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Title: The RHIC 2 in 1 with SSC Common Iron

Task Force: Coil Geometry Analysis

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The RHIC 2 in 1 with SSC common iron

The SSC reference design dipole has two layers of wide NbTi superconductor. with inner coil diameter 2.002 cm. The purpose of the present note is to determine if the same iron can be used with a single coil layer to acheive the field needed for the RHIC. yet with sufficiently small "cross talk" to permit one aperture to be operated with 40% of the field in the other aperture.

A single layer of the extra-wide. LBL designed cable used in the SSC reference design would give a higher field than needed for RHIC. so a coil configuration using the standard CBA cable was attempted. It was not possible to satisfy the field quality requirements using a standard thickness CBA cable but a solution was found based on a 29 wire cable with CBA width and it was designated RHIC-21. This coil configuration has the usual gap of 0.503 cm between the bare coil outer edge and the iron. the latter having an aperture radius of 4.392 cm. The wire size is .02126 inch. and the packing factor required to attain the desired mid-thickness of 0.0442 inch (incl. insul.) is 86.2%. The cable is assumed to be fuly keystoned. which may present some difficulty. The difference in bare cable thickness between inner and outer edges is 9.9 mil which is 46.6% of the wire diameter: for comparison. FNAL keystone is 11 mil which is 41.0% of the 26.8 mil wire diameter. The coil parameters are given in Table 1. Three wedges are required.

Table 1

LL=9.195 G/A Ri = 3.106 Ro = 3.889 w = 0.783 cm

no. of turns	phi i	phi f
14	0.12	25.89
8	27.80	42.53
6	47.94	58.99
3	69.31	74.83

The performance of the iron was calculated using MDP at 600 A intervals to 4800 A. using the LBL03 asymmetric model (1). The results are given in Table 2. The data are given in groups of 4 rows: the first row is with equal excitation and the second and third rows are with 40 % of the current in the right aperture in the left aperture. The 4th row gives the change in bi' in the right aperture when the current in the left aperture is reduced to 40% of the right.

(1) G. Morgan. R. Fernow "SSC Reference Design Dipole". Magnet Division Note 53-1 (3/8/84)

Table 2
LBL03 iron with RHIC 21 coils
prime radius 2.07 cm

I	Bo	Bo/I	b1′	b2′	b3′	b4′	b5′	b6′	b7′
600 L&R	5466.8	1.0000	9.6	-22.6	-4.8	1.4	-2.7	0.5	0.5
600 R	5454.8		6.0	-21.7	-5.2	2.3	-3.2	0.7	0.3
240 L	2198.2		16.9	-25.0	-3.7	-0.9	-1.7	0.1	0.8
delta R	-22.0		-3.6	0.9	-0.4	0.9	-0.4	0.2	-0.1
1200 L&R	10935.7	1.0002	10.4	-18.0	-4.9	5.2	-2.7	0.8	-0.3
1200 R	10911.5		6.5	-17.5	-5.3	6.1	-3.1	0.9	-0.4
480 L	4400.5		20.0	-20.7	-3.7	2.7	-1.6	0.3	0.1
delta R	-22.1		-3.9	0.5	-0.4	0.9	-0.4	0.1	-0.1
1800 L&R	16401.1	1.0000	10.1	-17.9	-4.6	4.9	-2.6	0.8	-0.2
1800 R	16365.9		6.2	-18.2	-4.2	5.1	-2.7	0.8	-0.3
720 L	6603.1		20.4	-21.3	-3.0	2.2	-1.4	0.2	0.1
delta R	-21.5		-3.9	-0.4	0.4	0.2	-0.1	0.0	-0.1
2400 L&R	21855.1	.9994	8.37	-17.2	-3.6	4.0	-2.2	0.7	-0.2
2400 R	21814.9		5.78	-18.4	-3.2	4.1	-2.1	0.7	-0.3
960 L	8804.3		18.8	-22.0	-2.2	1.8	-1.1	0.1	0.1
delta R	-18.4		-2.6	-1.2	0.5	0.1	0.1	0.0	-0.1
3000 L&R	27284.0	.9982	6.0	-14.2	-2.8	2.8	-1.8	0.7	-0.2
3000 R	27235.8		5.6	-16.7	-2.4	2.8	-1.6	0.7	-0.2
1200 L	11003.2		15.4	-22.5	-1.3	1.4	-0.9	0.1	0.1
delta R	-17.7		-0.4	-2.5	0.4	0.0	0.2	0.0	0.0
3600 L&R	32621.5	.9945	4.4	-5.8	-2.0	0.5	-1.3	0.8	-0.2
3600 R	32565.6		5.4	-9.2	-1.4	0.4	-1.0	0.8	-0.2
1440 L	13202.1		11.2	-22.9	-0.1	1.0	-0.7	0.1	0.1
delta R	-17.1		1.0	-3.4	0.5	-0.1	0.3	-0.1	0.0
4200 L&R	37694.0	.9850	2.1	21.6	-0.8	-3.2	-1.0	0.7	-0.1
4200 R	37613.3		3.6	17.2	0.1	-3.4	-0.8	0.6	-0.1
1680 L	15403.1		6.1	-23.1	1.6	0.2	-0.4	0.1	0.1
delta R	-21.4		1.5	-4.4	0.8	-0.2	0.2	-0.1	0.0
4800 L&R	42482.7	.9714	-0.7	47.8	-0.7	-2.3	-0.7	0.1	-0.1
4800 R	42345.1		1.6	40.8	0.0	-3.1	-0.5	0.0	-0.1
1920 L	17604.5		-0.4	-23.2	3.8	-0.7	-0.2	0.1	0.1
delta R	-32.4		2.4	-7.0	0.7	-0.8	0.2	-0.1	0.0

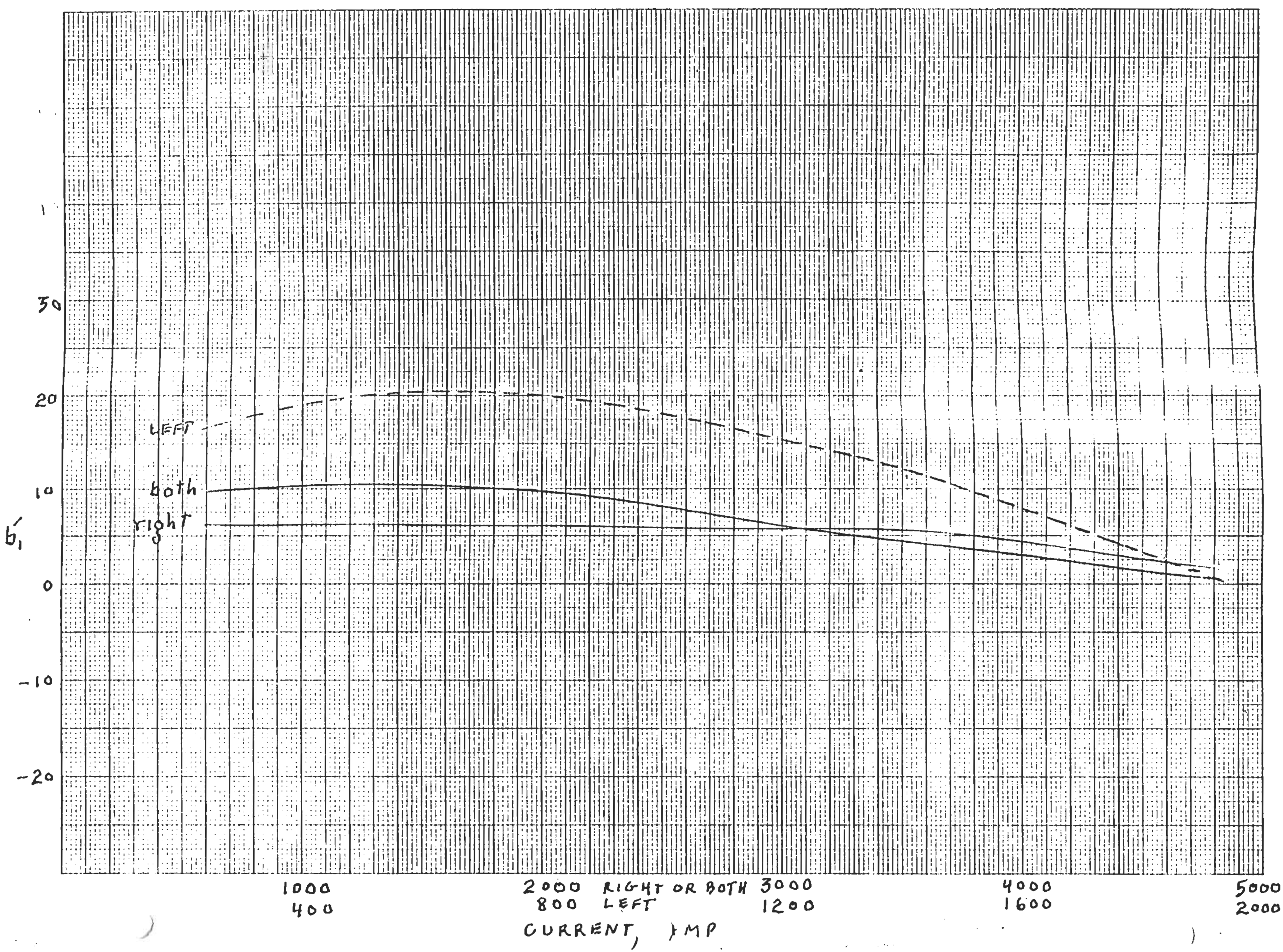
The harmonics listed for the left aperture are signed as though they were in the right aperture. i.e. $B_i/B_o = b_i$, i odd, have changed signs. Some of the data of Table 2 are plotted in Figures 1 and 2, showing b1′ and b2′ resp. of the right aperture with equal excitation ("both") and the right and left apertures with unequal excitation ("right" and "left"). The bi′ are calculated at 2/3 the coil inner radius, 2.07 cm.

Cross talk is usually taken to be the change in the right aperture resulting from a given change in the left. For example, at 3600 A, the changes in b1′ and b2′ in the right aperture are 1.05 and -3.42 when the left aperture is reduced from 3600 A to 1440 A. and the change in Bo is -0.17%. or -17 prime units. However, it is unlikely that the accelerator would be operated in this way. It will be shown below that a reasonable maximum field for this magnet is 35.2 kG. at about 3900 A. so injection field would be about 3.9 kG. If both beams are accelerated to 1560 A (14.2 kG) b1' and b2' in both apertures are about 11 and -17.5, resp. If the left aperture is held constant while the right is accelerated to 3900 A. the net changes in b1' and b2' in the left aperture are -2 and -5.5, while the net changes in the right aperture are -6 and +17. from the figures.

The peak fields in the windings at 4200 A are almost equal in the left and right sides of the right aperture. 41611 G and 41605 G. resp. The peak field point is in the block nearest the pole, 0.3 of the distance from inner to outer on the side closest to the pole. The peak field is 10.4% higher than the central field. By interpolation, at 3900 A the peak field is 38826 G and the central field is 35171 G. At this field, if one assumes a copper to superconductor ratio of 2.24, the critical current of the cable is estimated to be 4618 A at 4.5K, 18.4% higher than 3900 A. The current density in the copper is S=84761 A/sq cm and in the entire metal cross-section is J=58600: the product of these two numbers is JS=4.97 exp9, which compares to the CBA values of S=89228 and JS=4.99 exp9 at Bo = 6.22T and I = 4682 A. (The value of 2.24 for Cu/sc was chosen to make JS about equal to the CBA values.) The critical current is based upon CBA performance of 4050 A at 56.1 kG and 4.5K, assuming 10% peak field enhancement, as found by Brechna.

If an operating current of 4000 A is examined in the same way, to achieve JS=5.04 exp9, Cu/sc must be 2.53: then Ic/I = 1.04, hence 4 kA does not leave sufficient margin.

It is interesting to note that saturation onset is at about 3600 A or 32.6 kg Bo. With the two-layer coil design of ref (1), the identical iron, with identical gap between outer coil and iron, has a saturation onset of about 46 kG, and a peak b2' enhancement of only 13 units, compared to the more than 70 units seen in Fig. 1. This profound difference is attributed to the conductor in the single layer design being closer to the iron at the poles. This suggests that removing the iron just outside the coils at the poles would reduce the saturation onset, an idea which occurred independently to P. Thompson. It should be noted that Danby and Jackson have used the same trick to reduce saturation in picture-frame dipoles. A possible implementation would be an elliptical aperture in the iron, retaining circular coils, but some other symmetric aperture might be needed to control higher harmonics than b2. A non-symmetric aperture in 2 in 1 designs would probably not be suitable for controlling b1, which is not due to pole tip saturation. Since a non-circular aperture will introduce allowed harmonics at low field, the coils must compensate for this in an iterative process. A further disadvantage will be a reduction in the low field load line.



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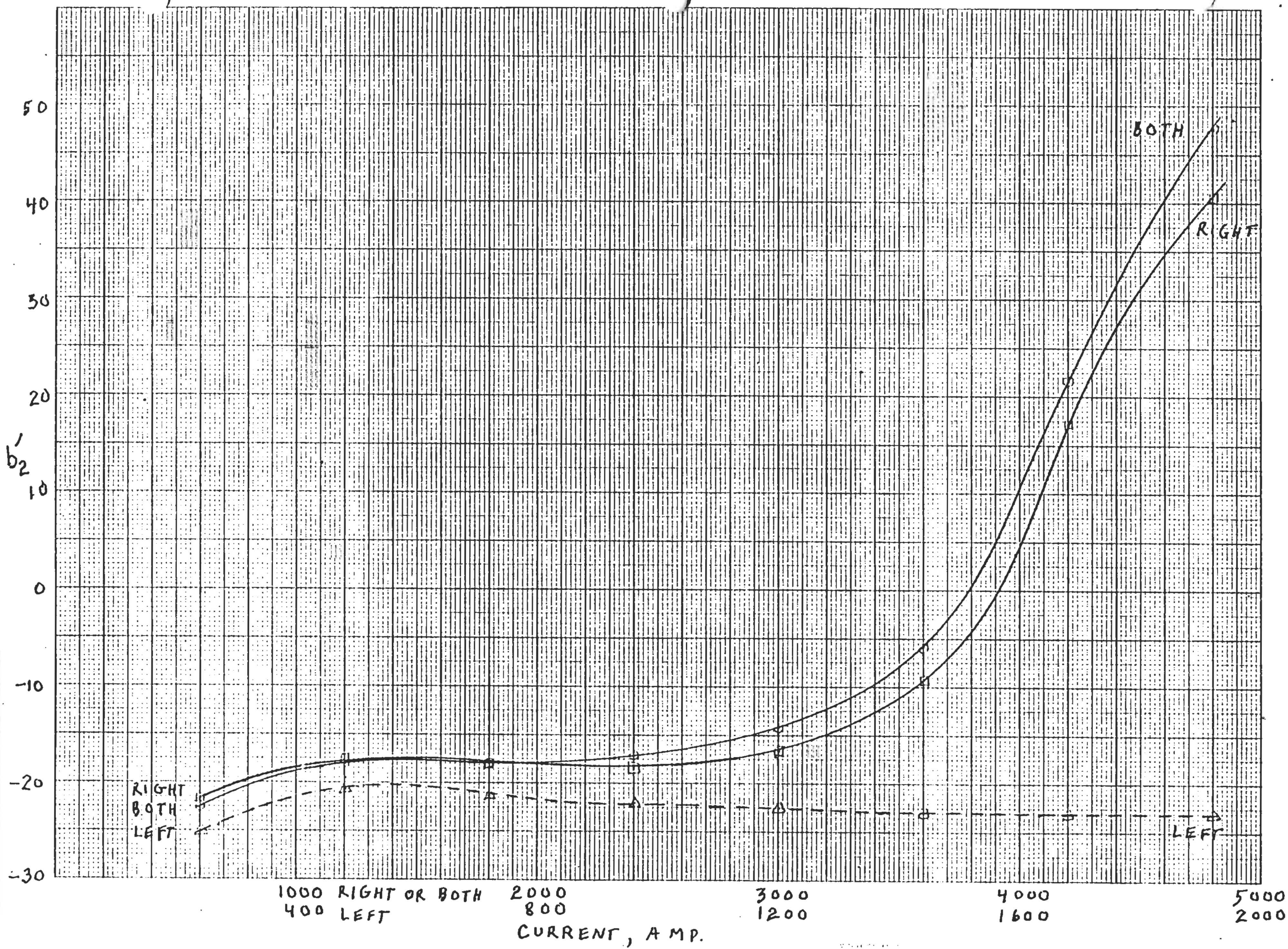

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CURRENT, AMP.

Author: G. Morgan and R. Fernow

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No.: 54-1 (This is an Addendum)

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Addendum to Magnet Div. Note 54-1
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3/26/84

The harmonics presented in the parent note have been recalculated at a radius of 2.5 cm in place of 2.07 (2/3 coil id). Table 2′ contains the data of Table 2 of the parent note. Figures 3 and 4 give b1′ and b2′ at 2.5 cm as a function of current. In each figure, the curves give the harmonics in one aperture while the other aperture has 0.4,1.0 or 2.5 times the current in the reference aperture.

Table 2

LDL 03 + RHIC 21
prime radius 2.5 cm

I	b_1'	b_2'	b_3'	b_4'	b_5'	b_6'	b_8'
600 L+R	11.6	-33.0	-8.5	3.0	-6.9	1.6	2.3
600 R	7.2	-31.7	-9.2	4.9	-8.2	2.2	1.4
240 L	20.4	-36.5	-6.5	-1.9	-4.4	0.3	3.6
1200 L+R	12.6	-26.3	-8.6	11.1	-6.9	2.5	-2.3
1200 R	7.9	-25.5	-9.3	13.0	-8.0	2.8	-1.8
480 L	24.2	-30.2	-6.5	5.7	-4.1	0.9	0.4
1800 L+R	12.2	-26.1	-8.1	10.4	-6.7	2.5	-0.9
1800 R	7.5	-26.5	-7.4	10.9	-6.9	2.5	-1.4
720 L	24.6	-31.1	-5.3	4.7	-3.6	0.6	0.4
2400 L+R	10.1	-25.1	-6.3	8.5	-5.7	2.2	-0.9
2400 R	7.0	-26.8	-5.6	8.7	-5.4	2.2	-1.4
960 L	22.7	-32.1	-3.9	3.8	-2.8	0.3	0.4
3000 L+R	7.2	-20.7	-4.9	6.0	-4.6	2.2	-0.9
3000 R	6.8	-24.4	-4.2	6.0	-4.1	2.2	-0.9
1200 L	18.6	-32.8	-2.3	3.0	-2.3	0.3	0.4
3600 L+R	5.3	-8.5	-3.5	1.1	-3.3	2.5	-0.9
3600 R	6.5	-13.4	-2.5	0.9	-2.6	2.5	-0.9
1440 L	13.5	-33.4	-0.2	2.1	-1.8	0.3	0.4
4200 L+R	2.5	31.5	-1.4	-6.8	-2.6	2.2	-0.4
4200 R	4.3	25.1	0.2	-7.2	-2.1	1.9	-0.4
1680 L	7.4	-33.7	2.8	0.4	-1.0	0.3	0.4
4800 L+R	-0.8	69.7	-1.2	-4.9	-1.8	0.3	-0.4
4800 R	1.9	59.5	0.0	-6.6	-1.3	0.0	-0.4
1920 L	-0.5	-33.8	6.7	-1.5	-0.5	0.3	0.4

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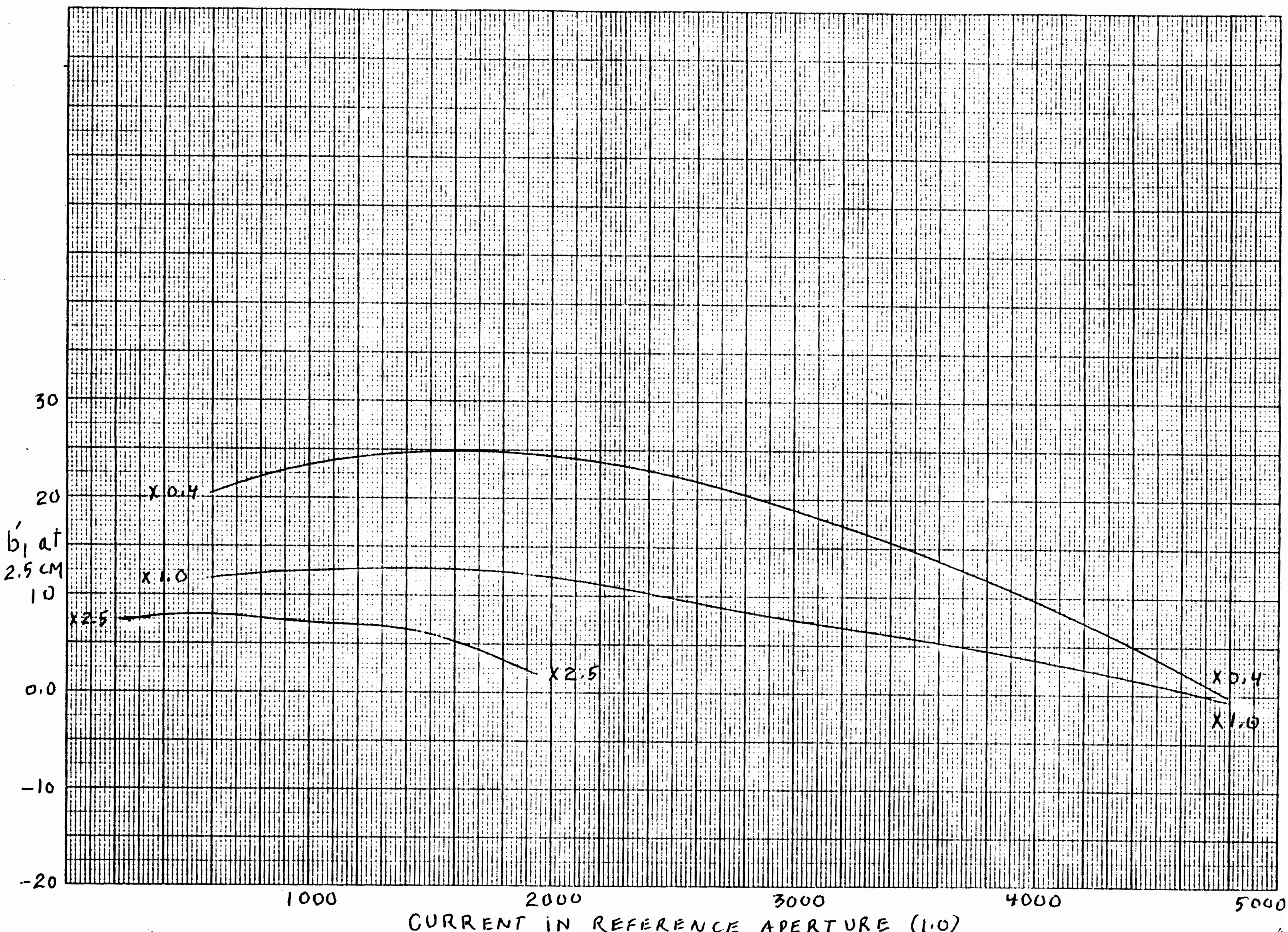

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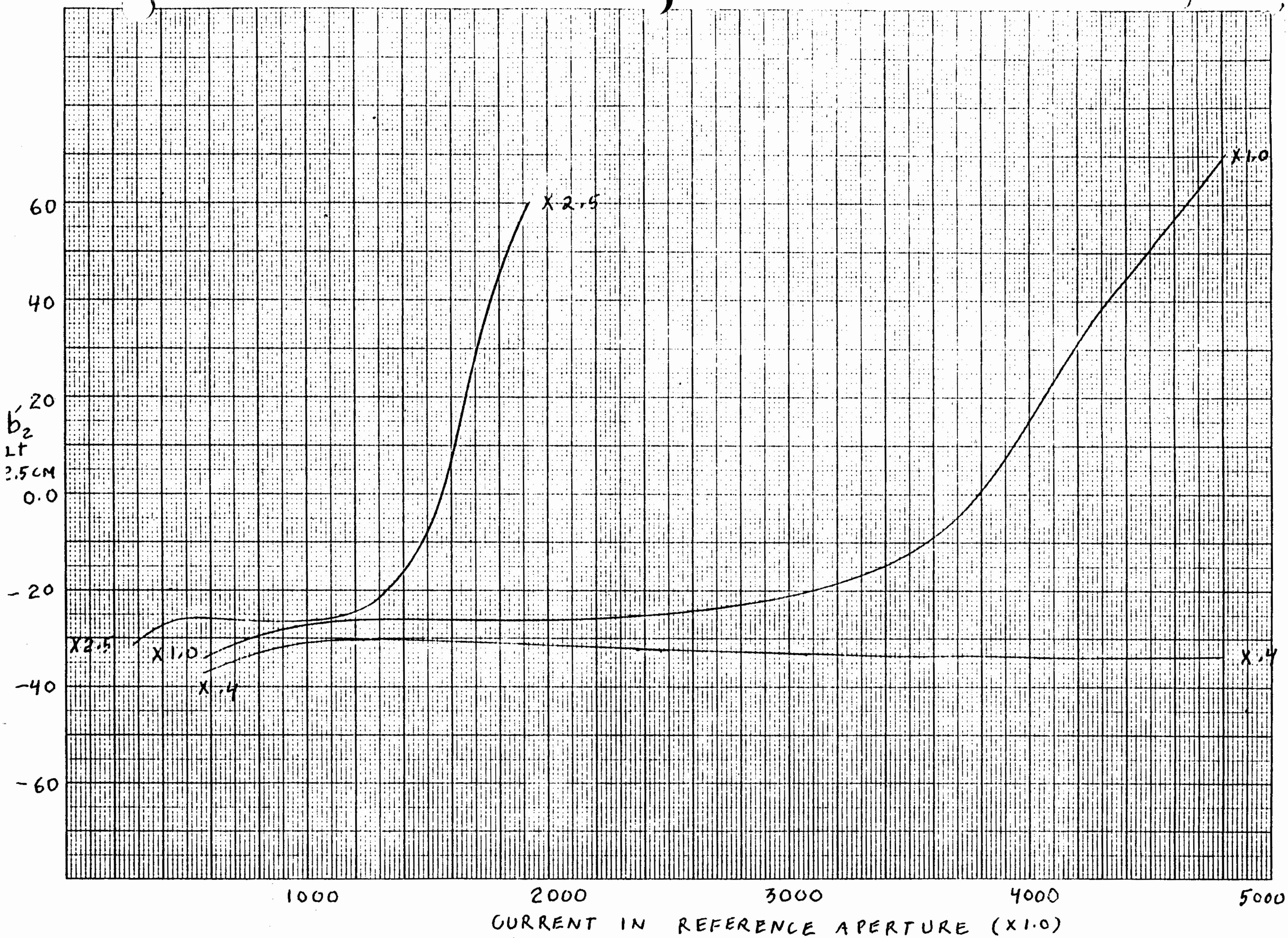

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CURRENT IN REFERENCE APERTURE (X1.0)