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BOOSTER LONG QUADRUPOLE PRODUCTION MEASUREMENTS

E. Bleser

September 1990

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

BOOSTER LONG QUADRUPOLE PRODUCTION MEASUREMENTS

BOOSTER TECHNICAL NOTE
NO. 176

E. BLESER

SEPTEMBER 13, 1990

ALTERNATING GRADIENT SYNCHROTRON DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

BOOSTER LONG QUADRUPOLE PRODUCTION MEASUREMENTS
I.

E. Bleser
September 21, 1990

INTRODUCTION

This note is a first report on the long Booster quadrupoles and follows exactly the format of the first report on the short Booster quadrupoles, Booster Technical Note # 174. It consists of three parts. Part A is a progress report on the recent production measurement results. It includes results on 14 of the 25 long quads. Part B is an example of a detailed report which is generated for each magnet. These reports will not be given wide circulation, but they will be stored as part of the permanent record for each magnet. Any suggestions or comments will be gratefully received. Part C is a data sheet for the Booster long quadrupole. It is intended as a replacement for Table 3-5 of the Design Manual. This data sheet is being built into the Booster data base, which should provide for easy updating and distribution. Any comments or criticisms will be promptly acted upon.

A. PRELIMINARY REPORT ON RECENT RESULTS

This note reports on results for fourteen Booster long quads: BMQL01 through BMQL13 and BMQL25. BMQL01, an early magnet, will be used in the ring but is not representative of our present production skills and procedures and is justifiably excluded from the analysis. BMQL25 was assembled from lamination quadrants rejected for production magnets and will be used not in the ring but for the Gauss clock and is also excluded from the analysis. The magnets were measured by the AD Group and the results were reported in their TMG Series of notes as well as being made available to us on the VAX computer.

The nomenclature we shall use is as follows:

$$B_y(X) = B_o + B_1 \cdot X + B_2 \cdot X^2 + B_3 \cdot X^3 + \ldots$$
$$B_x(X) = A_o + A_1 \cdot X + A_2 \cdot X^2 + A_3 \cdot X^3 + \ldots$$

In a quadrupole the only allowed terms are B_1, B_5, etc.

All the measurements are DC and are made with a rotating coil, 36.5 inches long, which projects well outside the ends of the magnets. Therefore, all our data is in the form of integrated field values, written as $B_1 \cdot L_{eff}$ etc. Figure 1 shows a typical plot of $B_1 \cdot L_{eff}$, the integrated gradient, versus the current, I. Figure 2 is a more interesting plot of the integrated gradient divided by I versus I. This shows quite clearly the saturation effect at high currents and the residual field effects at low currents. The relative measurement accuracy is reported in Booster Technical Note # 174 as one part in ten thousand. This applies to all of the quads. The absolute measurement accuracy (essentially the area of the measuring coil) must be known to compare the quads against the dipoles but has not yet been calibrated and at present can only be estimated to be accurate to one or two per cent.

The accuracy required in manufacturing the magnets is that the rms spread in the fractional variation in the value of the integrated field be less than one part in one thousand.

This corresponds to a spread in the average value of the radius of the quadrupoles of 0.001 7 inches. Figure 3 shows the standard deviation of the fractional differences from the mean of the integrated gradient of magnets BMQL02 through BMQL13. We conclude that up to 4000 amps the magnets agree to 2 parts in ten thousand. Above 4000 amps the spread is 4 parts in ten thousand. This could be real or instrumental. Thus, we are beating the allowed tolerance by factor of five. The assembly procedure is producing magnets that are good to 0.000 3 inches.

Since the quadrupoles are so very precise we find that the higher order field terms are also very good. Figure 4 shows the average value and the standard deviation of the measured higher harmonic fields as a fraction of the theoretically specified tolerance. Note that except for B_5 and A_3 all these terms are on the average consistent with zero as they should be. Note also that they are all at the level of a few per cent of the allowed tolerance. Since B_5 is an allowed term it might well differ from zero. That A_3 differs from zero is interesting and is being studied with all the urgency that we can devote to an one per cent problem.

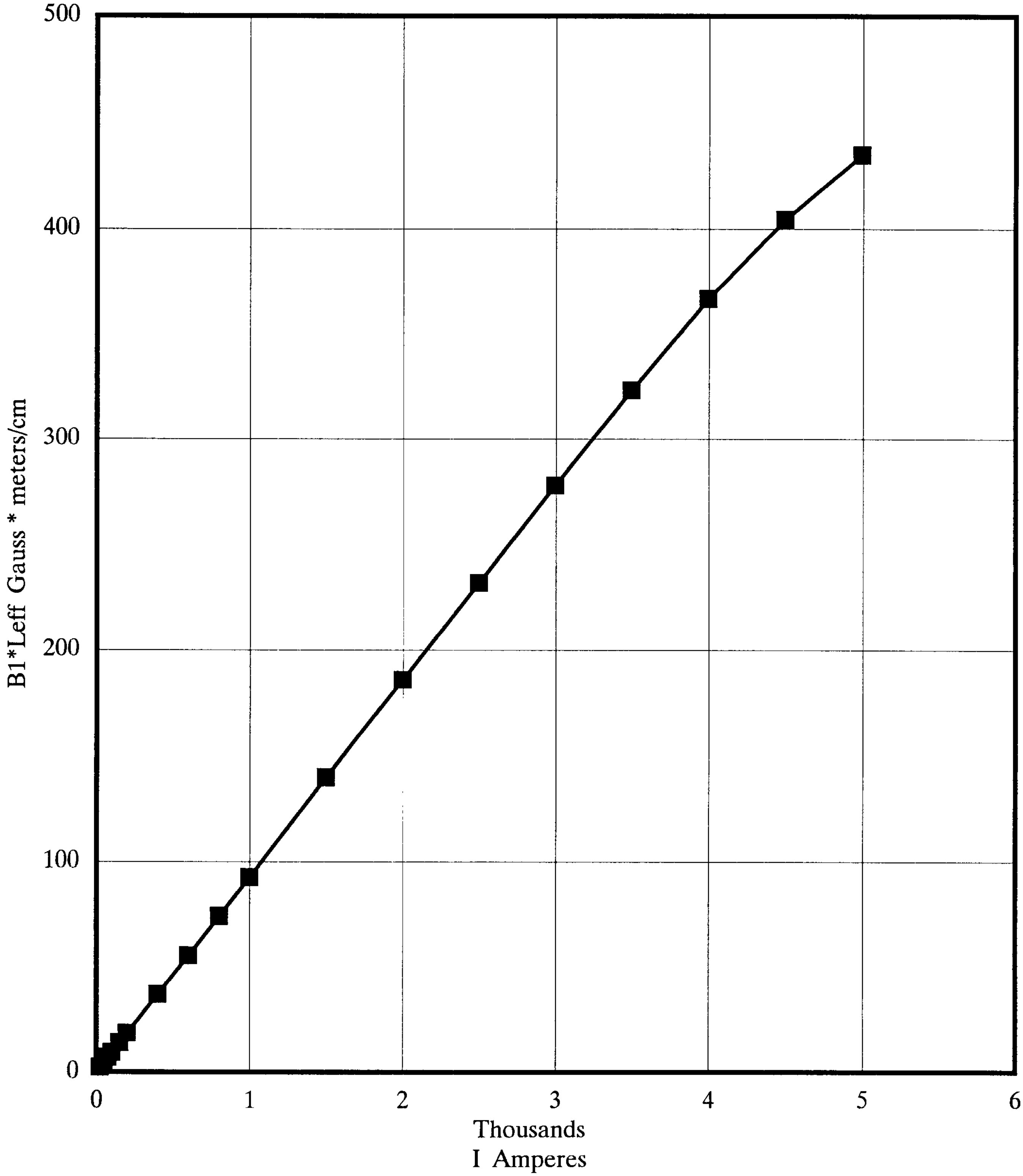
Our conclusions are that the magnets are identical and that the field shape is very good. The factory is running well. Questions we must still deal with are the absolute value of the integrated field, the eddy current effects, and some loose ends similar to the A_3 problem.

The two magnets excluded from this analysis seem to behave as might be expected. BMQL01 has an integrated gradient low by 1.2 parts per thousand relative to the average measured value. the theoretical tolerance is 1 part per thousand, but the acceptance criteria is 2.5 times the tolerance, so this magnet was accepted for the ring. It was assembled before we had our fully refined assembly procedures in operation. The quadrants did not fit together as perfectly as they do now, and we might conclude that the radius is oversized by 0.0002 inches.

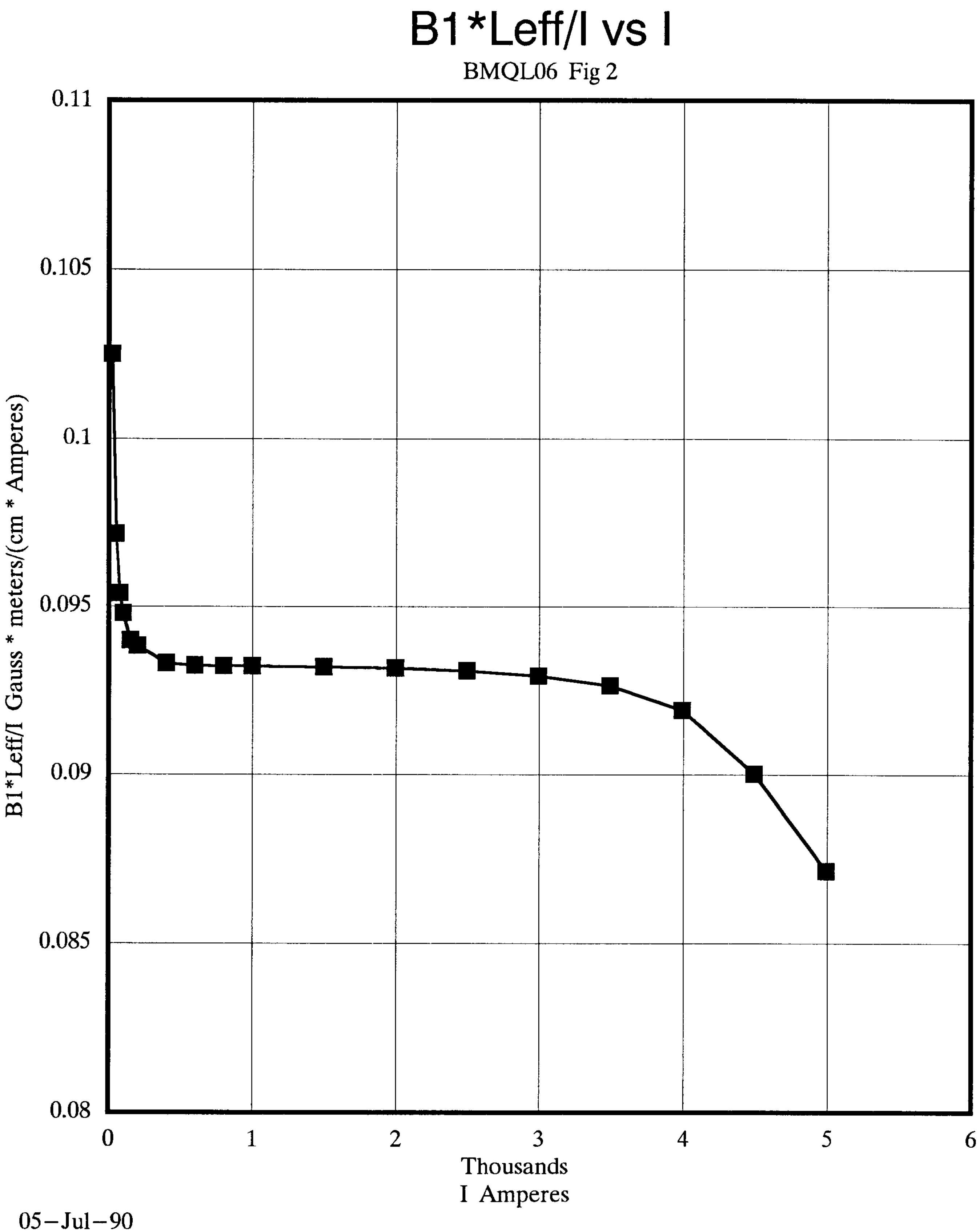
BMQL25, which will be used in the Gauss clock, was assembled from quadrants that were rejected for the normal magnets. It is 1.2 pounds underweight, or about 0.85 parts per thousand. This is a good magnet except that its saturation is worse than that of any of the others. At 5000 Amperes it is 1.2 parts per thousand more saturated than the average of the other magnets, which in addition show an rms spread of only 0.4 parts per thousand.

B1*Leff vs I

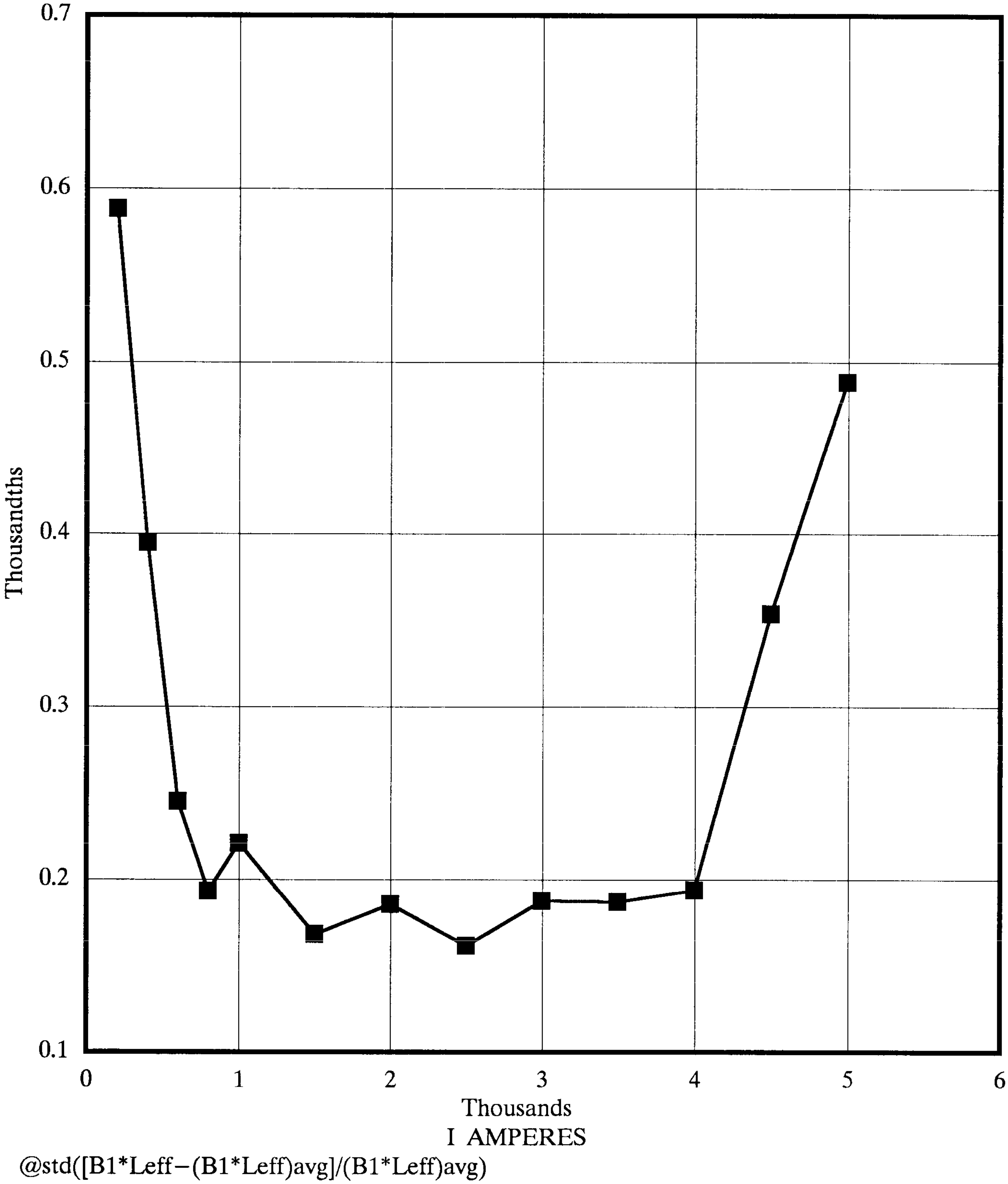
BMQL06 Fig 1



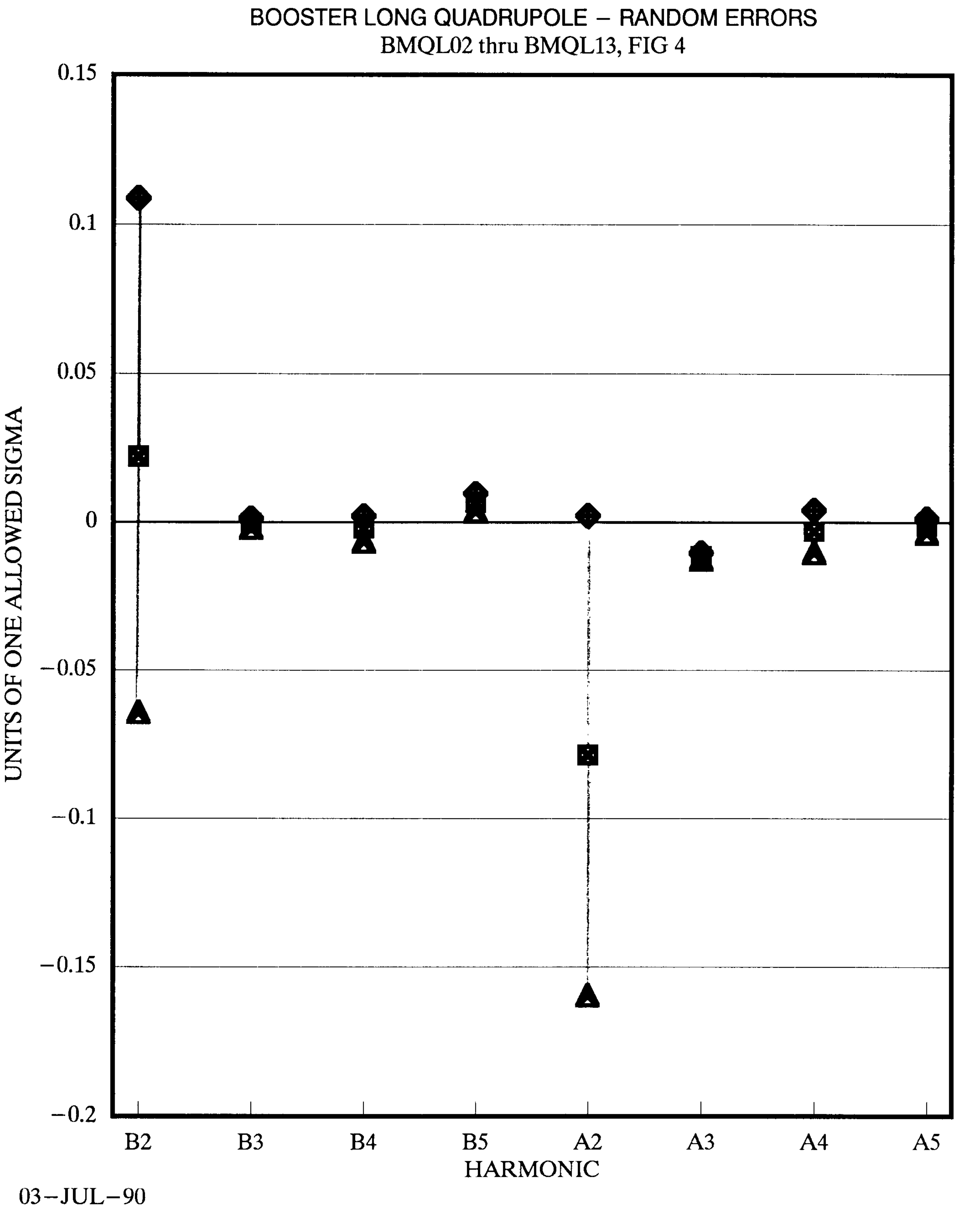
05–Jul–90


B1*Leff/I vs I
BMQL06 Fig 2
0.11
0.105
0.1
0.095
0.09
0.085
0.08
B1*Leff/I Gauss * meters/(cm * Amperes)
0
1
2
3
4
5
6
Thousands
I Amperes
05-Jul-90

STANDARD DEVIATION of FRACTIONAL DIFFERENCES
BMQL02 through BMGL13, FIG 3



@std([B1*Leff−(B1*Leff)avg]/(B1*Leff)avg)
03−JUL−90


BOOSTER LONG QUADRUPOLE – RANDOM ERRORS
BMQL02 thru BMQL13, FIG 4
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
UNITS OF ONE ALLOWED SIGMA
B2
B3
B4
B5
A2
A3
A4
A5
HARMONIC
03–JUL–90

B. STANDARD MEASUREMENT REPORT

The appended report will be generated and permanently stored for each magnet. It is intended to be self-explanatory. Therefore, no explanation will be given. If you do not understand it, please address your questions to the author who may well have lapsed into incomprehensible jargon.

ANALYSIS of FIELD SHAPE MEASUREMENTS

MAGNET TYPE: BLQ (BOOSTER LONG QUADRUPOLE)
MAGNET NUMBER: BMQL06
RUN NUMBER: BMQL06.101T1
DATE of MEASUREMENT: 29 MAY 1990
DATE of ANALYSIS: 27 JUNE 1990

SHORT SUMMARY of MAGNET QUALITY

SUMMARY OF QUADRUPOLE FIELD RESULTS

$B1 \cdot L_{eff}/I$ @ 2500 A 0.09311 $G \cdot m/(cm \cdot A)$
$B1 \cdot L_{eff}/I$ @ 5000 A 0.08716 $G \cdot m/(cm \cdot A)$

SATURATION EFFECT 1.06823

SUMMARY of HARMONIC CONTENTS			
	AVG	STD DEV	UNITS
B2/B1	-3.25E-06	2.5E-06	cm^{-1}
A2/B1	-2.23-05	1.7E-06	cm^{-1}
B3/B1	5.59E-07	1.3E-07	cm^{-2}
A3/B1	-1.06E-05	3.5E-07	cm^{-2}
B4/B1	-7.66E-08	6.9e-08	cm^{-3}
A4/B1	-1.22E-07	7.7E-08	cm^{-3}
B5/B1	1.09E-07	2.3E-08	cm^{-4}
A5/B1	-6.01E-08	2.3E-08	cm^{-4}
SUMMARY of ALIGNMENT PARAMETERS			
xo	3.44E-02	6.7E-04	cm
	13.6	0.3	0.001 Inches
yo	-4.19E-02	1.2E-03	cm
	-16.5	0.5	0.001 Inches
Theta	-7.09E-04	7.0E-05	Radians

SUMMARY of RESIDUAL FIELDS			
Bo · L_{eff}	0.501		Gauss · m
Ao · L_{eff}	-0.016		Gauss · m
B1 · L_{eff}	0.252		Gauss · m/cm
A1 · L_{eff}	0.007		Gauss · m/cm

BASIC MEASUREMENT RESULTS

	I AMPS	B1·L_{EFF} Gauss·m/cm	Bo·L_{eff} Gauss·m	B2·L_{eff} G·m/cm^{-2}	B3·L_{eff} G·m/cm^{-3}	B4·L_{eff} G·m/cm^{-4}	B5·L_{eff} G·m/cm^{-5}
1	0.004	0.252	0.501	8.9E-05	1.3E-05	1.1E-06	-4.16E-06
2	-0.01	0.251	0.502	3.2E-04	8.1E-06	7.1E-08	4.21E-07
3	24.566	2.519	0.577	-6.1E-05	1.7E-05	-5.6E-07	-1.83E-06
4	49.576	4.817	0.659	-1.9E-04	-1.1E-05	6.3E-06	3.75E-06
5	74.529	7.110	0.743	1.7E-04	3.2E-06	1.1E-05	-1.40E-06
6	99.384	9.423	0.820	-5.4E-05	3.4E-05	6.2E-06	1.42E-06
7	149.377	14.042	0.986	-6.6E-05	-1.7E-05	1.9E-05	2.98E-06
8	199.072	18.680	1.149	-6.6E-05	1.1E-05	3.8E-06	-2.57E-06
9	398.691	37.207	1.794	-9.2E-05	5.5E-05	-2.2E-07	7.44E-06
10	598.214	55.791	2.449	9.3E-05	5.5E-05	-2.7E-05	1.08E-05
11	797.561	74.364	3.098	6.9E-05	6.9E-05	-7.7E-06	6.80E-06
12	997.165	92.976	3.778	-1.8E-05	6.3E-05	4.3E-06	9.29E-06
13	1495.96	139.454	5.384	-3.1E-04	8.5E-05	4.3E-06	1.09E-05
14	1995.01	185.904	7.045	-6.4E-04	1.3E-04	-3.2E.05	1.74E-05
15	2493.99	232.212	8.551	-1.1E-03	1.3E-04	-2.3E-05	2.05E-05
16	2993.11	278.214	10.094	-1.4E-03	1.2E-04	-1.7E-05	1.58E-05
17	3492.41	323.586	11.545	-2.4E-03	1.5E-04	-4.2E-05	1.58E-05
18	3991.82	366.945	13.066	-3.9E-03	1.9E-04	-5.6E-05	6.03E-06
19	4491.1	404.342	14.012	-6.2E-03	1.5E-04	-6.3E-05	-2.40E-05
20	4990.45	434.975	14.876	-9.0E-03	1.4E-04	-6.6E-05	-4.45E-05

	I AMPS	A1·L_{eff} Gauss·m/cm	Ao·L_{eff} Gauss·m	A2·L_{eff} G·m/cm^2	A3·L_{eff} G·m/cm^3	A4·L_{eff} G·m/cm^4	A5·L_{eff} G·m/cm^5
1	0.004	0.007	- 0.016	3.8E-04	6.7E-05	-1.6E-06	7.95E-06
2	-0.01	0.007	- 0.012	8.4E-05	-1.3E-05	-3.4E-07	-2.20E-06
3	24.566	0.000	- 0.106	-5.0E-05	-4.0E-05	-7.1E-06	-1.46E-06
4	49.576	0.024	- 0.204	3.7E-04	-3.2E-06	-9.4E-06	-2.15E-06
5	74.529	0.016	- 0.297	-3.8E-04	-1.4E-04	-1.1E-05	-1.18E-05
6	99.384	0.006	- 0.394	4.5E-04	9.9E-06	1.4E-05	3.10E-06
7	149.377	0.002	- 0.589	-2.3E-04	-1.3E-04	-1.1E-06	4.16E-06
8	199.072	-0.004	- 0.781	4.6E-05	-1.7E-04	-6.8E-06	-7.49E-06
9	398.691	-0.019	- 1.514	-4.5E-04	-3.3E-04	-7.3E-06	-1.54E-06
10	598.214	-0.028	- 2.270	-1.1E-03	-5.4E-04	-1.4E-05	-3.21E-06
11	797.561	-0.036	- 3.031	-1.3E-03	-7.7E-04	-1.6E-06	-7.62E-07
12	997.165	-0.066	- 3.851	-1.5E-03	-8.9E-04	-6.6E-07	1.42E-06
13	1495.96	-0.085	- 5.815	-2.6E-03	-1.4E-03	-2.6E-05	-1.82E-06
14	1995.01	-0.120	- 7.694	-3.8E-03	-1.8E-03	-3.0E-05	-9.30E-06
15	2493.99	-0.169	- 9.533	-4.6E-03	-2.3E-03	-3.6E-05	8.92E-07
16	2993.11	-0.178	-11.505	-5.7E-03	-2.8E-03	-4.7E-05	-2.28E-06
17	3492.41	-0.257	-13.225	-6.7E-03	-3.3E-03	-4.1E-05	-6.39E-06
18	3991.82	-0.281	-15.385	-5.9E-03	-3.8E-03	-2.5E-05	1.90E-06
19	4491.1	-0.273	-17.553	4.0E-04	-4.3E-03	-5.6E-05	-8.01E-06
20	4990.45	-0.306	-19.563	7.2E-03	-4.7E-03	-6.5E-05	-2.39E-05

GRADIENT and POSITION ANALYSIS

			Residual Field Subtracted			
	I AMPS	B1·L_{eff}/I G·m/cm·A	B1·L_{eff}/I G·m/cm·A	Theta A1/B1 radians	xo Bo/B1 cm	yo Ao/B1 cm
1	0.004	---	0			
2	- 0.01	---	0			
3	24.566	0.10252	0.09276	-3.14E-03	2.70E-02	-5.34E-02
4	49.576	0.09715	0.09232	3.61E-03	3.14E-02	-4.80E-02
5	74.529	0.09540	0.09218	1.24E-03	3.31E-02	-4.55E-02
6	99.384	0.09481	0.09240	-9.97E-05	3.32E-02	-4.46E-02
7	149.377	0.09401	0.09240	-3.53E-04	3.41E-02	-4.38E-02
8	199.072	0.09383	0.09263	-6.30E-04	3.44E-02	-4.32E-02
9	398.691	0.09332	0.09272	-7.19E-04	3.46E-02	-4.14E-02
10	598.214	0.09326	0.09286	-6.39E-04	3.48E-02	-4.12E-02
11	797.561	0.09324	0.09294	-5.81E-04	3.48E-02	-4.11E-02
12	997.165	0.09324	0.09300	-7.91E-04	3.52E-02	-4.17E-02
13	1495.96	0.09322	0.09306	-6.61E-04	3.50E-02	-4.19E-02
14	1995.01	0.09318	0.09306	-6.85E-04	3.52E-04	-4.15E-02
15	2493.99	0.09311	0.09301	-7.61E-04	3.46E-04	-4.12E-02
16	2993.11	0.09295	0.09287	-6.67E-04	3.45E-02	-4.14E-02
17	3492.41	0.09265	0.09259	-8.19E-04	3.41E-02	-4.09E-02
18	3991.82	0.09192	0.09186	-7.85E-04	3.42E-02	-4.20E-02
19	4491.1	0.09003	0.08998	-6.93E-04	3.34E-02	-4.35E-02
20	4990.45	0.08716	0.08711	-7.21E-04	3.30E-02	-4.50E-02

AVERAGE (600 TO 5000 Amps) = -7.09E-04 3.44E-02 -4.19E-02
STANDARD DEVIATION = 7.0E-05 6.7E-04 1.2E-03

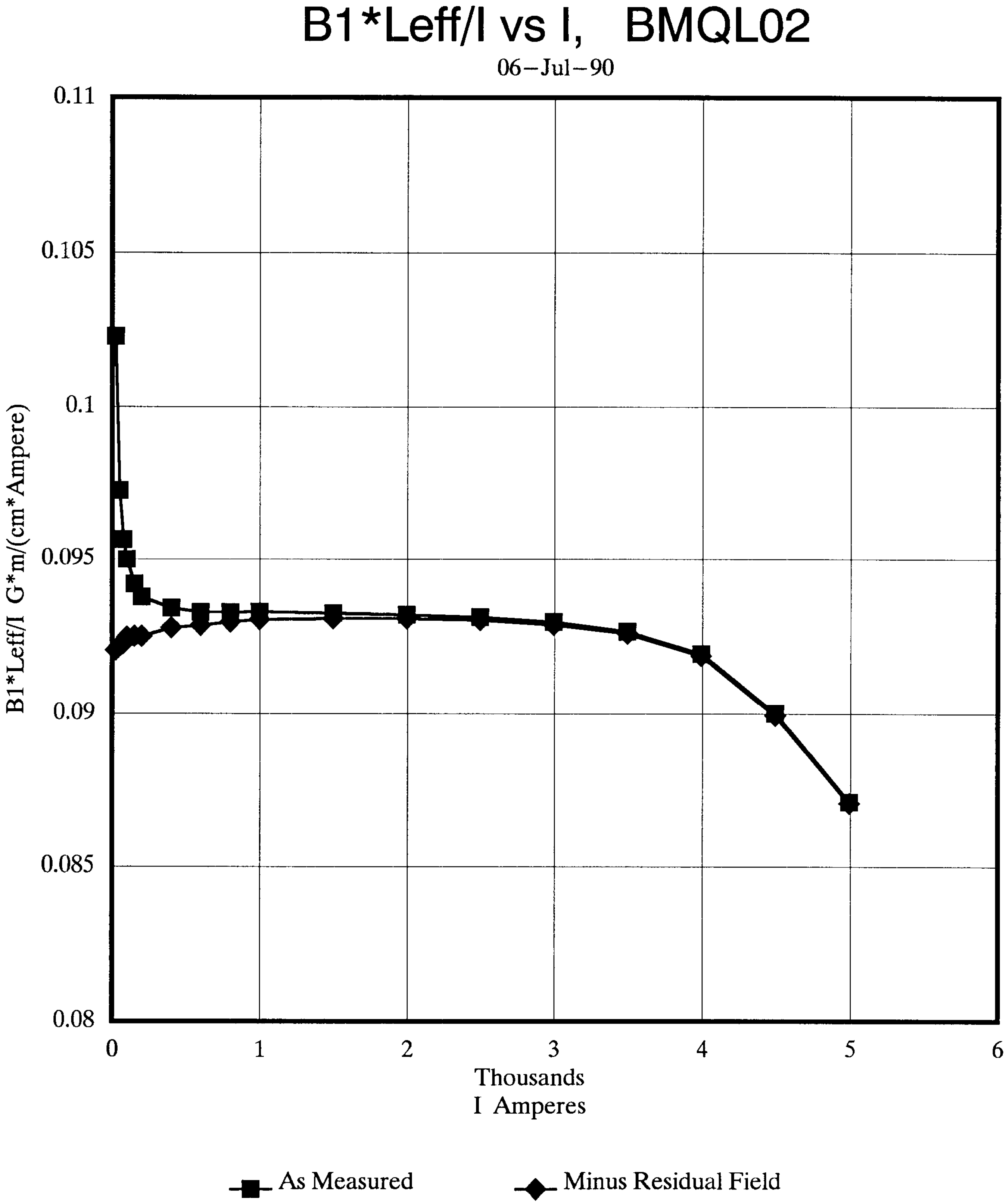
HARMONIC CONTENT

	I AMPS	B1·Leff/I G·m/(cm·A)	Bo/B1 cm	B2/B1 cm^{-1}	B3/B1 cm^{-2}	B4/B1 cm^{-3}	B5/B1 cm^{-4}
1	0.004						
2	0.001						
3	24.566	0.10251	0.033	-6.60E-05	1.37E-06	-7.2E-06	1.0E-06
4	49.576	0.09715	0.035	-6.13E-05	-5.38E-06	1.1E-06	1.7E-06
5	74.529	0.09540	0.035	1.14E-05	-1.49E-06	1.5E-06	4.0E-07
6	99.384	0.09481	0.035	-1.55E-05	2.30E-06	5.6E-07	6.1E-07
7	149.377	0.09401	0.035	-1.13E-05	-2.17E-06	1.3E-06	5.2E-07
8	199.072	0.09383	0.035	-8.39E-06	-1.23E-07	1.5E-07	8.6E-08
9	398.691	0.09332	0.035	-4.90E-06	1.13E-06	-3.5E-08	3.1E-07
10	598.214	0.09326	0.035	7.93E-08	7.46E-07	-6.9E-08	2.7E-07
11	797.561	0.09324	0.035	-2.71E-07	7.46E-07	-1.2E-07	1.5E-07
12	997.165	0.09324	0.035	-1.16E-06	5.30E-07	3.5E-08	1.4E-07
13	1495.96	0.09322	0.035	-2.85E-06	5.15E-07	2.3E-08	1.1E-07
14	1995.01	0.09318	0.035	-3.91E-06	6.29E-07	-1.8E-07	1.2E-07
15	2493.99	0.09311	0.035	-5.01E-06	4.98E-07	-1.1E-07	1.1E-07
16	2993.11	0.09295	0.035	-5.28E-06	3.81E-07	-6.6E-08	7.2E-08
17	3492.41	0.09265	0.034	-7.60E-06	4.30E-07	-1.3E-07	6.2E-08
18	3991.82	0.09192	0.034	-1.10E-05	4.84E-07	-1.5E-07	2.8E-08
19	4491.1	0.09003	0.033	-1.56E-05	3.50E-07	-1.6E-07	-4.9E-08
20	4990.45	0.08716	0.003	-2.09E-05	3.02E-07	-1.5E-07	-9.3E-08

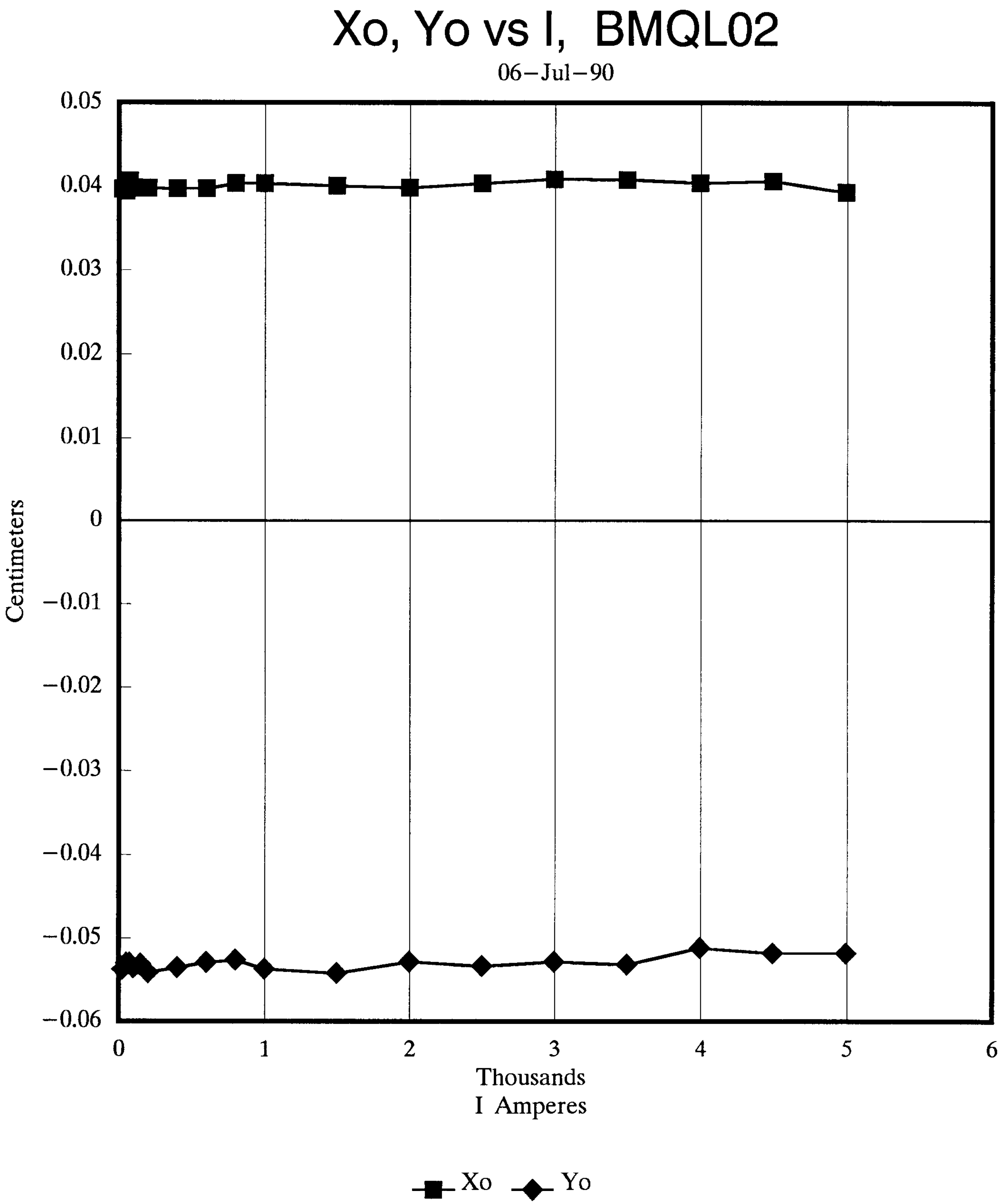
AVERAGE (600 TO 3500 Amps) =	-3.25E-06	5.59E-07	-7.66E-08	1.09E-07
STANDARD DEVIATION =	2.5E-06	1.3E-07	6.9E-08	2.3E-08

	I AMPS	A1/B1 radians	Ao/B1 cm	A2/B1 cm^{-1}	A3/B1 cm^{-2}	A4/B1 cm^{-3}	A5/B1 cm^{-4}
1	0.004						
2	-0.01						
3	24.566	-3.0E-03	-0.040	-1.90E-04	-4.74E-05	-2.4E-06	-4.2E-06
4	49.576	3.7E-03	-0.041	-2.73E-06	-1.54E-05	-1.7E-06	-2.2E-06
5	74.529	1.3E-03	-0.041	-1.10E-04	-3.00E-05	-1.3E-06	-2.9E-06
6	99.384	-5.9E-05	-0.041	7.17E-06	-6.24E-06	1.7E-06	-5.3E-07
7	149.377	-3.3E-04	-0.042	-4.41E-05	-1.40E-05	3.7E-08	-2.7E-07
8	199.072	-6.1E-04	-0.042	-1.82E-05	-1.26E-05	-2.8E-07	-8.4E-07
9	398.691	-7.1E-04	-0.041	-2.24E-05	-1.08E-05	-1.6E-07	-2.6E-07
10	598.214	-6.3E-04	-0.041	-2.62E-05	-1.10E-05	-2.2E-07	-2.0E-07
11	797.561	-5.8E-04	-0.041	-2.33E-05	-1.12E-05	-7.4E-10	-1.2E-07
12	997.165	-7.9E-04	-0.041	-2.00E-05	-1.04E-05	9.8E-09	-7.0E-08
13	1495.96	-6.6E-04	-0.042	-2.14E-05	-1.07E-05	-1.7E-07	-7.0E-08
14	1995.01	-6.8E-04	-0.041	-2.25E-05	-1.03E-05	-1.5E-07	-9.3E-08
15	2493.99	-7.6E-04	-0.041	-2.15E-05	-1.02E-05	-1.5E-07	-3.0E-08
16	2993.11	-6.7E-04	-0.041	-2.18E-05	-1.04E-05	-1.6E-07	-3.7E-08
17	3492.41	-8.2E-04	-0.041	-2.20E-05	-1.04E-05	1.2E-07	-4.4E-08
18	3991.82	-7.8E-04	-0.042	-1.70E-05	-1.04E-05	-6.4E-08	-1.7E-08
19	4491.1	-6.9E-04	-0.043	4.76E-08	-1.08E-05	-1.3E-07	-3.9E-08
20	4990.45	-7.2E-04	-0.045	1.58E-05	-1.10E-05	-1.5E-07	-7.3E-08

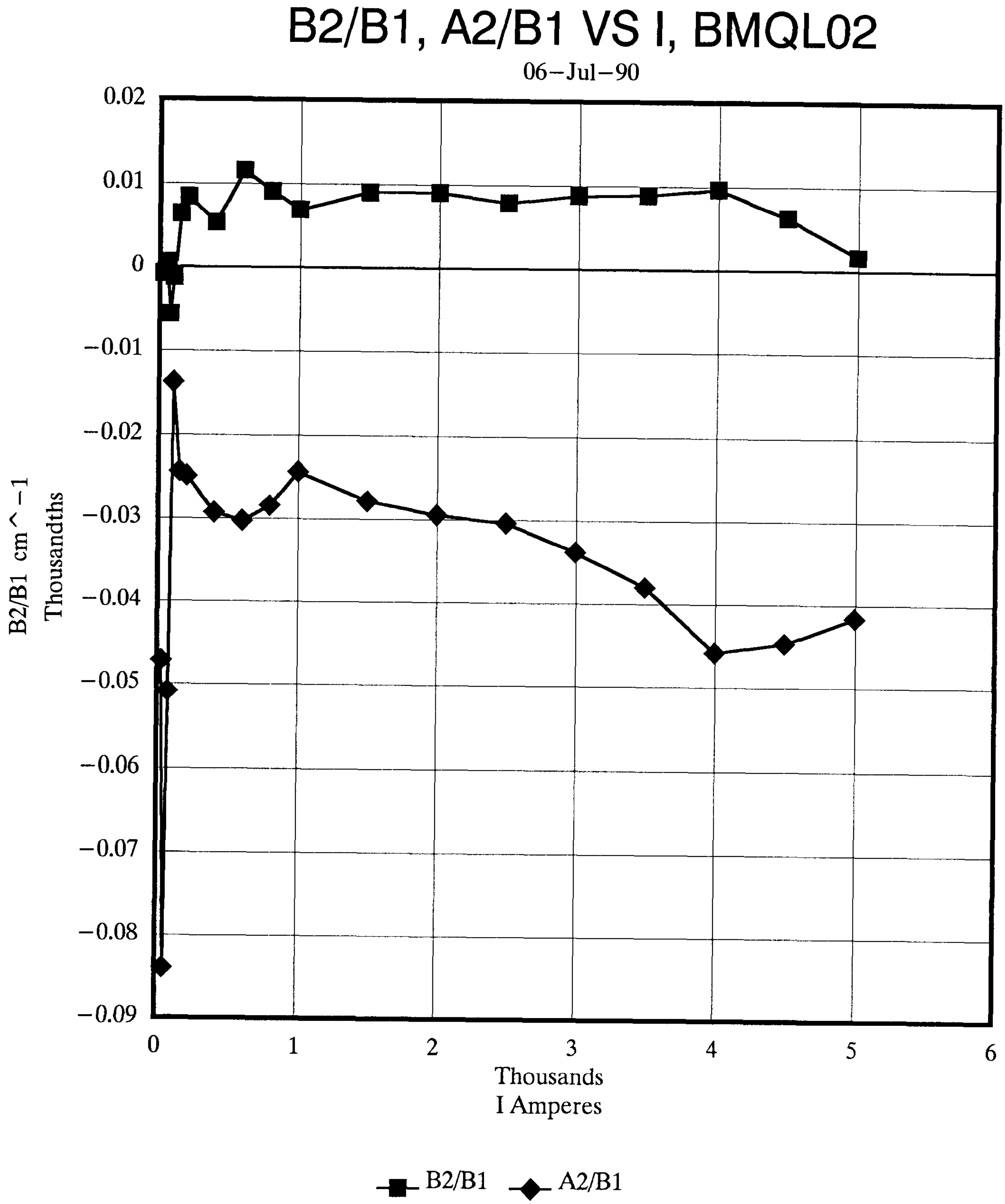
AVERAGE (600 to 3500 Amps)	=	-2.23E-05	-1.06E-05	-1.22E-07	-6.01E-08
STANDARD DEVIATION	=	1.7E-06	3.5E-07	7.7E-08	2.3E-08



B1*Leff/I at 2500 Amps = 0.09312
B1*Leff/I at 5000 Amps = 0.08712

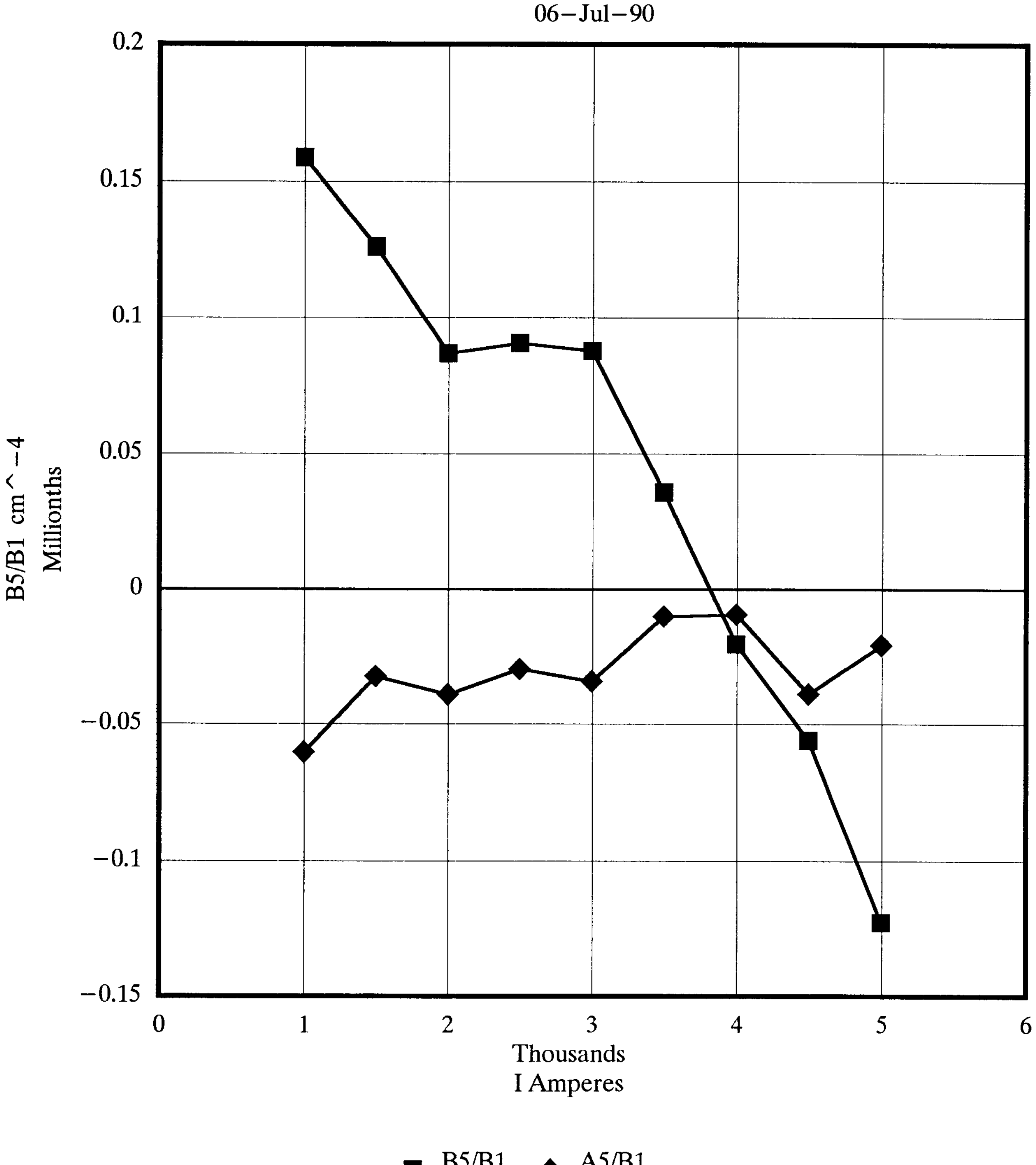


Xo = 0.016 inches
Yo = −0.021 inches



B2/B1 = 0.000009
A2/B1 = −0.000030

B5/B1, A5/B1 VS I, BMQL02



B5/B1(FROM 1000 TO 3000 AMPS) = 0.000000110
A5/B1(FROM 1000 TO 3000 AMPS) = –0.000000039

C. DATA SHEET FOR SHORT QUAD

The appended data sheet (which at press time may still contain some blanks to be filled in, labelled NA) is an attempt to provide a fairly complete description of a magnet. It will be incorporated into the Booster data base (E. Auerbach). If the categories are not clear, if the data is in error or incomplete, or if their are insufficiencies or redundancies please comment to the author.

ACKNOWLEDGEMENTS

This note is a report on the analysis of recent measurement results for the Booster quad. The analysis and the conclusions are the responsibility of the author alone and represent his sole contribution to this effort. The measurements were carried out by the Measurements Group of the Accelerator Development Division, using a system developed over many years by many people, with a particular effort having been expended over the past several years to adapt the systems to the present application. To mention a dozen individuals would be insufficient, so we shall acknowledge just one, Rich Riesen, who is personally setting up and carrying out the measurements on every one of the Booster main magnets.

The conclusion of this note, that the Booster quadrupole is very good, is a tribute to Gordon Danby and John Jackson who designed and developed this magnet, to those people who carried out the engineering of it, and to the careful group that is building it.

BOOSTER LONG QUADRUPOLE DATA SHEET

Issued September 1, 1990

PROTOTYPE NAME — BMQL (BOOSTER MAIN QUADRUPOLE LONG)
MAGNET CLASS — QUADRUPOLE
NUMBER OF MAGNETS — 24 PLUS 1

	INCHES	MILLIMETERS	OTHER	REF
MECHANICAL				
CORE				
Lamination Length	17.25	438.2		a
Tolerance Specified	0.003	0.076		a
Tolerance Measured	0.0013	0.033		a
Structural Length	19.625	498.5		a
Coil Length	26.1	662.9		a
Overall Length	28.1	713.7		a
Aperture Shape	Round			
Radius at Pole Tip	3.25	82.55		a
Tolerance Specified	0.0013	0.033		a
Tolerance Measured	0.0003	0.008		e
Pole Width	5.125	130.2		a
Core Height	25.3	642.6		a
Core Width	25.3	642.6		a
LAMINATIONS				
Material	Armco M-36			a
Coating	Aisi Type - C5			a
Coating Thickness	0.0002	0.005		a
Overall Thickness	0.025	0.6		a
Approx. Lams per Block	690			
Quadrant Block Weight	367.28	166.6	Pounds, KG	a
Tolerance Specified	0.03	0.01	Pounds, KG	a
Tolerance Measured	0.03	0.01	Pounds, KG	a

	INCHES	MILLIMETERS	OTHER	REF
VACUUM PIPE				
Height - Outside	6	152.4		b
Width - Outside	6	152.4		b
Wall Thickness	0.063	1.6		b
Tolerance Specified	0.003	0.1		b
Tolerance Measured	NA	NA		
Half Height - Inside	2.937	74.6		
Half Width - Inside	2.937	74.6		
Material	Inconel 625			b
Resistivity	129		Micro-Ohm CM	b
Tolerance Specified	2		Micro-Ohm CM	b
Tolerance Measured	NA			
MAIN COIL				
COIL				
Turns per Pole	5			
Poles per Magnet	4			
Resistance per Magnet	0.83		Milliohms	g
Inductance per Magnet - DC	0.39		Millihenry	est
Inductance per Magnet - 1 k	0.36		Millihenry	est
CONDUCTOR				
Material	Copper - Alloy 0102			a
Shape	Square			
Width	1.122	28.50		a
Height	1.122	28.50		a
Cooling Hole Diameter	0.375	9.52		a
Area	1.134	731.6		a
Length per Pole	295	7493		a
Length per Magnet	1180	29972		

	INCHES	MILLIMETERS	OTHER	REF
INSULATION				
Material	Epoxy Fiberglass			a
Thickness	0.152	3.86		a
Tolerance	0.012	0.30		a
Ground Test	27		kVolts	c
Impulse Test	5		kVolts	c
COOLING				
Circuits per Magnet	2			a
Flow Rate per Magnet	1.6		Gallons/Minute	a
Input Pressure	50		PSI	a
Temp. Rise @ Ramp to Imax	20		Degrees F	a
CURRENT				
Imax (PS Limit)	5700		Amperes	c
Current Density @ Imax	5026.5	7.8	Amperes/Area	
DC Power @ Imax	27.		kWatts	
Stored Energy @ Imax	6.4		kJoules	
TUNE TRIM COIL				
COIL				
Turns per Pole	1			a
Poles per Magnet	4			
Resistance per Magnet	0.63		Milliohms	
Inductance per Magnet - DC	NA		Microhenry	
Inductance per Magnet - 1 k	17		Microhenry	
CONDUCTOR				
Material	Copper - ETP			a
Shape	Rectangular			a
Width	1.5	38.10		a
Height	0.1872	4.75		a
Cooling Hole Diameter	NAPP	NAPP		
Area	0.2808	181.16		
Length per Pole	52	1321		a

	INCHES	MILLIMETERS	OTHER	REF
Length per Magnet	232	5893		a
INSULATION				
Material	G10 Epoxy			a
Thickness	0.033	0.84		a
Tolerance	NA	NA		
Ground Test	5		kVolts	c
Impulse Test	3		kVolts	c
COOLING				
Circuits per Magnet	NAPP			
Flow Rate per Magnet	NAPP		Gallons/Minute	
Input Pressure	NAPP		PSI	
Temp Rise @ Ramp to Imax	NA		Degrees F	
CURRENT				
Imax (PS Limit)	700		Amperes	c
Current Density @ Imax	2493	3.9	Amperes/Area	
DC Power @ Imax	0.31		kWatts	
Stored Energy @ Imax	4.1		Joules	
STOP BAND TRIM COILS				
COIL				
Turns per Pole	2			a
Poles per Magnet	4			
Resistance per Magnet	300		Milliohms	
Inductance per Magnet - DC	NA		Microhenry	
Inductance per Magnet - 1 k	64		Microhenry	
CONDUCTOR				
Material	Copper - ETP			a
Shape	Round #8 Wire			a
Width	0.129	3.28		a
Height	0.129	3.28		a
Cooling Hole Diameter	NAPP	NAPP		
Area	0.01307	8.43		

	INCHES	MILLIMETERS	OTHER	REF
Length per Pole	104	2640		
Length per Magnet	444	11280		
INSULATION				
Material	G10 Epoxy			a
Thickness	0.033	0.84		a
Tolerance	NA			
DC Test	5		kVolts	c
1 kHertz Test	3		kVolts	c
COOLING				
Circuits per Magnet	NAPP			
Flow Rate per Magnet	NAPP		Gallons/Minute	
Input Pressure	NAPP		PSI	
Temp Rise @ Ramp to Imax	NA		Degrees F	
CURRENT				
Imax (PS Limit)	50		Amperes	c
Current Density @ Imax	3826	5.9	Amperes/Area	
DC Power @ Imax	.75		kWatts	
Stored Energy	.08		kJoules	

MAGNETIC PROPERTIES OF THE MAIN COIL

SYSTEMATIC TOLERANCES	SPECIFIED	MEASURED		OTHER	REF
bn=Bn/B0,an=AN/A0		bn	an		
n = 1	4×10^{-4}	NA	NA		d
n = 2	1×10^{-4}	2×10^{-1}	-8×10^{-7}	cmc^{-2}	d,e
n = 3	3×10^{-4}	-5×10^{-1}	-8×10^{-7}	cm^{-3}	d,e
n = 4	1×10^{-6}	-5×10^{-1}	-7×10^{-7}	cm^{-4}	d,e
n = 5	6×10^{-6}	7×10^{-1}	-1×10^{-7}	cm^{-5}	d,e
n = 6	1×10^{-8}	NA	NA		d

	SPECIFIED	MEASURED		OTHER	REF
RANDOM TOLERANCES					
bn=Bn/B0, an=An/A0		bn	an		
n = 0	4×10^{-2}	NA	NA		d
n = 1	8×10^{-5}	2×10^{-5}	NA	cm^{-1}	d,e
n = 2	1×10^{-5}	9×10^{-7}	8×10^{-7}	cm^{-2}	d,e
n = 3	7×10^{-5}	1×10^{-8}	8×10^{-8}	cm^{-3}	d,e
n = 4	2×10^{-6}	9×10^{-8}	1×10^{-8}	cm^{-4}	d,e
n = 5	1×10^{-6}	3×10^{-1}	5×10^{-2}	cm^{-5}	d,e
n = 6	1×10^{-7}	NA	NA		d
TYPICAL MEASUREMENTS					
$B1 \cdot L_{eff}$@I = 0	0.25	(G/cm) · m			e
$B1 \cdot L_{eff}/I$					
@ 200 AMPS	0.09383	(G/cm) · m/A)			e
@ 600 AMPS	0.09326	(G/cm · m/A)			e
@2500 AMPS	0.09311	(G/cm · m/A)			e
@5000 AMPS	0.08716	(G/cm · m/A)			e
SATURATION EFFECT					
5000/2500	6.71%				
CALCULATIONS					
B1/I					
@ 200 AMPS	0.1845	(G/cm)/A			f
@ 600 AMPS	0.1851	(G/cm)/A			f
@2500 AMPS	0.1853	(G/cm)/A			f
@5000 AMPS	0.1817	(G/cm)/A			f
@5700 AMPS	0.178	(G/cm)/A			f
SATURATION EFFECT					
5000/2500	1.94%				
Leff					

	SPECIFIED	MEASURED	OTHER	REF
@ 600 AMPS	0.509	meters		
@ 600 AMPS	0.504	meters		
@2500 AMPS	0.502	meters		
@5000 AMPS	0.480	meters		
@7500 AMPS				
POLE TIP FIELD				
@ 200 AMPS	305	G		
@ 600 AMPS	917	G		
@2500 AMPS	3824	G		
@5000 AMPS	7500	G		
@5700 AMPS	8375	G		
MAGNETIC PROPERTIES OF THE TUNE TRIM COIL				
TYPICAL MEASUREMENTS				
B1 · Leff/I	NA			
B5 · Leff/I	NA			
CALCULATIONS				
B1/I	0.03706	(G/cm)/A		
Leff	NA			
MAGNETIC PROPERTIES OF THE TUNE TRIM COIL				
TYPICAL MEASUREMENTS				
B1 · Leff/I				
B5 · Leff/I				
CALCULATIONS				
B1/I	0.07412	(G/cm)/A		
Leff	NA			

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a. J. Koehler, Private Communication
b. H. Hseuh, Private Communication
c. A. Soukas, Private Communication
d. A. Ruggiero, Memo to W. Weng, 1/23/90
e. E. Bleser
f. M. Goldman, Booster Tech. Note
g. W. Eng