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DATA SHEETS FOR THE AGS HIGH FIELD QUAD

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Technical Note

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E. Bleser and M. Tanaka

January 14, 1988

This note presents material we have collected on the 24 high field quads installed in the AGS. The information is summarized in a one page data sheet with various appendices giving back-up information. The nominal name for this type of magnet is 6Q24. In the ring there are twelve magnets connected in series located at horizontal maxima and twelve connected in series at vertical maxima. In AGAST they are designated QHORZ and QVERT. The 4 skew quads, 8Q16, are not discussed in this note.

New precision power supplies (BNL AGS Spec-879) will be available for these magnets soon. In order to derive full benefits from these supplies it will ultimately be necessary to take account of the hysteresis loops shown in Appendix B.

PROPERTIES OF THE HIGH FIELD QUADRUPOLE

	Inches	Centimeters	Ref
1. **Physical Description**			
A. Core			a
Core length	24	60.960	
Gap radius	3.218	8.174	
B. Coil			a
Turns per pole - 16			
Conductor dimensions	0.812 x 0.343	2.062 x 0.871	
Cooling hole diameter	0.156	0.396	
Conductor cross section	0.2593 sq. in.	1.673 sq. cm.	
Approximate conductor length per pole	1056	2682	
C. Vacuum Tube			b
O.D.	5.875	14.923	
I.D.	5.745	14.592	
Material - SS 304			
D. Locations			
Horizontal quads, 12 places A17...L17			c
Vertical quads, 12 places A3...L3			c
Distance from mag to mag	64	162.6	d
Distance from mag to quad	25	58.4	b

2. Electrical Properties — Ref e

Per Magnet

Resistance, measured	-	11.7 milliohms
calculated at 60°F	-	11.2 milliohms
calculated at 100°F	-	12.3 milliohms
Inductance, measured	-	2.32 millihenrys

Per 12 Magnets

Resistance, measured	-	208 milliohms
Inductance, measured	-	30 milliohms

Properites of the High Field Quadrupole (continued)

Ref

3. Magnetic Properties f

G x L/I, measured	-	41.08 Gauss/Amp
Chosen effective length	-	68 cm
Then gradient, G/I	-	0.6041 Gauss/(cm x Amp)
Calculated gradient, G/I	-	0.6019 Gauss/(cm x Amp)
B5 x L/I	-	-8×10^{-4} Gauss/(Amp x cm^4)

4. Tune Control g

$\Delta Q_x = (0.0262 \times I_x + 0.0121 \times I_y)/P$
$\Delta Q_y = -(0.0121 \times I_x + 0.0261 \times I_y)/P$
I_x = current in Amps in 12 HF horizontal quads
I_y = current in Amps in 12 HF vertical quads
P = beam momentum in GeV/c

References

a. Mechanical Drawing D03-M-1222-5.

b. Mechanical Drawing C-D05-M-959-4.

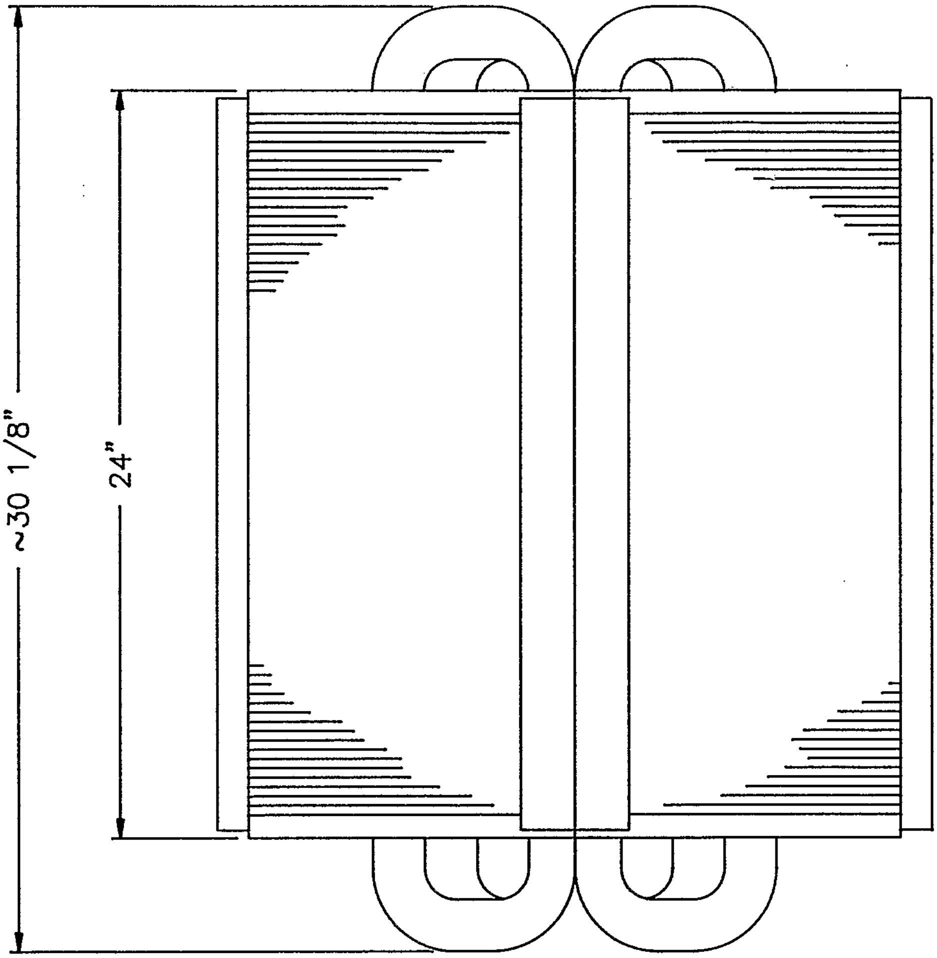
c. Devices in the AGS Ring, M. Zguris, K. Brown. June 1, 1987.

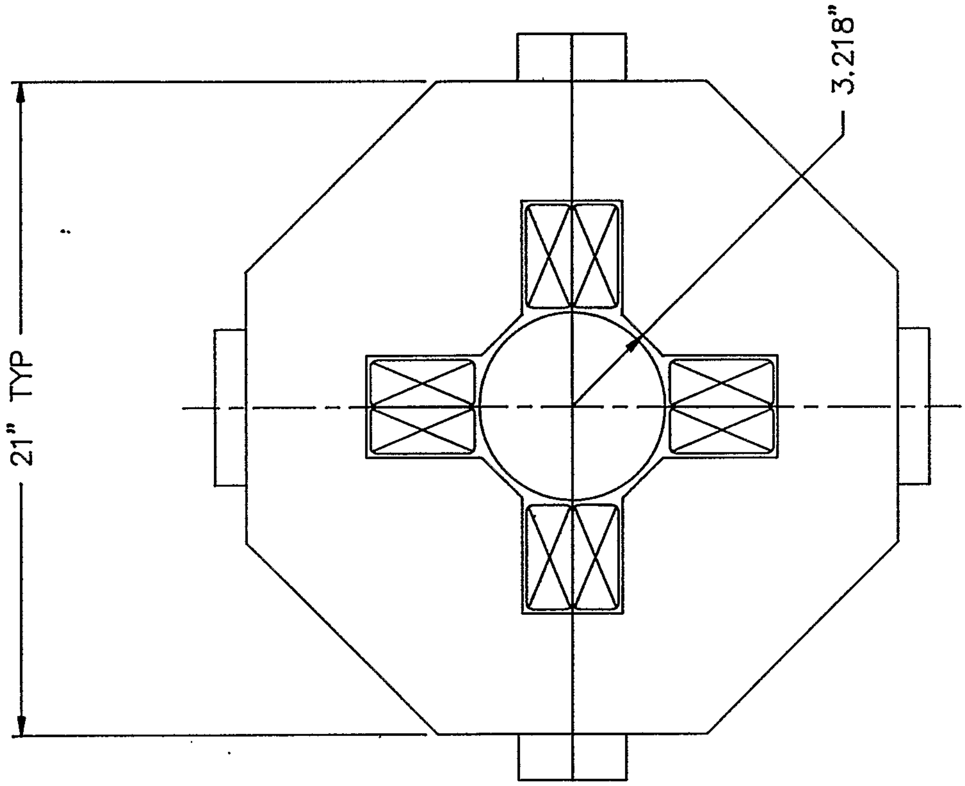
d. WHERE ARE THE AGS MAGENTS? E. Bleser, TN 215, May 20, 1985.

e. Appendix A.

f. Appendix B.

g. Appendix C.


~30 1/8"
24"


21" TYP
3.218"

Appendix A

THE ELECTRICAL PROPERTIES OF THE HIGH FIELD QUADRUPOLES

The material in this appendix was collected or calculated largely by Bill Leonhardt. Figure A1 shows the pressure drop across a magnet as a function of the flow rate, calculated at T = 70°F and 100°F and measured at 70°F. Figure A2 shows the calculated temperature rise versus pressure drop for DC currents of 600 and 800 Amps. Table A1 gives the measured pressure drop across each magnet as it operates in the AGS. The magnets usually run at less than 500 Amps with a duty cycle of less than 50%, suggesting that they are normally quite cool. There are at present 8 water circuits on a magnet, connected in two series of four. The cooling could be increased by connecting as many as all eight circuits in parallel.

The most recent measurements of the resistance and inductence of a magnet (Joe Funaro and Lou Mazurakis, November 1987) confirm earlier measurements and give:

Per Magnet: $R = 11.7$ milliohm
$L = 2.32$ millihenry

Per 12 Magnet System: $R = 208$ milliohm
$L = 30$ millihenry

Table A1

WATER SUPPLY READINGS ON HIGH FIELD QUADS

Location	Supply psi	Return psi	Pressure Drop psid
A-3	100	32	68
B-3	103	34	69
C-3	105	35	70
D-3	106	44	62
E-3	106	40	66
F-3			
G-3	85	18	67
H-3	87	20	67
I-3	90	21	69
J-3	93	23	70
K-3	96	24	72
L-3	98	32	66
			67.8 Mean

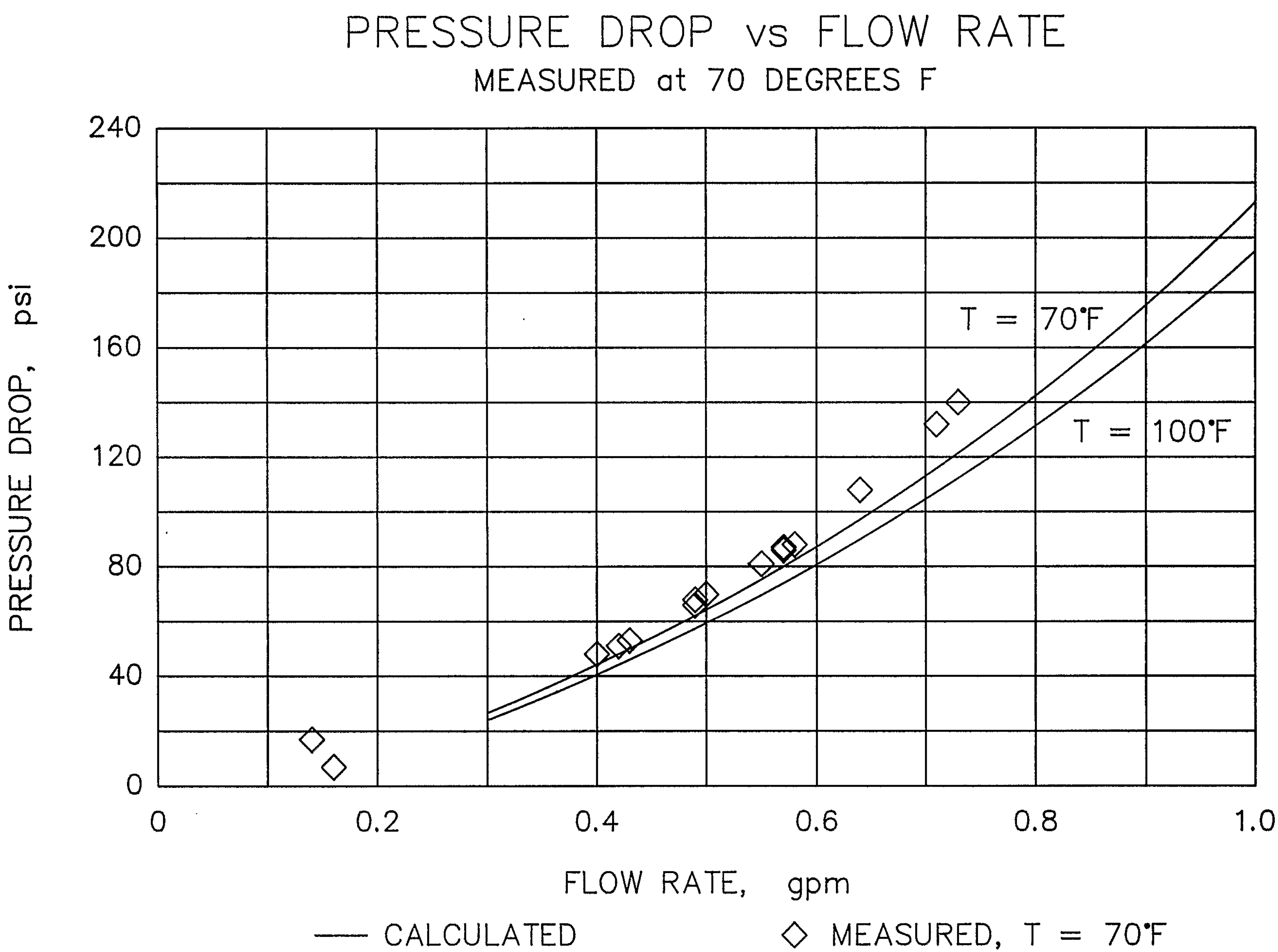

PRESSURE DROP vs FLOW RATE
MEASURED at 70 DEGREES F
PRESSURE DROP, psi
240
200
160
120
80
40
0
0
0.2
0.4
0.6
0.8
1.0
FLOW RATE, gpm
T = 70°F
T = 100°F
CALCULATED
MEASURED, T = 70°F

Figure A1

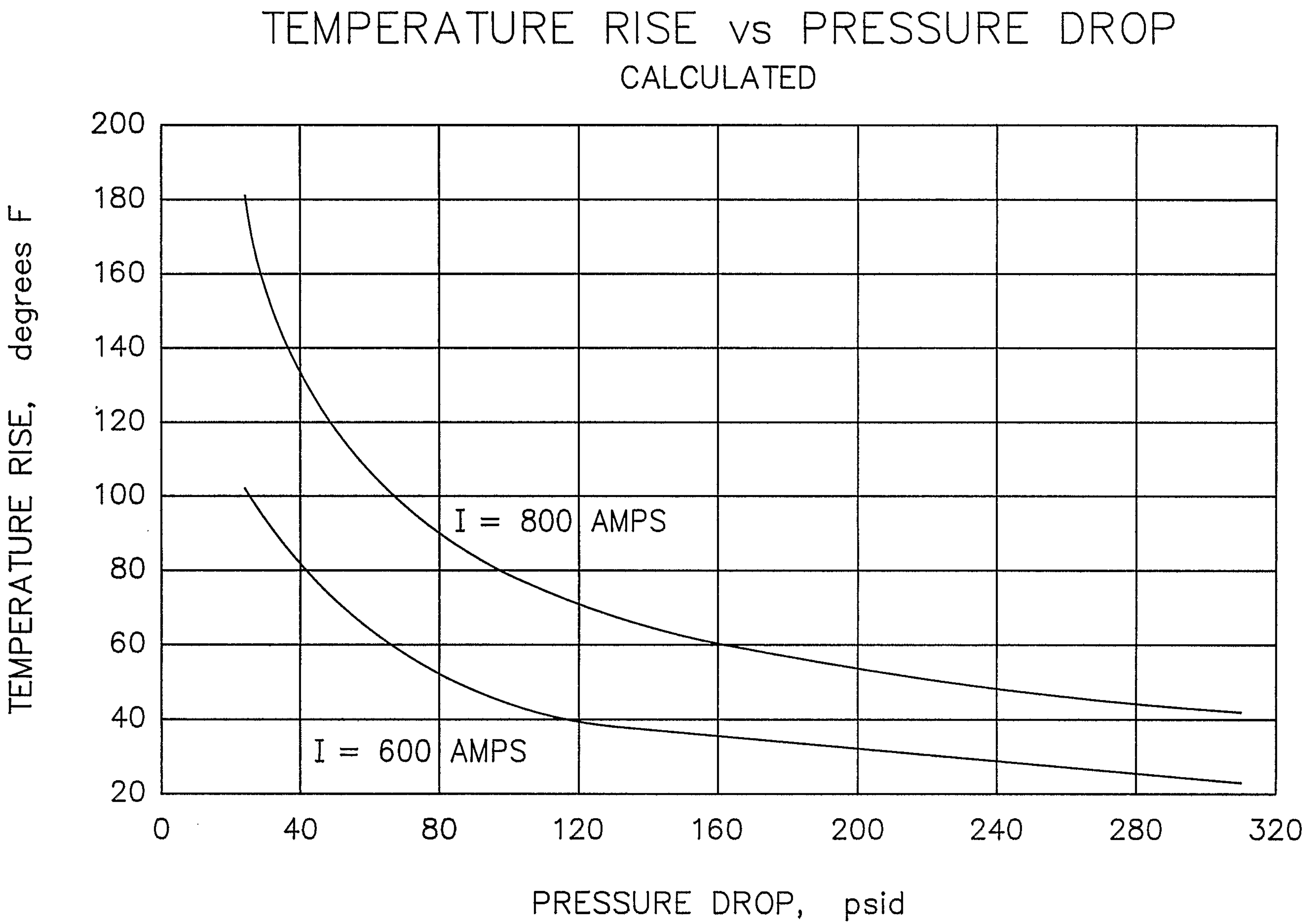

TEMPERATURE RISE vs PRESSURE DROP
CALCULATED
TEMPERATURE RISE, degrees F
200
180
160
140
120
100
80
60
40
20
0
40
80
120
160
200
240
280
320
PRESSURE DROP, psid
I = 800 AMPS
I = 600 AMPS

Figure A2

Appendix B

THE MAGNETIC PROPERTIES OF THE HIGH FIELD QUADRUPOLE MAGNETS

The High Field Quadrupole Magnets were designed in 1958. Other than the mechanical drawings, which seem to be complete and readily available, we have found little information on them. There are 24 magnets installed in the AGS and one spare. This spare was carefully measured by the Magnetic Measurements Group of the ADD Department in March of 1987. We would like to thank Peter Wanderer for supporting this work, John Herrera for stalwart efforts to understand the results, and Bob Gottschalk and his group for carrying out the measurements.

The measurements were made with a rotating coil, 74 inches long, giving the gradient integrated through the length of the magnet. The results are given in Table B1 and plotted in Figure B1. There are some hysteresis effects, not particularly visible in this plot, which give us some options in defining the gradient as a function of the current. For our present purposes, it is sufficient to use a straight line connecting the origin and the point of the highest positive current. These two points then give us:

$$G \times L/I = 41.08 \text{ Gauss/Amp}$$

This simple result is sufficient for most present uses of the magnets.

It is useful to consider also the gradient rather than the integrated gradient. However, we do not have a point measurement of the gradient in the center-of-the-magnet. Therefore, we must pick an effective length somewhat arbitrarily We have defined the effective length of this magnet to be:

$$L_{eff} = 68 \text{ cm}$$

Then

$$G/I = 0.6041 \text{ Gauss/(cm x Amp)}$$

A simple calculation gives:

$$G/I = 0.8 \times \pi \times N/a^2$$

$$= 0.6019 \text{ Gauss/(cm x Amp)}$$

where N = the number of turns and a = the radius of the bore. We have chosen L_{eff} to be the core length plus 0.86*a, which is a very reasonable choice, so we feel the overall picture is consistent.

Appendix B (continued)

For convenience we replot Fig. B1 with the integrated gradient divided by the effective length to get Fig. B2. In order to see the hysteresis effects, we replot in Fig. B3 the data from Fig. B2 with 0.6041*I, the postulated straight line, subtracted from the data. The squares indicate increments of positive current; the circles increments of negative current. Figure B3 clearly shows the hysteresis effect and the residual fields, which correspond to a current error of about 1 Ampere. If we require greater accuracy we shall have to undertake a program of cycling the magnets. From the tune shifts calculated in Appendix C, we see that at heavy ion injection, the residual fields in the high field quadrupoles can give tune shifts as large as $\pm$ 0.1.

For completeness we show plots of G x L/I vs I and I/(G x L) vs (G x L) in Figures B4 and B5.

For a quadrupole magnet, the gradient B1, is the primary allowed term. The allowed higher harmonics are the duodecupole, B5, and the twenty-pole B9. These have been measured and the results are shown in Figs. B6 and B7. These fields are very small and can presumably be ignored. The measuring system is a tangential coil, rotating at a radius of 3.81 centimeters, whose voltage output is analyzed to give harmonics through B19. The data suggests that this remarkably fine system is even able to measure the next allowed term, the twenty-eight-pole, B13. The non-allowed terms have been measured, are all small, and since they are presumably due to random errors in magnet construction, no meaningful statements can be made about the results from only one magnet. Our conclusion is that we can treat these magnets as perfect quadrupoles.

Appendix B (continued)

TABLE B1
INTEGRATED FIELD MEASUREMENTS

CURRENT	B1*L Gauss	B5*L Gauss/cm**4	B9*L Gauss/cm**8
0.0	-36.46	0.001	-1.37E-07
99.9	4086.12	-0.078	-1.52E-05
199.6	8188.98	-0.158	-3.04E-05
299.4	12295.55	-0.238	-4.56E-05
399.2	16393.68	-0.317	-6.03E-05
449.0	18446.23	-0.357	-6.78E-05
399.2	16412.29	-0.317	-6.03E-05
299.4	12323.20	-0.238	-4.53E-05
199.6	8230.19	-0.160	-3.04E-05
99.9	4130.87	-0.080	-1.53E-05
0.0	40.60	-0.001	-7.04E-08
-99.9	-4080.82	0.079	1.51E-05
-199.6	-8177.41	0.159	2.99E-05
-299.4	-12276.55	0.238	4.48E-05
-399.1	-16371.54	0.318	6.01E-05
-449.0	-18420.34	0.357	6.75E-05
-399.1	-16388.66	0.318	6.02E-05
-299.4	-12308.75	0.239	4.50E-05
-199.6	-8219.43	0.160	2.99E-05
-99.9	-4125.36	0.081	1.48E-05
0.0	-36.36	0.002	-2.77E-07

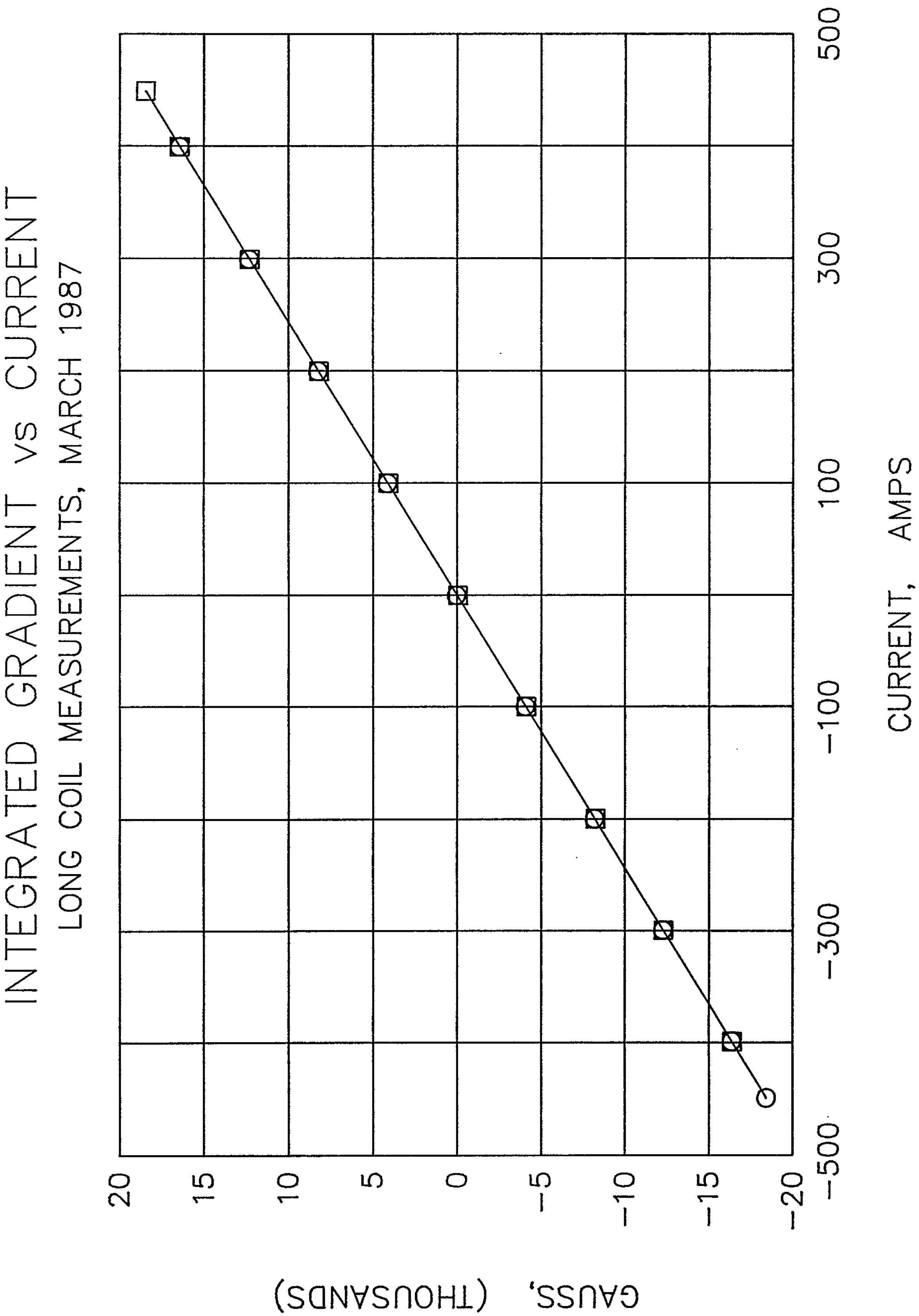

INTEGRATED GRADIENT vs CURRENT
LONG COIL MEASUREMENTS, MARCH 1987
GAUSS, (THOUSANDS)
20
15
10
5
0
−5
−10
−15
−20
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B1

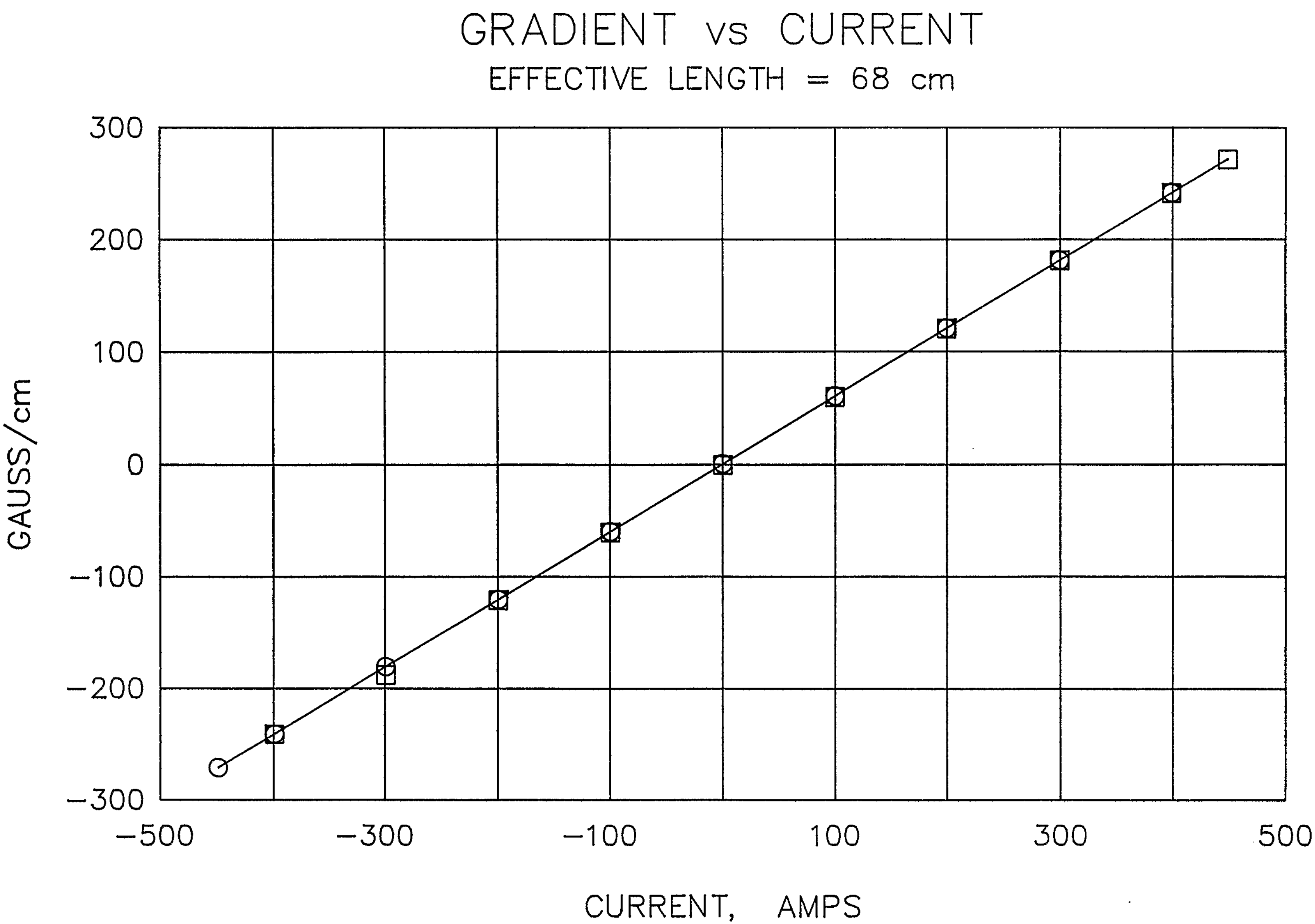

GRADIENT vs CURRENT
EFFECTIVE LENGTH = 68 cm
GAUSS/cm
300
200
100
0
−100
−200
−300
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B2

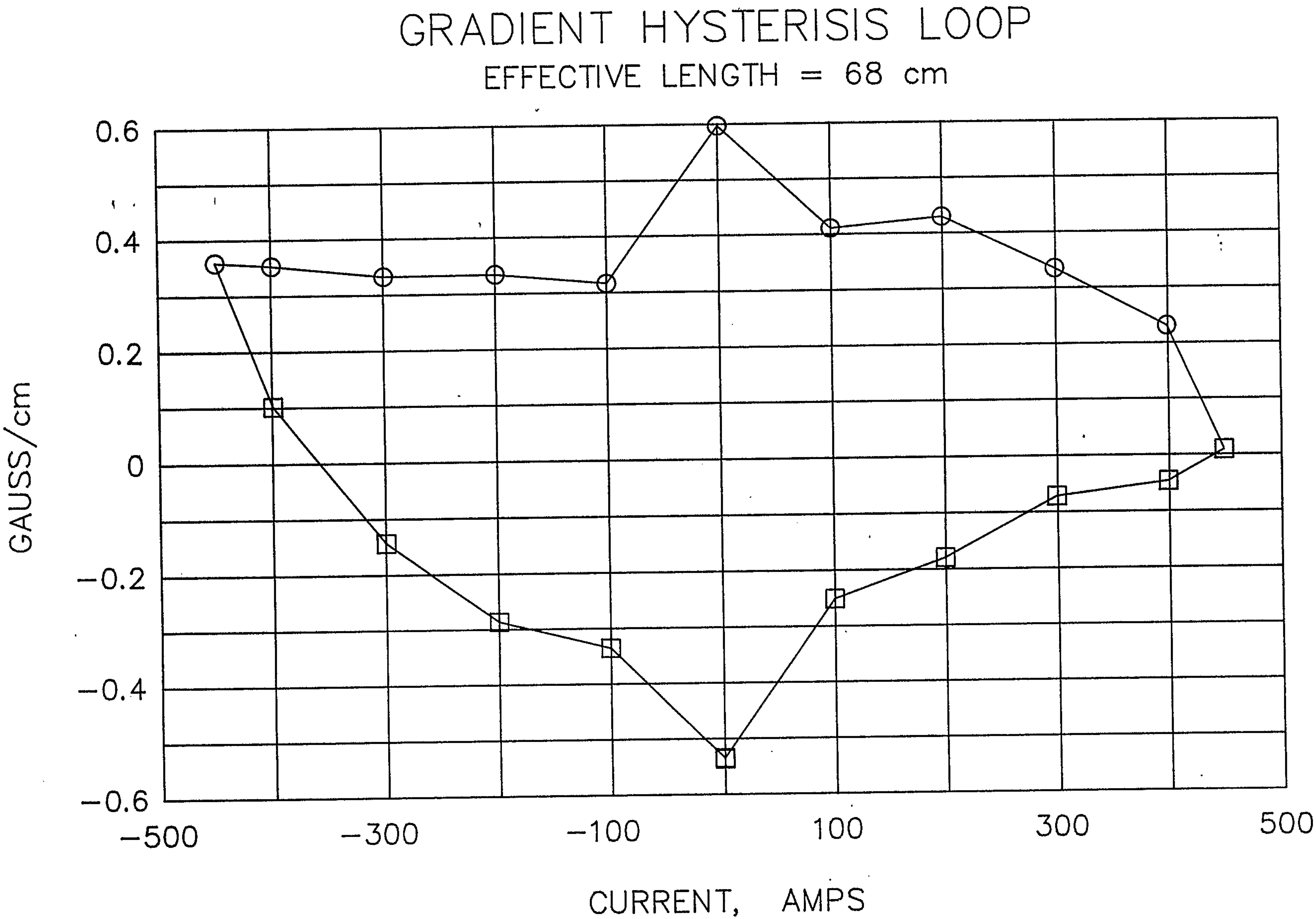

GRADIENT HYSTERISIS LOOP
EFFECTIVE LENGTH = 68 cm
GAUSS/cm
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B3

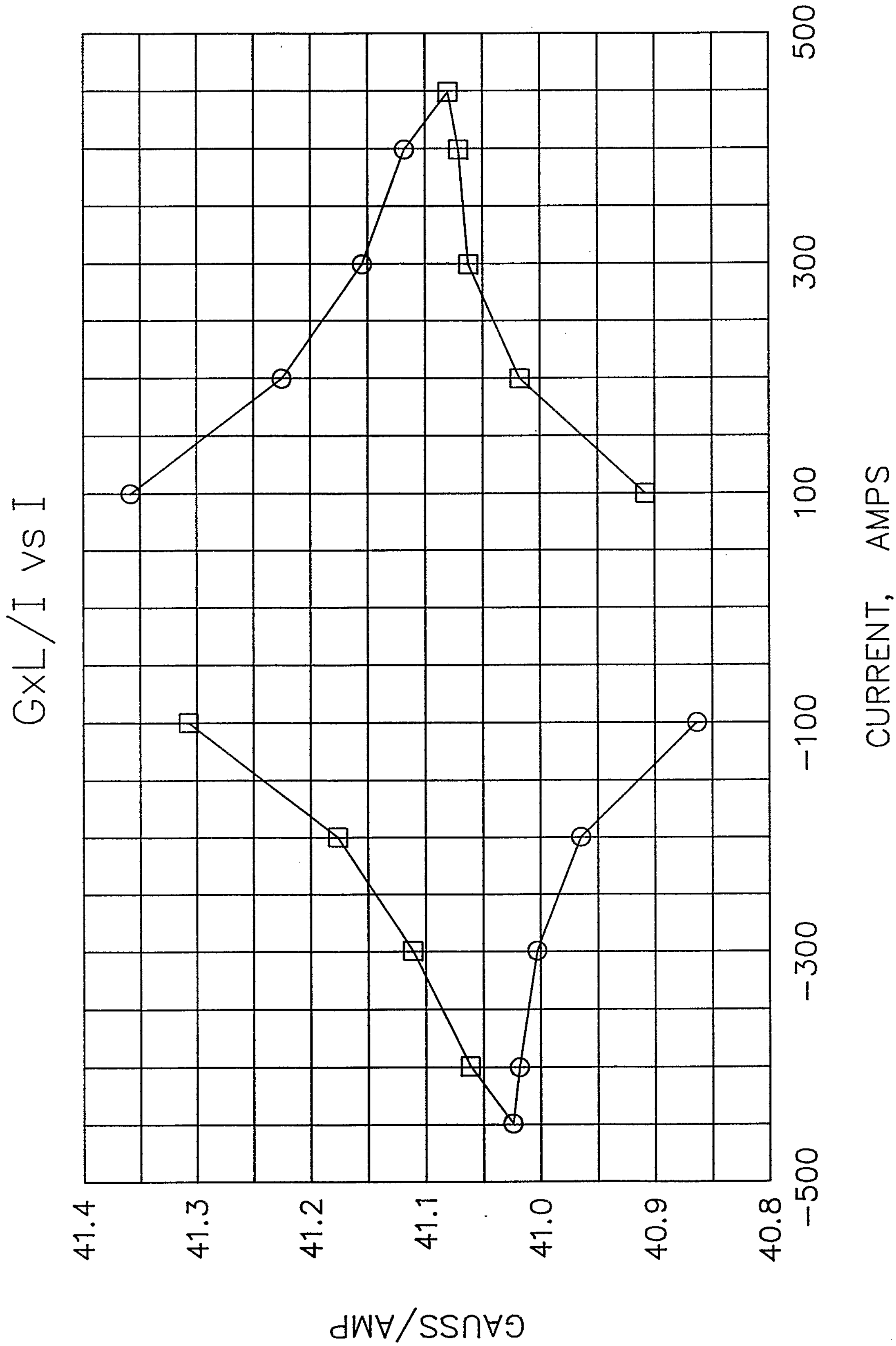

GxL/I VS I
GAUSS/AMP
41.4
41.3
41.2
41.1
41.0
40.9
40.8
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B4

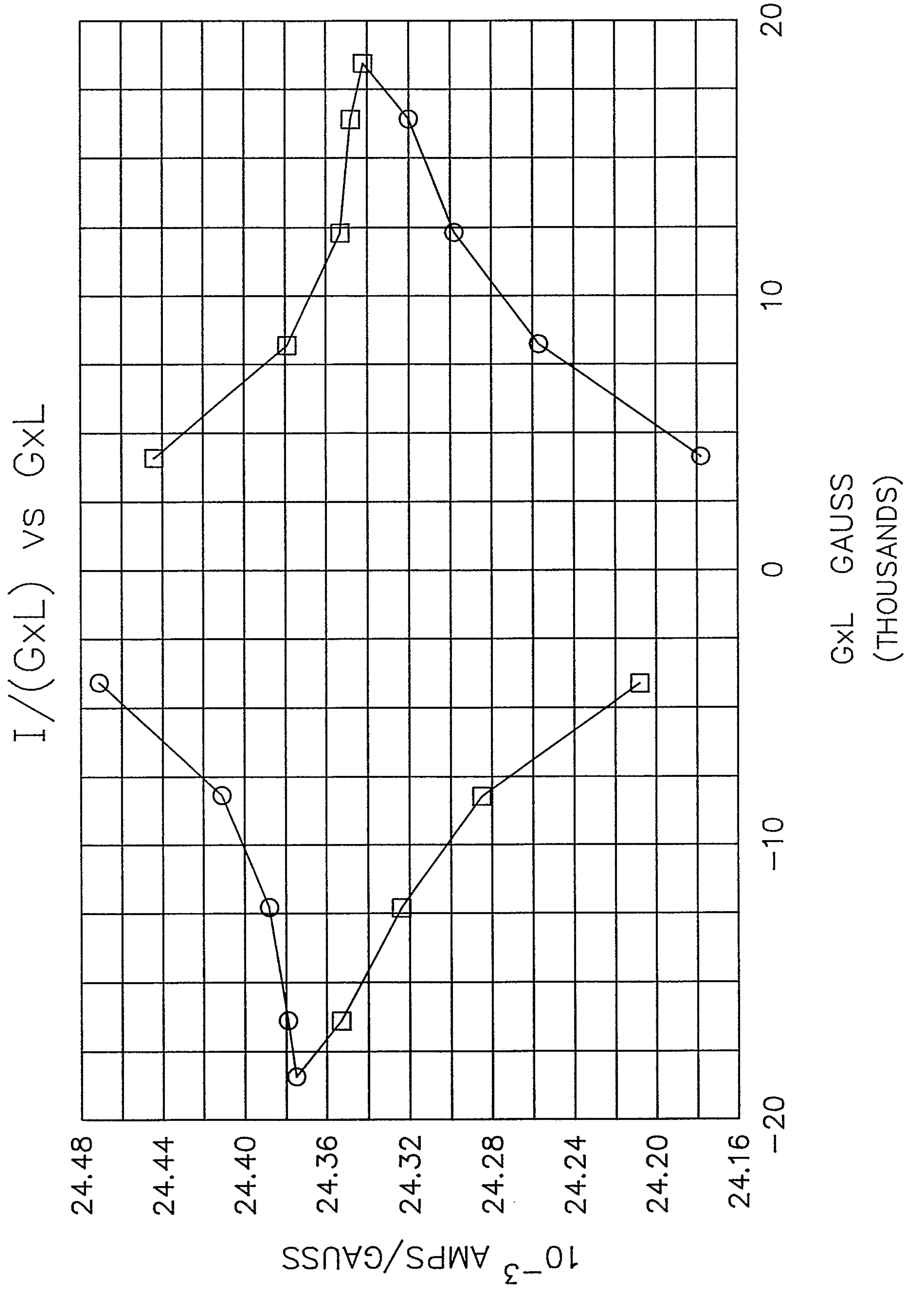

I/(GxL) VS GxL
24.48
24.44
24.40
24.36
24.32
24.28
24.24
24.20
24.16
10^-3 AMPS/GAUSS
−20
−10
0
10
20
GxL GAUSS
(THOUSANDS)

Figure B5

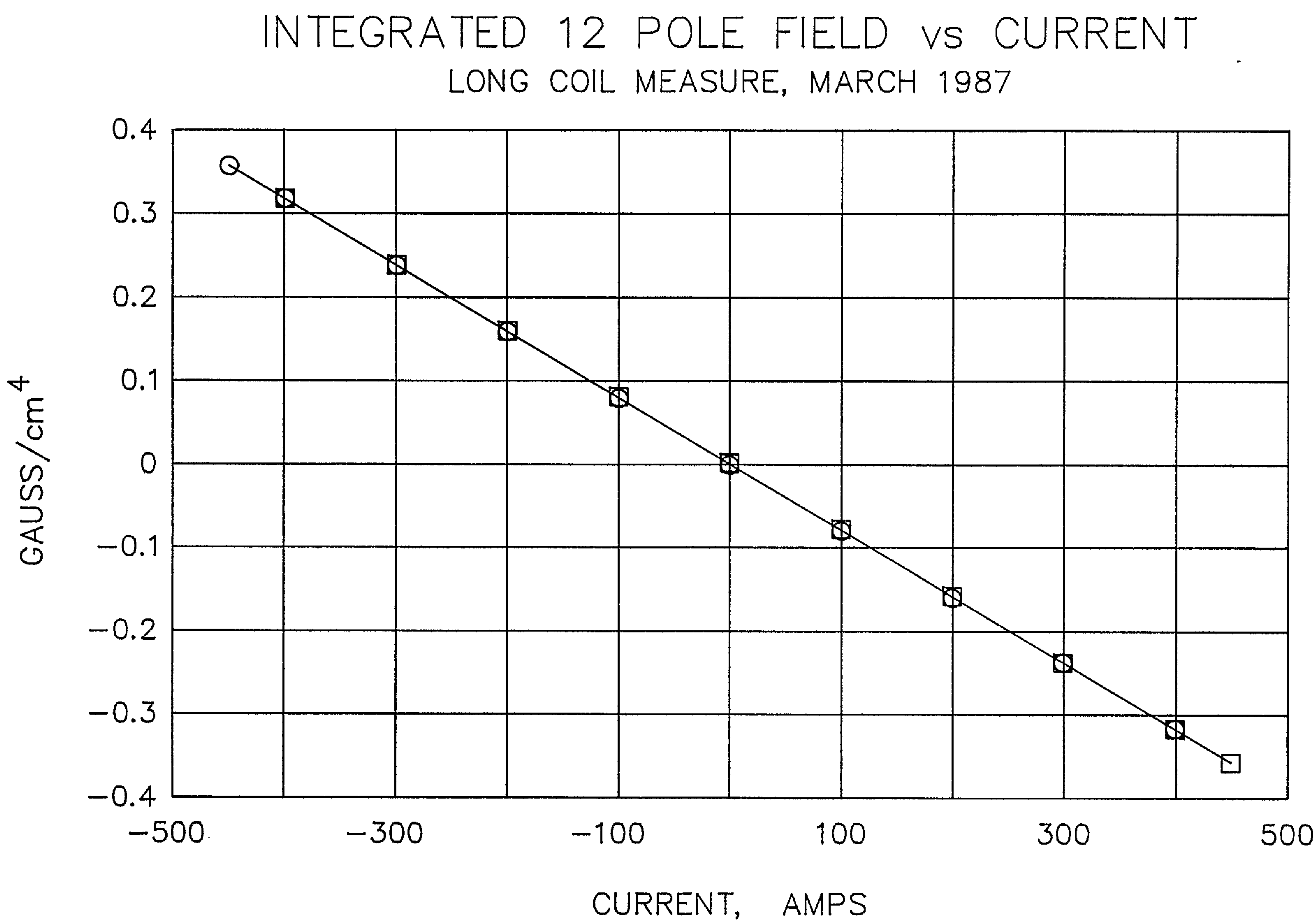

INTEGRATED 12 POLE FIELD vs CURRENT
LONG COIL MEASURE, MARCH 1987
GAUSS/cm4
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B6

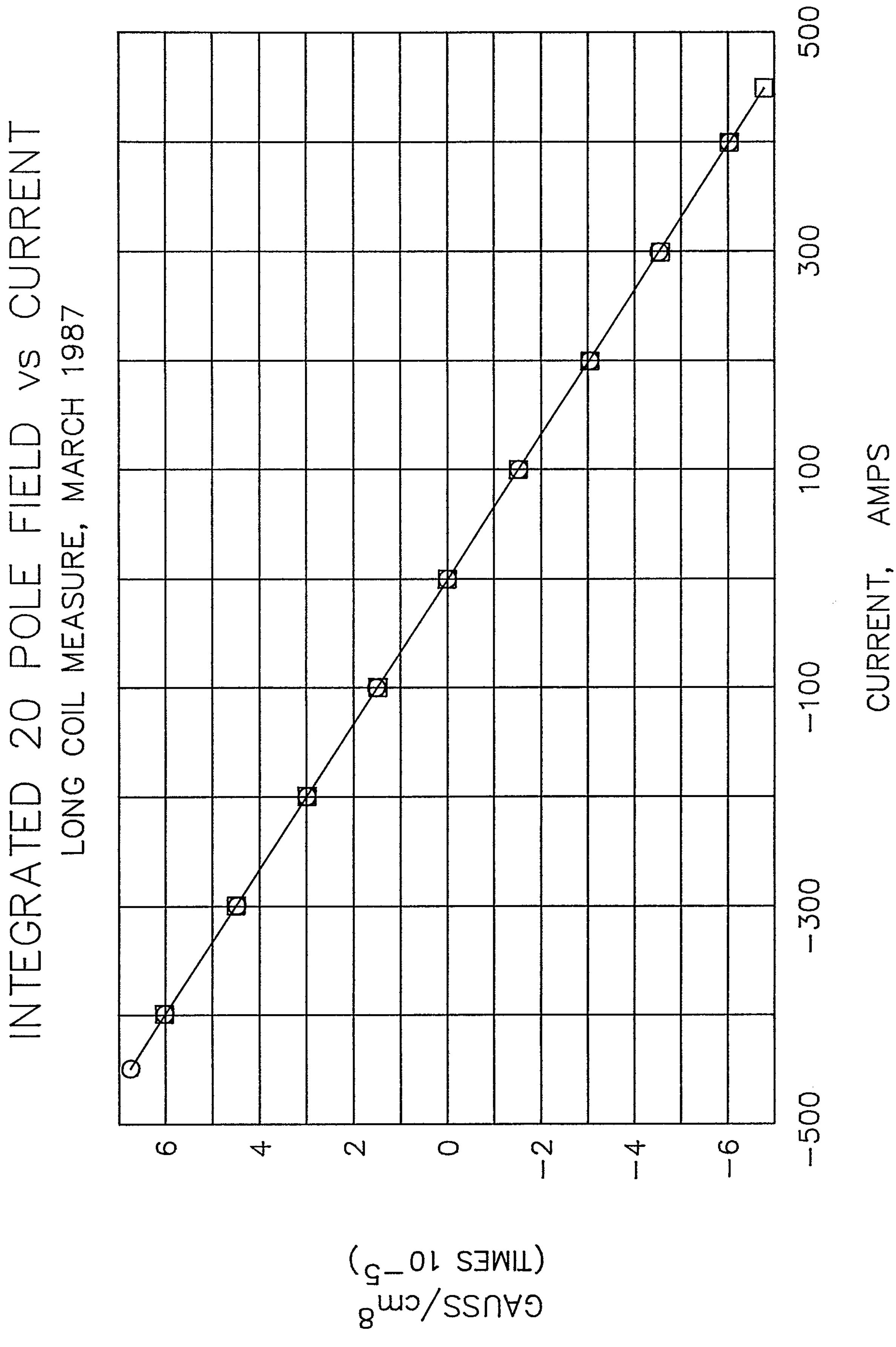

INTEGRATED 20 POLE FIELD vs CURRENT
LONG COIL MEASURE, MARCH 1987
6
4
2
0
−2
−4
−6
GAUSS/cm^8
(TIMES 10^{-5})
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B7

Appendix C

THE TUNE SHIFT PRODUCED BY THE HIGH FIELD QUADRUPOLES

The usual expression for a tune shift produced by a quadrupole perturbation is:

$$\Delta Q = - \frac{1}{4\pi} \int \beta K \, dL$$

The quadrupoles are located at the appropriate extremum of the beta functions, and the beta functions are therefore very flat through the quads. Values calculated by MAD are shown in Table C1 and Figures C1 and C2. In addition:

$$K = - G/B\rho$$

$$GdL = 41.08 \text{ I}$$

$$\frac{1}{B\rho} = \frac{3 \times 10^{-7}}{p}$$

Giving

$$\Delta Q = \frac{1}{4\pi} \sum_{1}^{12} 41.08 \times 3 \times 10^{-7} \, \beta I/p$$

$$= 117.7 \times 10^{-7} \, \beta I/p$$

The units for these formula are Gauss, centimeters, Amperes, and GeV/c.

Using the β values for 15 GeV/c we have:

$$\begin{bmatrix} \Delta Q_x \\ \Delta Q_y \end{bmatrix} = \begin{bmatrix} 0.0262 & 0.0121 \\ -0.0121 & -0.0261 \end{bmatrix} \begin{bmatrix} I_x/p \\ I_y/p \end{bmatrix}$$

TABLE C1
BETA FUNCTIONS CALCULATED BY MAD

P GEV/c	SS-3 BETA X meters	SS-3 BETA Y meters	SS-17 BETA X meters	SS-17 BETA Y meters
0.21	14.350	17.791	17.794	14.234
0.22	14.172	17.942	17.951	13.921
0.23	13.822	18.112	18.118	13.710
0.25	13.445	18.401	18.410	13.336
0.60	11.336	20.522	20.583	11.254
0.65	11.243	20.656	20.722	11.162
0.70	11.177	20.750	20.819	11.097
15	10.322	22.166	22.283	10.258
20	10.351	22.148	22.258	10.290
25	10.406	22.156	22.247	10.353
27	10.430	22.207	22.291	10.381
29	10.487	22.273	22.358	10.438
32	10.655	22.564	22.660	10.603

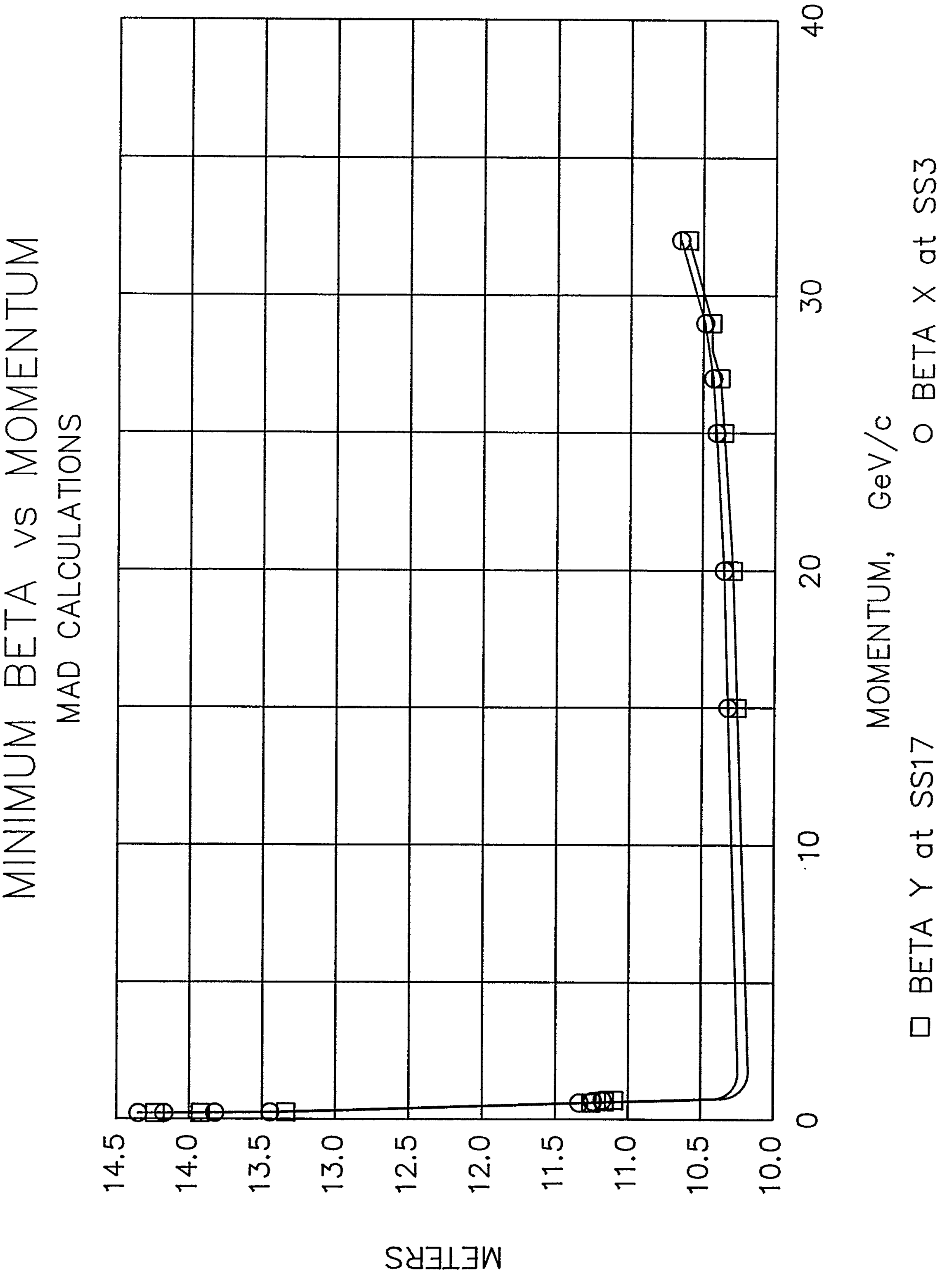

MINIMUM BETA vs MOMENTUM
MAD CALCULATIONS
METERS
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
0
10
20
30
40
MOMENTUM, GeV/c
□ BETA Y at SS17
○ BETA X at SS3

Figure C1

MAXIMUM BETA vs MOMENTUM

MAD CALCULATIONS

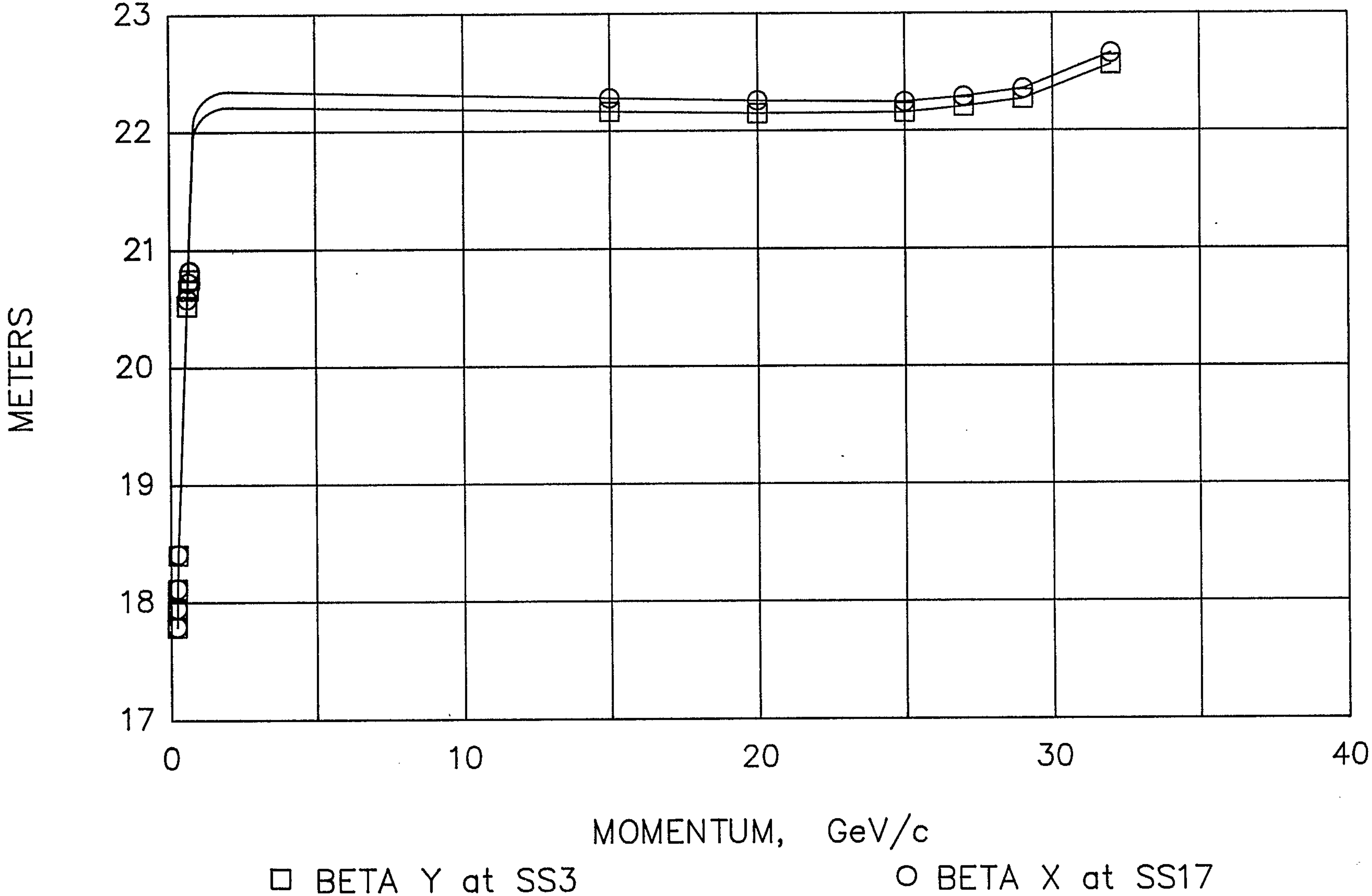


Figure C2