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DATA SHEETS FOR THE HIGH FIELD CHROMATIC SEXTUPOLES

E. J. Bleser

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Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

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Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
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Upton, New York 11973

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Technical Note

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DATA SHEETS FOR THE HIGH FIELD CHROMATIC SEXTUPOLES

E. Bleser and M. Tanaka

February 12, 1988

This note presents material collected on the 20 high field sextupoles installed in the AGS to control the horizontal and vertical chromaticity ($\xi = (\Delta Q/Q)/(\Delta P/P)$. The information is summarized in a data sheet with various appendices giving backup information. The nominal name for this type of magnet is 6S24. In the ring there are eight magnets connected in series located at horizontal maxima in Straight Sections 13, and 12 magnets connected in series at vertical maxima in Straight Sections 7. The four drive sextupoles for the slow extracted beam occupy the other four SS 13 locations and are not discussed in this note. In AGAST the horizontal sextupoles are designated SHORT and the vertical, SVERT.

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 SEXTUPOLE

	Inches	Centimeters	Ref.
1. PHYSICAL DESCRIPTION			
A. Core			
Core Length	24.0	60.96	a
Gap Radius	3.000	7.620	
B. Coil			a
Turns Per Pole	12		
Conductor Dimensions	0.469 x 0.338	1.191 x 0.858	
Cooling Hole Diameter	0.156	0.396	
Conductor Cross Section	0.139 sq. in.	0.897 sq. cm.	
Approx. Conductor Length per Pole	698	1773	
C. Vacuum Tube			b
O.D.	5.875	14.923	
I.D.	5.745	14.592	
Material	SS 304		
D. Locations			
Horizontal Sextupoles	8 places: A,B,D,E,G,H,J,K13		c
Vertical Sextupoles	12 places: A7 → L7		c

2. ELECTRICAL PROPERTIES — d

PER MAGNET

Resistance, measured	23.7	milliohms
calculated 60°F	20.5	milliohms
calcualted 100°F	22.5	milliohms
Inductance, measured	3.08	millihenrys

PER 12 MAGNETS

Resistance, measured	340	milliohms
Inductance, measured	38	millihenrys

3. MAGNETIC PROPERTIES — e

B_2 x L/I, measured	6.654 Gauss/(Amp x cm)
Chosen Effective Length, L	65.5 cm
Then, B2/I	0.1016 Gauss/(Amp x cm^2)
Calculated, B2/I	0.1022 Gauss/(Amp x cm^2)
B_8 x L/I, measured	-3.5×10^{-8} Gauss/(Amp x cm^7)

4. CHROMATICITY CONTROL — f

$$\Delta \xi_H = (0.138 \times I_H + 0.071 \times I_V)/P$$

$$\Delta \xi_V = -(0.064 \times I_H + 0.151 \times I_V)/P$$

Evaluated at P = 29 GeV/c.
I_H = current in Amps in 8 HF horizontal sextupoles.
I_V = current in Amps in 12 HF vertical sextupoles.
P = beam momentum in GeV/c.

RFERENCES

a. Mechanical Drawing D03-M-1288-5.

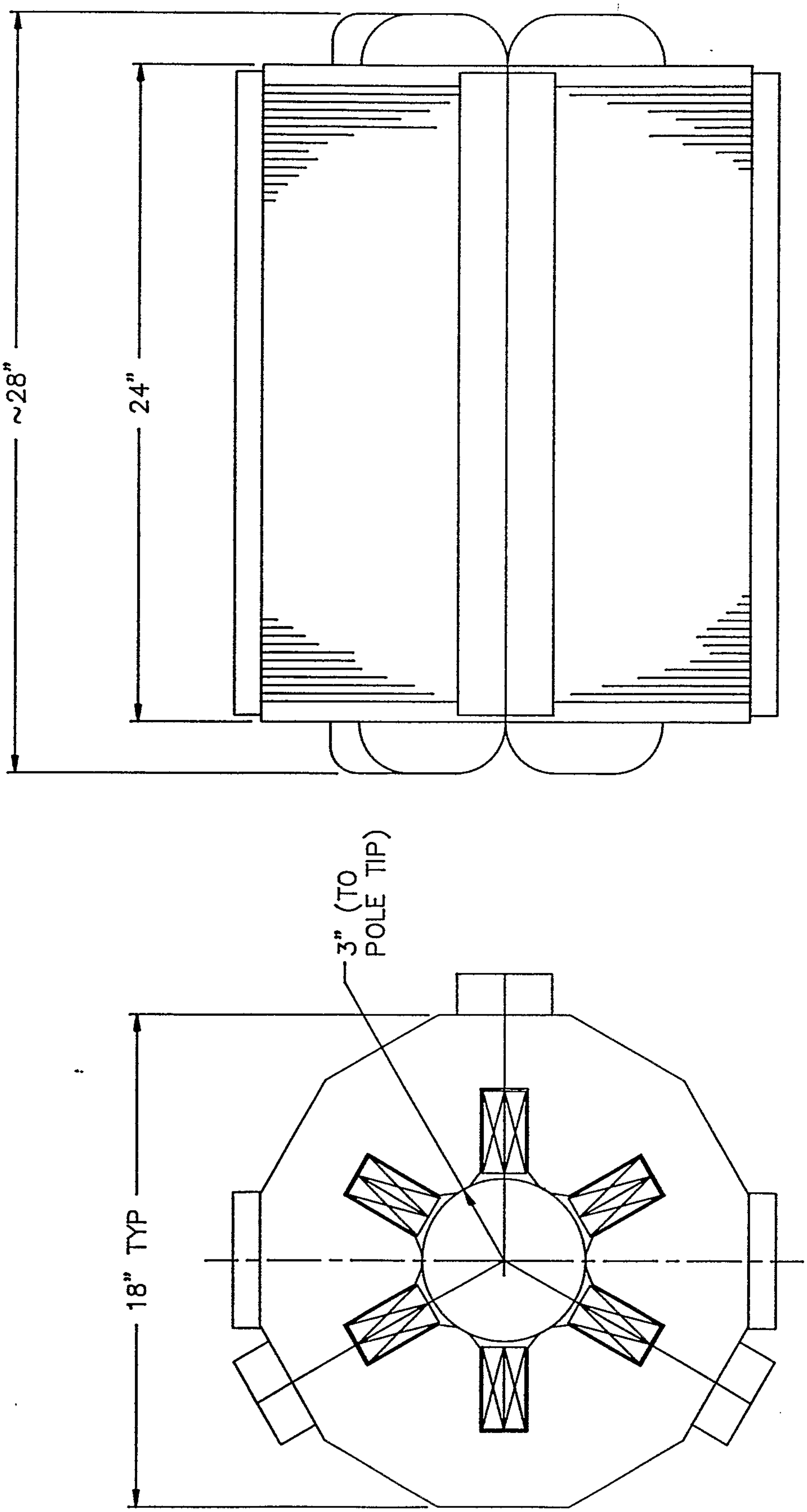
b. Mechanical Drawing C-D05-M-959-4.

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

d. Appendix A.

e. Appendix B.

f. Appendix C.


~28"
24"
3" (TO
POLE TIP)
18" TYP

APPENDIX A

THE ELECTRICAL PROPERTIES OF THE HIGH FIELD SEXTUPOLES

The material in this appendix was collected or calculated largely by Bill Leonhardt. Figure A-1 shows the calculated pressure drop across a magnet as a function of the flow rate and the calculated temperature rise versus flow rate for d.c. currents of 600 and 800 Amps. The magnets normally operate at less than 500 Amps with a duty cycle of less than 50% and a pressure drop of about 68 psid, suggesting that they are normally quite cool. There are at present 12 water circuits on a magnet, connected in two series of six. The cooling could be increased by connecting as many as all 12 circuits in parallel. The calculations are for a system of three series of four.

The most recent measurements of the resistance and inductance of a magnet (Joe Funaro and Lou Mazarakis, January, 1988) confirm earlier measurements and give

PER MAGNET

R = 23.7 milliohm

L = 3.08 millihenry

PER 12 MAGNET SYSTEM

R = 340 milliohm

L = 38 millihenry

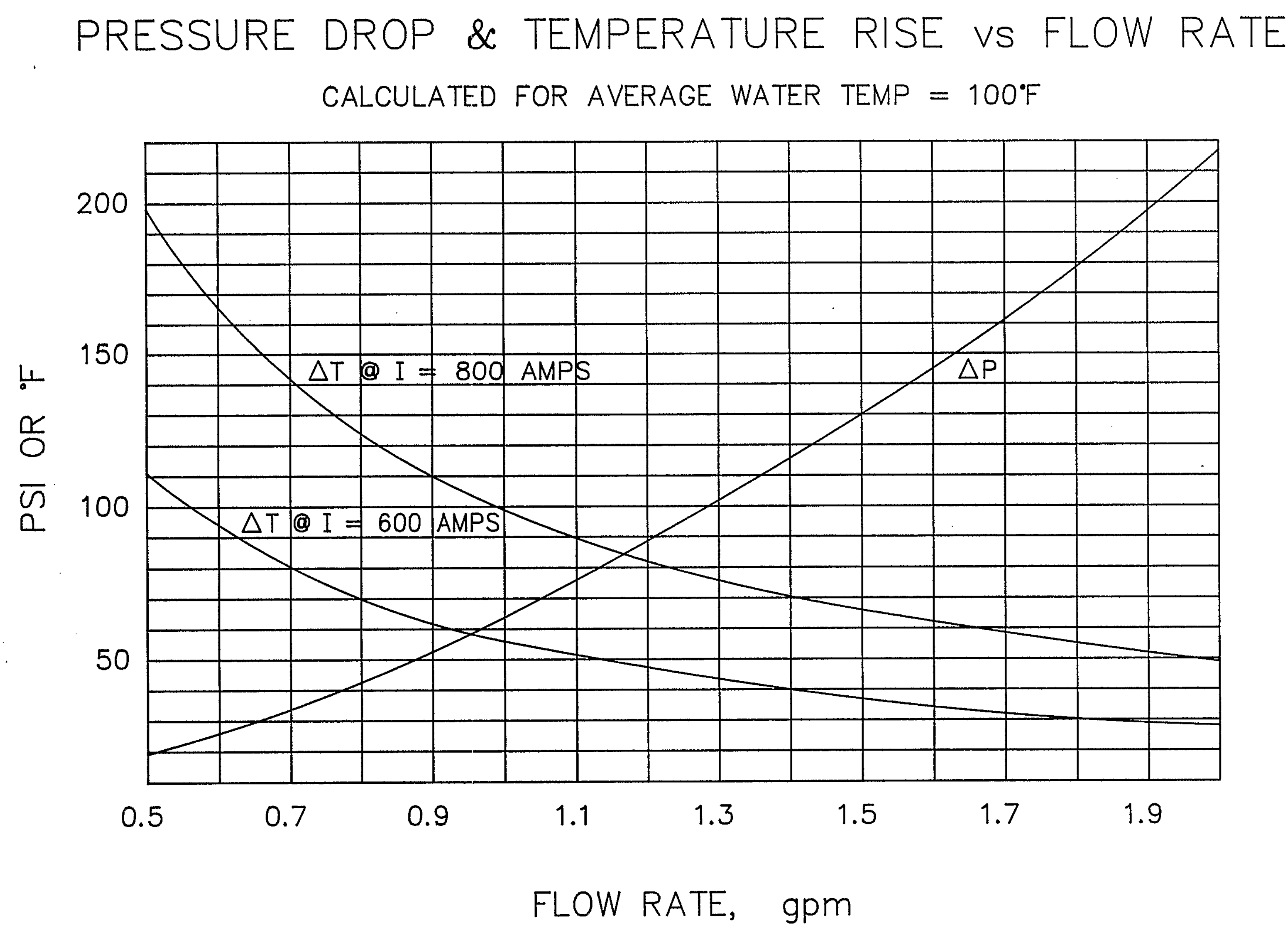

PRESSURE DROP & TEMPERATURE RISE vs FLOW RATE
CALCULATED FOR AVERAGE WATER TEMP = 100°F
200
150
100
50
PSI OR °F
ΔT @ I = 800 AMPS
ΔT @ I = 600 AMPS
ΔP
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
FLOW RATE, gpm

Figure A1

APPENDIX B

THE MAGNETIC PROPERTIES OF THE HIGH FIELD SEXTUPOLES

The high field sextupole magnets were designed in 1958. Other than the mechanical drawings, which seem to be complete and readily available, we have found little data on them. There are 20 magnets installed in the AGS and about 16 spares. One of the spares was carefully measured by the Magnetic Measurements Group of the AD Department in December, 1987. We would like to thank Peter Wanderer for supporting this effort, 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 sextupole field integrated through the length of the magnet. The results are given in Table B-1 and plotted in Figure B-1. There are some hysteresis effects, not particularly visible in this plot, which give us some options in defining the sextupole field 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

$$B_2 \times L/I = 6.654 \text{ Gauss/(Amp x cm)}.$$

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

It is useful to consider also the sextupole field strength rather than the integrated sextupole. However, we do not have a point measurement of the sextupole 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

$$L_{eff} = 65.5 \text{ cm}.$$

Then

$$B_2/I = 0.1016 \text{ Gauss/(Amp x cm}^2\text{)}.$$

A simple calculation gives

$$B_2/I = 1.2 \times \pi \times N/a^3$$

$$= 0.1022 \text{ Gauss/(Amp} \times \text{cm}^2)$$

where N = the number of turns and a = the radius of the bore. We have chosen L_{eff} to be the core length plus 0.6 x a, which is a very reasonable choice, so we feel the overall picture is consistent.

For convenience, we replot Fig. B-1 with the integrated gradient divided by the effective length to get Fig. B-2. In order to see the hysteresis effects, we replot in Fig. B-3 the data from Fig. B-2 with 0.1016 x I, the postulated straight line, subtracted from the data. Figure B-3 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 chromaticity shifts calculated in Appendix C, we see that at heavy ion injection the residual fields in the high field sextupoles can give chromaticity shifts as large as $\pm$ 1. For all of these plots, the squares indicate increasing current, the circles decreasing current.

For completeness, we show plots of B_2 x L/I vs I and I/(B_2 x L) vs (B_2 x L) in Figures B-4 and B-5.

We have defined the magnetic field on the midplane as

$$B_Y = B_o + B_1 X + B_2 X^2 + B_3 X^3 + \ldots\ldots$$

For a sextupole magnet B_2 is the primary allowed term. The first allowed higher harmonic is the eighteen-pole, B_8. This has been measured and the results are shown in Figure B-6. This field is 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 B_{19}. 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 sextupoles.

TABLE B1
INTEGRATED FIELD MEASUREMENTS

CURRENT AMPS	B2 x L Gauss/cm	B8 x L Gauss/cm**7
-0.3	-7.05	-4.96E-06
10.1	63.46	-1.66E-05
20.1	130.34	-4.20E-05
50.0	331.87	-1.30E-04
99.9	665.88	-2.46E-04
199.6	1331.99	-4.34E-04
299.4	1997.11	-4.61E-04
399.1	2657.64	-9.85E-04
449.0	2987.83	-1.03E-03
399.1	2661.48	-9.00E-04
299.4	2002.68	-6.48E-04
199.6	1339.27	-5.00E-04
99.9	674.82	-2.56E-04
50.0	341.38	-8.85E-05
20.1	140.09	-5.26E-05
10.1	72.99	-3.06E-05
0.3	7.44	-6.41E-06
-10.1	-63.07	2.61E-05
-20.0	-130.01	3.76E-05
-50.0	-331.41	1.37E-04
-99.9	-665.75	2.44E-04
-199.6	-1330.19	5.11E-04
-299.4	-1994.37	6.97E-04
-399.1	-2655.61	9.15E-04
-449.0	-2984.26	1.11E-03
-399.1	-2659.28	8.66E-04
-299.4	-2000.78	7.86E-04
-199.6	-1339.52	4.14E-04
-99.9	-674.54	2.63E-04
-50.0	-341.12	1.14E-04
-20.0	-139.80	4.96E-05
-10.1	-72.67	3.20E-05
-0.3	-7.05	4.55E-06

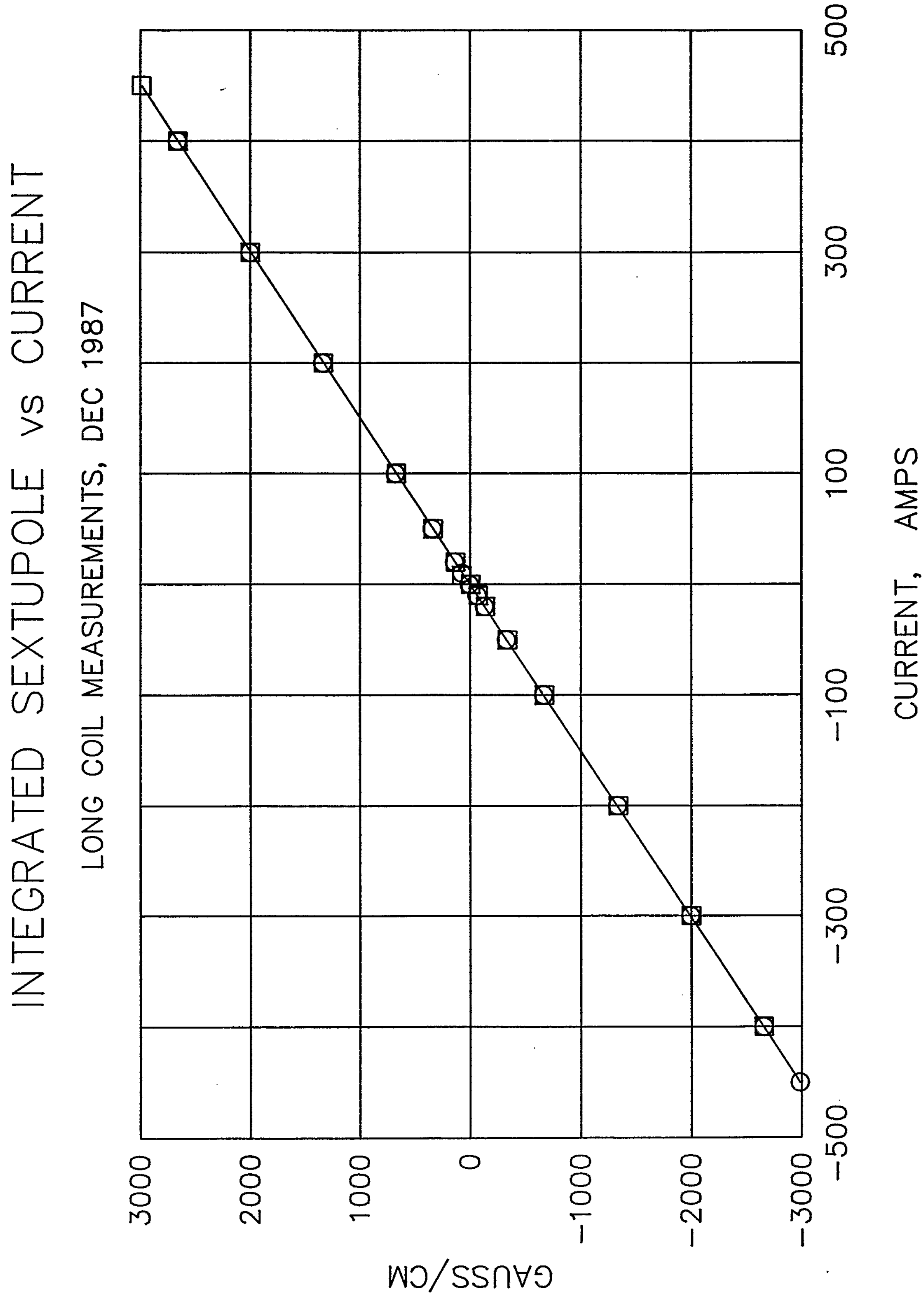

INTEGRATED SEXTUPOLE vs CURRENT
LONG COIL MEASUREMENTS, DEC 1987
GAUSS/CM
3000
2000
1000
0
−1000
−2000
−3000
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B1

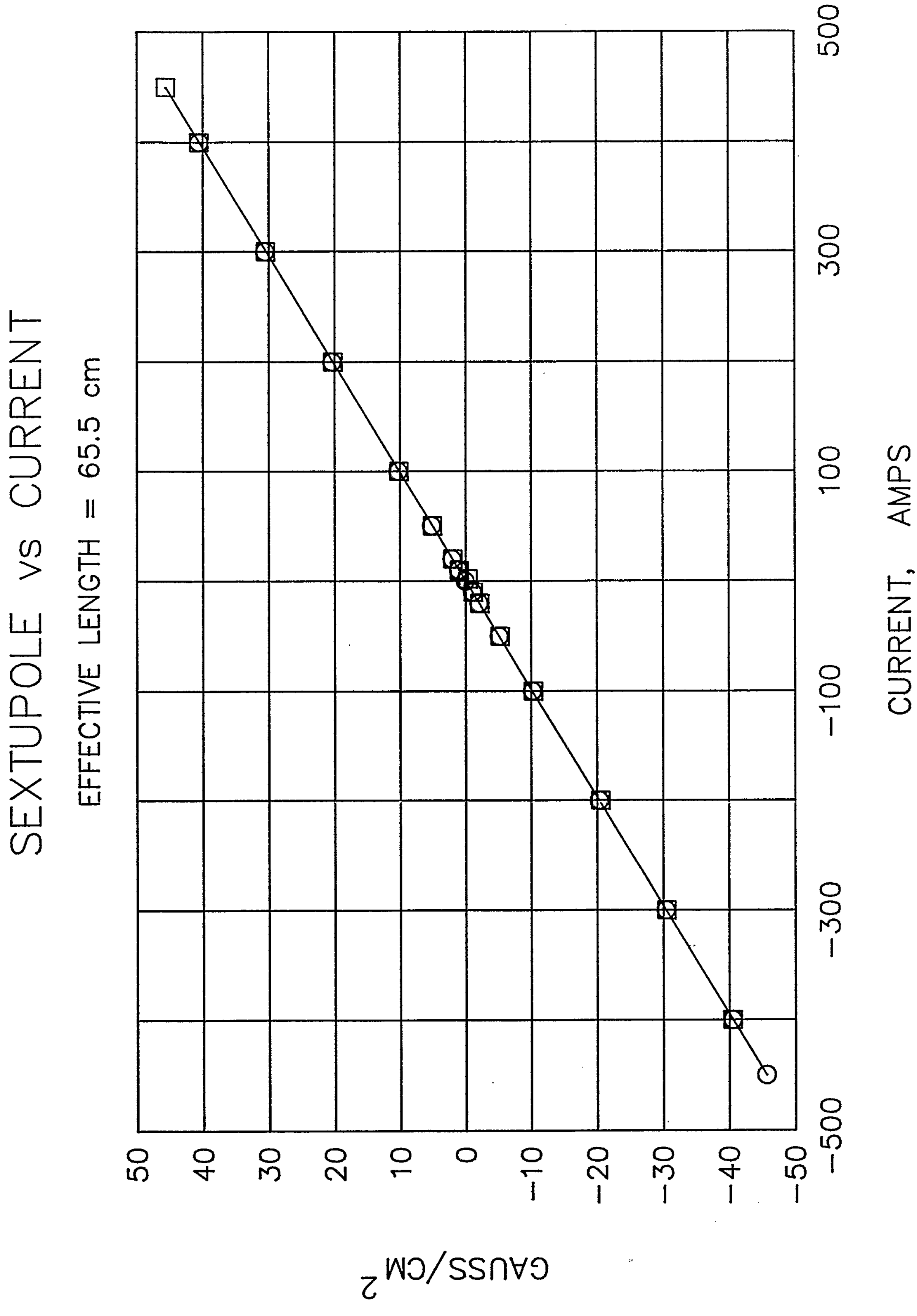

SEXTUPOLE vs CURRENT
EFFECTIVE LENGTH = 65.5 cm
GAUSS/CM^2
50
40
30
20
10
0
−10
−20
−30
−40
−50
−500
−300
−100
100
300
500
CURRENT, AMPS

Figure B2

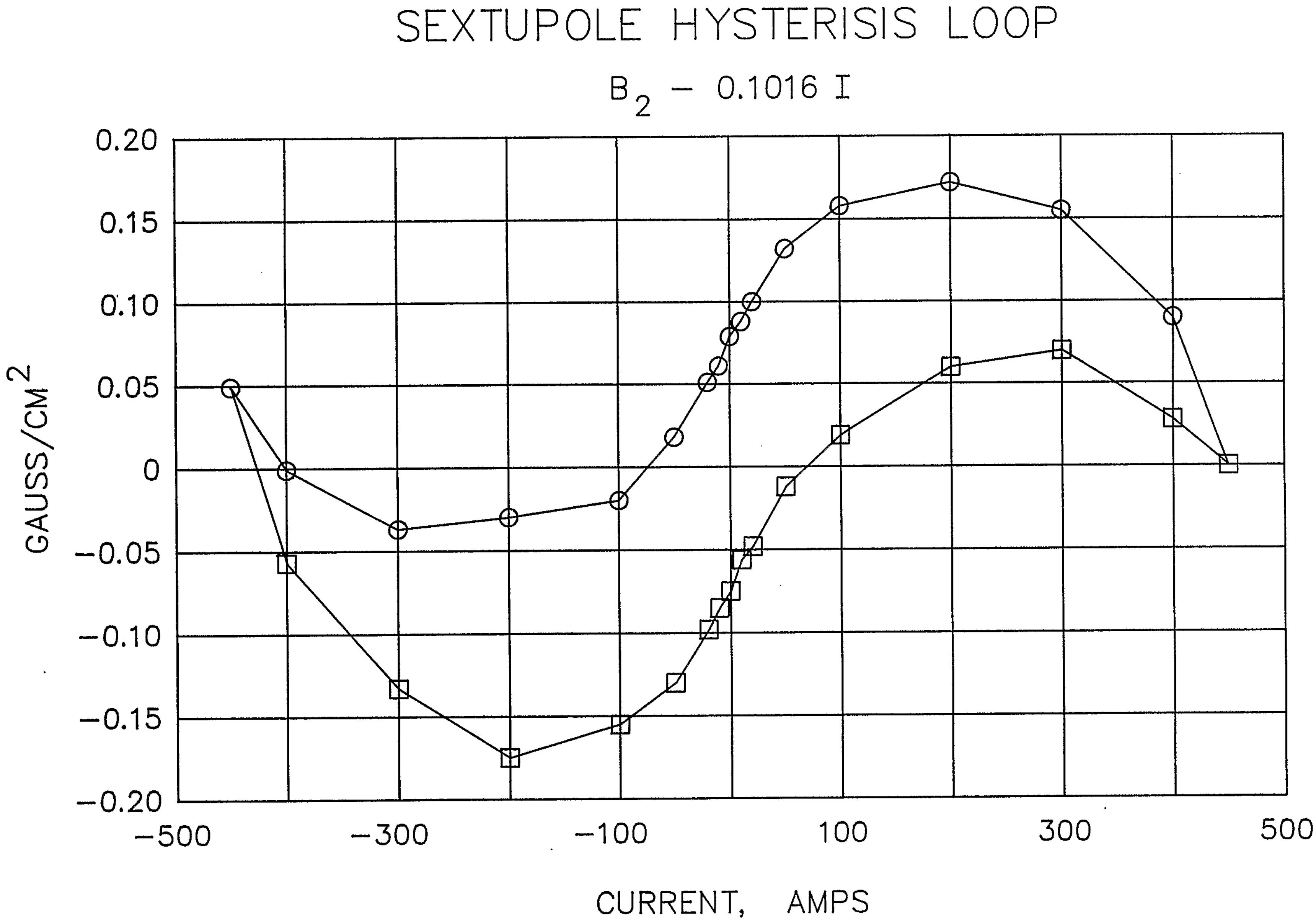

SEXTUPOLE HYSTERISIS LOOP
B2 – 0.1016 I
0.20
0.15
0.10
0.05
0
–0.05
–0.10
–0.15
–0.20
GAUSS/CM2
–500
–300
–100
100
300
500
CURRENT, AMPS

Figure B3

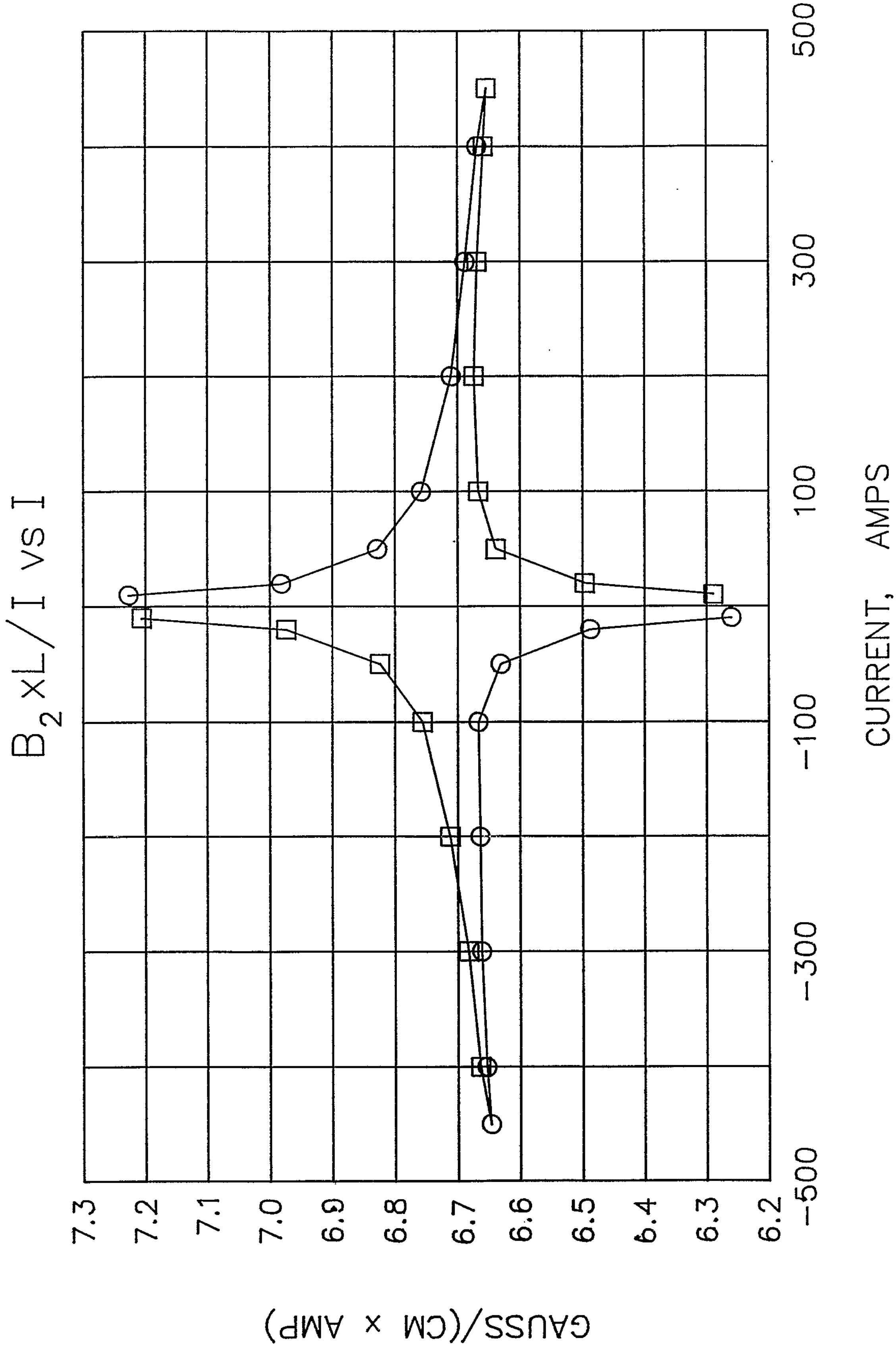
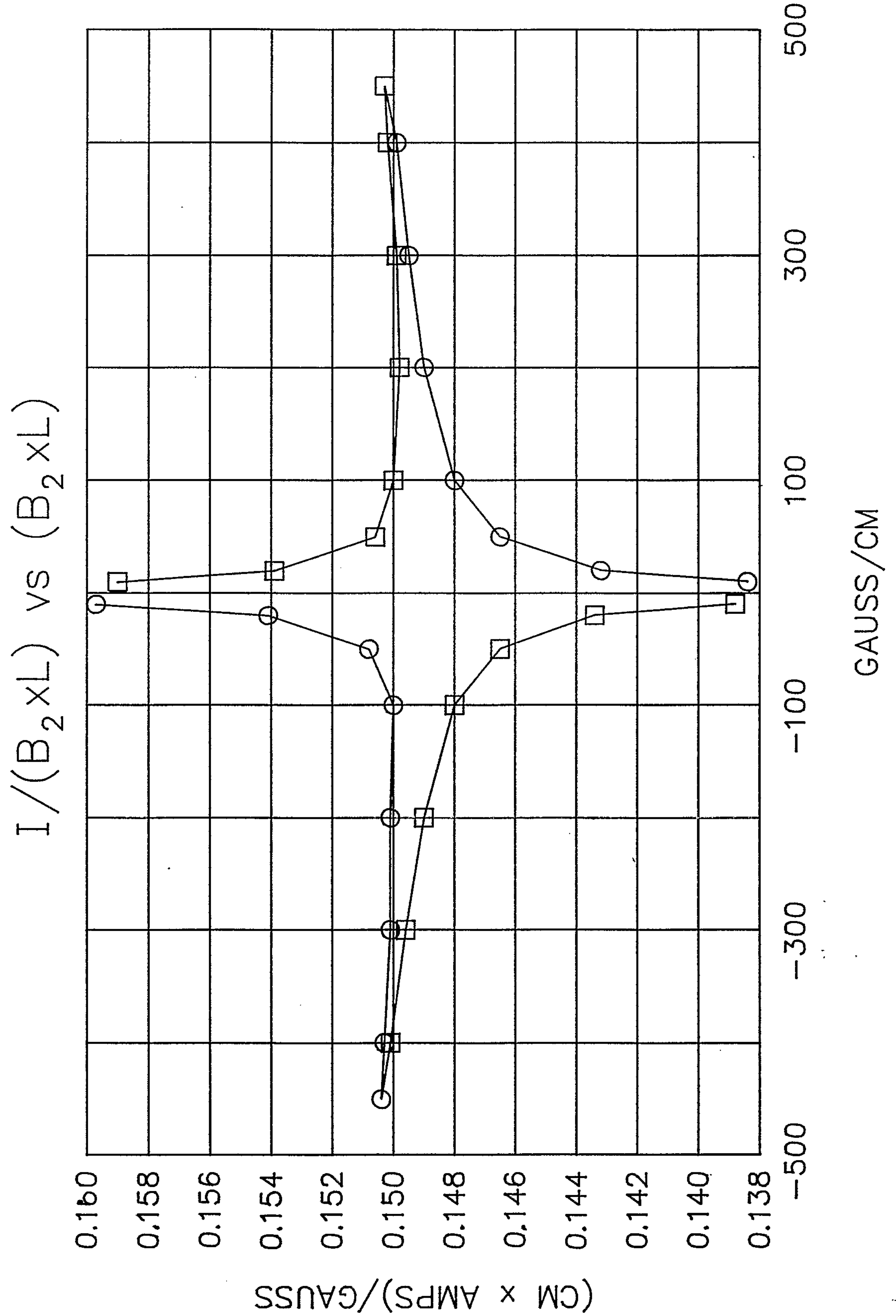

$B_2 xL/I$ vs I
GAUSS/(CM x AMP)
7.3
7.2
7.1
7.0
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
-500
-300
-100
100
300
500
CURRENT, AMPS

Figure B4



I/(B$_2$xL) VS (B$_2$xL)
(CM x AMPS)/GAUSS
0.160
0.158
0.156
0.154
0.152
0.150
0.148
0.146
0.144
0.142
0.140
0.138
−500
−300
−100
100
300
500
GAUSS/CM

Figure B5

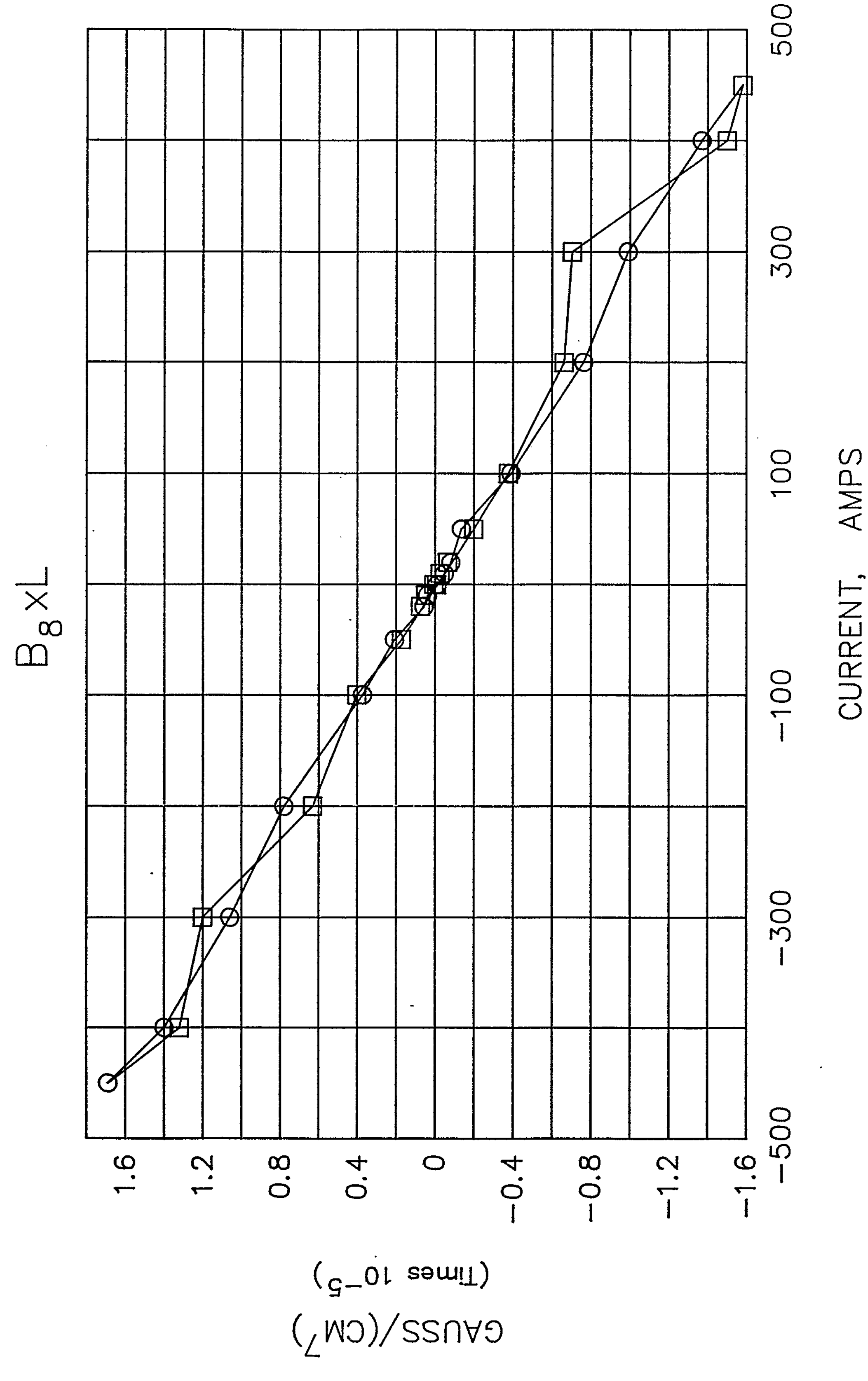

B8XL
CURRENT, AMPS
GAUSS/(CM7)
(Times 10-5)
-500
-300
-100
100
300
500
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6

Figure B6

APPENDIX C

CHROMATICITY SHIFT CALCULATION

More or less following a standard treatment (for instance Edwards, AIP Conference Proceedings No. 127), we define the chromaticity as the fractional tune shift divided by the fractional momentum shift

$$\xi = \frac{\Delta Q}{Q} \Big/ \frac{\Delta P}{P}.$$

In the AGS, the chromaticity can be adjusted by the horizontal and vertical sextupoles according to the formulae

$$\Delta \xi_H = \frac{1}{4\pi Q_H} \left[N_H \times \beta_H(13) \times \eta(13) \times S_H + N_V \times \beta_H(7) \times \eta(7) \times S_V\right]$$

$$\Delta \xi_V = \frac{1}{4\pi Q_V} \left[N_H \times \beta_V(13) \times \eta(13) \times S_H + N_V \times \beta_V(7) \times \eta(7) \times S_V\right].$$

Where

N_H = number of sextupoles at horizontal beta maximum;
= 8.

N_V = number of sextupoles at vertical beta maximum;
= 12.

$\beta_H(n)$ = horizontal beta function at the nth straight section.

$\beta_V(n)$ = vertical beta function at the nth straight section.

$\eta(n)$ = horizontal momentum dispersion at the nth straight section.

S = sextupole strength.

$$S = \frac{2 \times B_2 \times L}{B\rho}$$

$$B_2 \times L = 6.654\ I$$

$$B\rho = \frac{10^7}{2.9979}\ P.$$

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

The present version of MAD calculates the tunes, chromaticities, beta functions, and dispersions for a number of different momenta for a d.c. machine (Auerbach, unpublished). Eddy currents produced by a ramping accelerator can change these numbers significantly in some cases (Bleser, Accelerator Division Technical Note No. 288). Table C-1 shows the calculated beta and dispersion functions at Straight Sections 7 and 13, the vertical and horizontal beta maxima, and Table C-2 shows the calculated tunes and chromaticities, with the chromaticities corrected for the ramp rate effects. The calculations agree in general with the measurements, but not yet as well as we would like, so these tabulations should be taken as illustrative and not as exact.

If we use the values for P = 29 GeV/c, the chromaticity shifts are

$$\Delta \xi_H = (0.138\ I_H + 0.071\ I_V) / P, \text{ and}$$

$$\Delta \xi_V = -(0.064\ I_H + 0.151\ I_V) / P.$$

Figure C1 shows a plot of $\Delta \xi_V$ versus $\Delta \xi_H$ for I_H from +600 to -600 Amperes at three values of I_V, +600, 0, and -600 Amperes. The chromaticity adjustments available with the present set of correction magnets fall within this parallelogram.

TABLE C1 BETA & DISPERSION FUNCTIONS
MAD CALCULATIONS

	VERTICAL SEXTUPOLES SS 7			HORIZONTAL SETUPOLES SS 13		
P	BETA X	DX	BETA Y	BETA X	DX	BETA Y
GeV/c	CM	CM	CM	CM	CM	CM
0.21	1435	94	1779	1779	263	1423
0.22	1417	97	1794	1795	262	1392
0.23	1382	100	1811	1812	259	1371
0.25	1344	106	1840	1841	255	1334
0.60	1134	135	2052	2058	227	1125
0.65	1124	137	2066	2072	225	1116
0.70	1118	138	2075	2082	224	1110
15.00	1032	151	2217	2228	205	1026
20.00	1035	151	2215	2226	206	1029
25.00	1041	152	2216	2225	207	1035
27.00	1043	153	2221	2229	208	1038
29.00	1049	154	2227	2236	210	1044
32.00	1065	160	2256	2266	214	1060

TABLE C2 CALCULATED TUNES & CHROMATICITIES
MAD CALCULATION, CORRECTED FOR RAMP RATE
NOT FINAL

P GeV/c	Q(h)	Q(v)	Xi(h)	Xi(v)
0.21	8.568	8.597	0.358	-2.973
0.22	8.567	8.625	0.234	-2.833
0.23	8.599	8.631	0.122	-2.705
0.25	8.614	8.647	-0.076	-2.480
0.60	8.716	8.762	-1.403	-0.970
0.65	8.717	8.763	-1.476	-0.887
0.70	8.718	8.766	-1.540	-0.815
15.00	8.720	8.772	-2.117	-0.161
20.00	8.713	8.763	-2.351	0.073
25.00	8.692	8.734	-2.872	0.562
27.00	8.671	8.710	-3.388	1.034
29.00	8.633	8.670	-4.352	1.882
32.00	8.497	8.537		

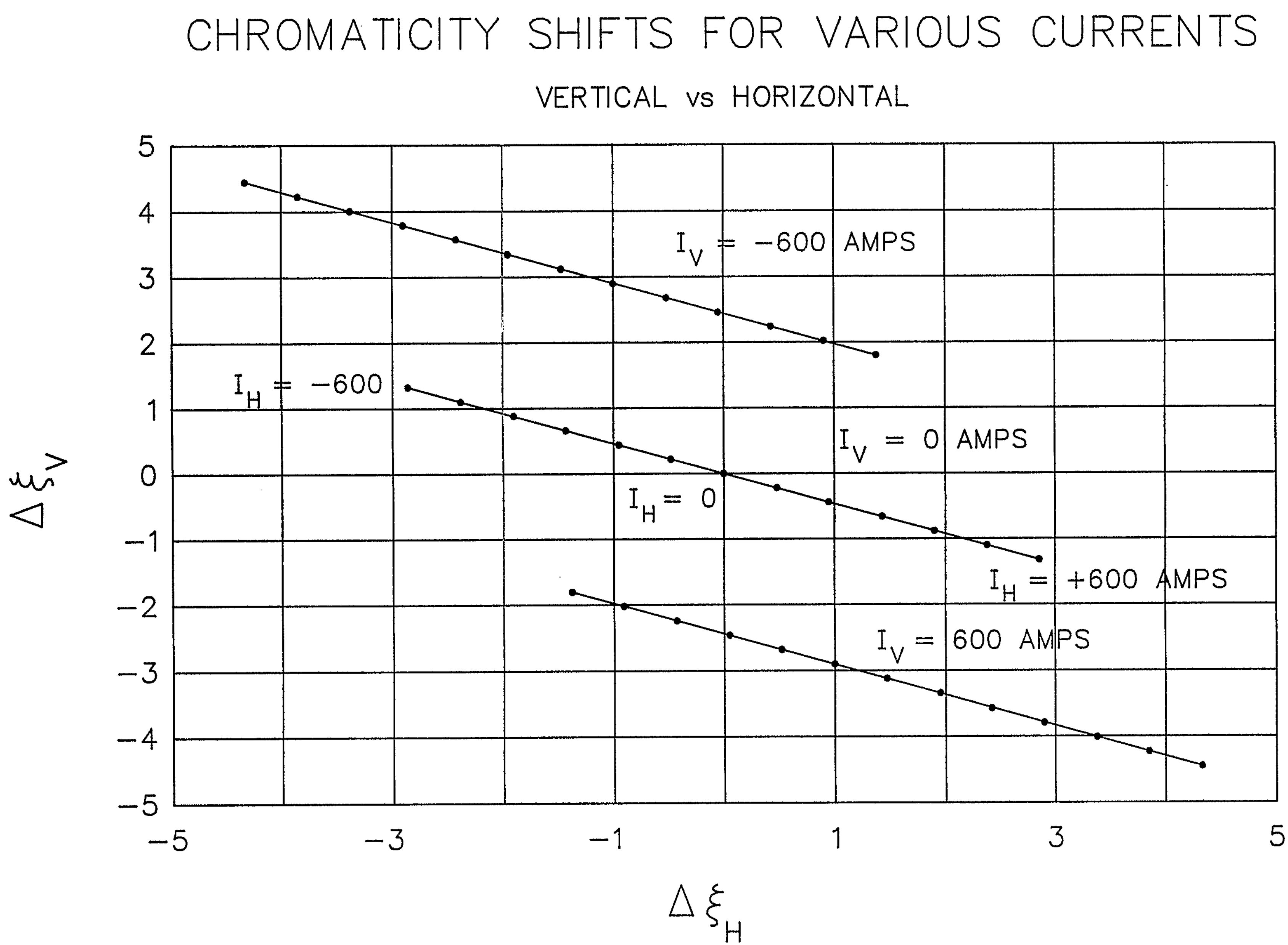

CHROMATICITY SHIFTS FOR VARIOUS CURRENTS
VERTICAL vs HORIZONTAL
I_V = −600 AMPS
I_V = 0 AMPS
I_V = 600 AMPS
I_H = −600
I_H = 0
I_H = +600 AMPS
5
4
3
2
1
0
−1
−2
−3
−4
−5
−5
−3
−1
1
3
5
$\Delta \xi_V$
$\Delta \xi_H$

Figure C1