z. Parsa, Booster Parameter List with 1,2,4,7 Sextupole Configurations, (2/12/86).
11. King-Yuen Ng, Single Bunch Instabilities of the RHIC Booster, (2/28/86).
12. E. Raka, RF Beam Loading in the Booster, (2/28/86).
13. H. Halama, Notes on Booster Vacuum, (2/27/86).
14. J. Cottingham, Ejection Septum Concept Design, (3/05/86).
15. G. F. Dell, S. Y. Lee, G. Parzen, The Dynamical Aperture of Booster , (3/05/86).
16. R. Gupta, S.Y. Lee, Y.Y. Lee, F. Zhao, Transfer Line Between the AGS Booster, (3/05/86).
17. E. Courant, Z. Parsa, Chromaticity Correction for the AGS Booster with 1,2,4,7 Sextupole Configurations, (3/05/86).
18. G. F. Dell, Aperture Study of the AGS Booster with and without Eddy Current Multipole, (3/10/86).
19. S. Y. Lee, J. M. Wang, Coherent Instability in the Booster, (3/10/86).
20. Z. Parsa, Booster Parameter List w/ 40 Kv RF Voltage, (3/10/86).

* Booster Tech. Note number is the same as reference number for references 1-60.

21. J. Claus, Eddy Current in Booster Vacuum Chambers, (3/14/86).

22. Y. Y. Lee, Aperture Comparison Between the AGS and the Booster, (3/18/86).

23. J. Kats, Evaluation of the Chromaticity Sextupoles for the AGS Booster, (3/20/86).

24. G. Parzen, Aperture Limitations Due to Non-Linear Coupling, (4/02/86).

25. Z. Parsa, Booster Parameter List with Enlarged QF, (4/17/86).

26. E. Courant, Z. Parsa, Booster Lattice with Enlarged Q5 & 1,2,4,7 Sextupole Configuration, (4/21/86).

27. Z. Parsa, Booster Coordinates w/ 1,2,4,7 Sextupoles, (4/23/85).

28. J. G. Cottingham, Consideration Effecting the Booster Magnet Cycle, (4/30/86).

29. G. Morgan, Effect of Interface Resistance Between Magnet Laminations, (4/30/86).

30. J. G. Cottingham, Booster Vacuum Chamber Considerations, (4/30/86).

31. J. G. Cottingham, R. F. Bucket Area, (5/06/86).

32. Z. Parsa, S. Tepikian, Alternate AGS-Booster Lattice, (5/07/86).

33. S. Y. Lee, Alternate Conceptual Lattice for the AGS-RHIC Booster, (5/16/86).

34. Z. Parsa, S. Tepikian, Analysis of Resonances in the AGS Booster, (5/17/86).

35. Z. Parsa, S. Tepikian, Resonance Analysis for Standard Booster Lattice with Split Tunes, (5/30/86).

36. J. Kats, Evaluation of the Booster Resonance Lines, (5/28/86).

37. G. F. Dell, Tracking Results From a Hybrid Booster Lattice at Working Points, $(\nu x, \nu y) = (4.83, 4.82)$ and (3.83 and 3.82), (5/30/86).

38. J. G. Cottingham, Four Kicker Injection Into The Booster, (5/30/86).

39. G. F. Dell, Comparison of On & Off Diagonal Working Points for the AGS Separated Function Booster, (6/02/86).

40. G. F. Dell, S. Y. Lee, Split Tune Operation of A Hybrid Booster Lattice $\nu x=3.820, \nu y=4.830$, (6/05/86).

41. G. Parzen, Space Charge Effect in the AGS Booster for High Intensity Proton Operation, (5/22/86).

42. Z.Parsa, S. Tepikian, Overview of the Structure Resonances in the AGS-Booster Lattices, (6/12/86).

43. Z. Parsa, Booster Parameter List w/ 60 kV RF Voltage and Increased Ejection Energies, (6/18/86).

44. R. Phillips, Report of Lamination Contour Measurements Using the Korda 83 w/ a Touch Probe (Renishaw TPI), (7/29/86).

45. M. Meth, Calculation of Booster Power Requirements Based on a Constant RF Bucket Area, (6/12/86).

46. J. Claus, S. Y. Lee, Combined Function Lattice for the AGS-RHIC Booster, (6/23/86).

47. Y.Y.Lee, L.G.Ratner, H- Injection for the AGS Booster, (6/23/86).

48. A. G. Ruggiero, Comment on Systomatic Resonances, (7/02/86).

49. J. G. Cottingham, Proton Cycle for the Booster, (7/02/86).

50. G. Morgan, Temperature Rise in the Vacuum Chamber Due to Eddy Currents, (7/08/86).

51. Y. Y. Lee, Estimate of Eddy Current Power, (7/09/86).

52. Y. Y. Lee, Heavy Ion Acceleration RF Program, (7/10/86).

53. Z. Parsa, Booster Parameter List With 90 Kv RF Voltage, (7/17/86).

54. M. Meth, Calculation of Booster Power Requirements & Power Line Flicker for 1.5 GEV Proton Operation, (7/17/86).

55. Y. Y. Lee, Expected Heavy Ion Intensity in the Booster, (7/19/86).

56. J.G.Cottingham, Capture and Acceleration of Heavy Ions, (7/17/86).

57. M. Meth, System Layout & Component Values of Dipole & Quadrupole Power Supplies, (7/25/86).

58. Z. Parsa, S. Tepikian, E. Courant, Fourth Order Resonances in the AGS Booster Lattice, (10/14/86).

59. Z. Parsa, S. Tepikian, Analysis of Alternate Booster Lattices, (8/18/86).

60. Z. Parsa, Booster Parameter List, Draft, (8/24/86).

I . Z. Parsa, R. Thomas, eds., Preliminary Booster Design Manual, May 1986).

II. Z. Parsa, R. Thomas, eds., Booster Design Manual, (to be published).

TABLE
AGS BOOSTER PARAMETER LIST

	Protons	Polarized Protons	Heavy Ions
Energy			
Injection	200 MeV	200 MeV	$>$ 1 MeV/nucleon
Ejection	1.5 GeV	1.5 GeV	$p = 5.25\ Q/A$ (GeV/c)/nucleon
Lattice			
Circumference		201.78 m (1/4 AGS)	
Periodicity		6	
Number of cells		24 FODO	
Cell length		8.4075 m	
Phase advance/cell		72.3°/72.45°	
ν_x/ν_y (nominal)		4.82/4.83	
β_y max/min		13.6/3.7 m	
x_p max		2.95 m	
transition γ		4.88	
RF System			
Number of stations	2	2	2
Harmonic number	3	3	3
Frequency range (MHz)	2.5 — 4.11	2.5 — 4.11	0.200 — 2.5
Peak RF voltage	90	90	17
Acceleration time (ms)	62	62	500
Reptition rate	7.5 Hz (4/AGS pulse)	1 Hz (1/AGS)	1 Hz (1/AGS)
Dipoles			
Number		36	
Length (magnetic)		2.4 m	
Gap		82.55 mm	
Vacuum chamber aperture		66 mm	
Good field region ($< 10^{-4}$)		16 × 6.6 cm	
Injection field (kG)	1.56	1.56	0.108 A/Q
Ejection field	5.46	5.46	12.74
Quadrupoles			
Number		48	
Length (magnetic)		50.375 cm	
Aperture		16.5 cm	
Vacuum chamber aperture		15.25 cm	
Injection pole tip field (kG)	1.02	1.02	0.068 A/Q
Ejection pole tipe filed (kG)	3.6	3.6	8.3
Field Quality 6/2		0.0	
All other harmonics		$< 10^{-4}$	
Chromaticity Sextupoles			
Number		2 × 12	
Length (magnetic)		10 cm	
Max. pole tip field (kG)		3.0	
Max. Vacuum Pressure		3×10^{-11} torr	