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## BOOSTER SEXTUPOLE PRODUCTION MEASUREMENTS I

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**Brookhaven National Laboratory**

**U.S. Department of Energy**

USDOE Office of Science (SC)

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**BOOSTER SEXTUPOLE PRODUCTION MEASUREMENTS**

**I**

**BOOSTER TECHNICAL NOTE  
NO. 182**

**E. BLESER**

**MARCH 13, 1991**

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

## INTRODUCTION

This note is a report on the Booster sextupoles and follows the format of earlier reports on the Booster quadrupoles, BTN 174 and BTN 176. It consists of three parts. Part A reports on production measurement results on all of the 52 sextupoles. 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. Part C is a data sheet for the Booster sextupole. It is intended as a replacement for Table 3-6 of the Design Manual. This data sheet is being built into the Booster data base, which should provide for easy updating and distribution.

### A. Booster Sextupole Production Measurement Results

This note reports on results from 52 Booster sextupoles. 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:

$$B_y(X) = B_0 + B_1*X + B_2*X^2 + B_3*X^3 + \dots$$

$$B_x(X) = A_0 + A_1*X + A_2*X^2 + A_3*X^3 + \dots$$

In a sextupole the only allowed terms are  $B_2$  and  $B_8$  etc.

All the measurements are DC, and are made with a rotating coil, 44 millimeters in diameter and 36.5 inches long, which projects well outside the ends of the magnets. Therefore, all our data are in the form of integrated field values, written as  $B_2*L_{\text{eff}}$  etc. Figure 1 shows a typical plot of  $B_2*L_{\text{eff}}$ , the integrated sextupole field, versus the current, I. Figure 2 is a more interesting plot of the integrated sextupole field divided by I versus I. This shows the saturation effect at high currents and the residual field effects at low currents.

This curve represents averaged results from the 52 magnets. Table 1 lists the data points. This data should be used to characterize the DC performance of these magnets. The individual magnets vary from this curve with an rms spread to three parts in 1000. However, above 200 Amperes, all the magnets display the same shape as this curve to an accuracy of three parts in 10,000. Thus, any magnet can be parameterized as a function of current by adding to the data of Table 1 a small constant, given for each magnet in Table 2. For completeness, Figure 3 and Table 3 give the current, I, as a function the integrated sextupole field divided by I.

It should be noted that these measurements are DC production measurements and that the actual sextupole in the Booster will be determined in addition by the AC behavior of these magnets, as well as by the AC behavior of the dipoles, the dipole vacuum chambers, and the dipole correction coils. Thus, although we could easily use our data to

specify the exact variability in DC strength of the sextupole strings as they are installed around the ring, the other sources of variability are unknown in detail and may be larger, making such an effort questionable. However, the information is available if it is desired.

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 hundred. This corresponds to a spread in the average value of the radius of the sextuples of 0.011 inches or in the length of the sextupoles of 0.030 inches. These requirements are easily met. Figure 4 is a histogram of the offsets from Table 2, divided by the mean value,  $B2*Leff/I = 0.00656 \text{ (T/m}^2\text{)}*\text{m/A}$ . The rms spread here is 3.5 parts per 1000 well within the specified 1%. The total spread here is a four parts in 240 and our best guess is that much of this difference is due to the total number of laminations in the magnet varying from the required 240 by plus or minus 2. We do not have the data to test this hypothesis.

The field shape results are summarized in Table 4, the same data being shown in two different formats for convenience. The relatively large values for the dipole and quadrupole terms are presumably due to measuring coil placement, otherwise the field shape is very good.

Our conclusions are that the magnets are identical to within the specified tolerance. The manufacturer did a good job.

## **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.

## **C. Data Sheet for Booster Main Sextupole**

The appended data sheet is an attempt to provide a fairly complete description of the magnet. It will be incorporated into the Booster data base (E. Auerbach).

## **ACKNOWLEDGEMENTS**

This note is a report on the analysis of recent measurement results for the Booster sextupole. 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 Measurement 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 system to the present application. Our particular gratitude goes to Erich Willen and Peter Wanderer who gave generously of their time in overseeing this program.

The conclusion of this note, that the Booster sextupole is more than satisfactory, is a tribute to Gordon Danby, John Jackson, Rudy Damm, and John Brodowski who designed and developed this magnet.

TABLE 3  
OFFSET TO BE ADDED  
TO TABLE 1

TABLE 1  
STANDARD SEXTUPOLE EXCITATION CURVE

| I<br>Amperes | $[B_2] * L_{eff} / I$<br>$[T/M^2] * M/A$ |
|--------------|--|
| 25           | 6.685E-03                                |
| 50           | 6.602E-03                                |
| 75           | 6.580E-03                                |
| 100          | 6.573E-03                                |
| 200          | 6.568E-03                                |
| 300          | 6.566E-03                                |
| 400          | 6.563E-03                                |
| 500          | 6.558E-03                                |
| 600          | 6.549E-03                                |
| 700          | 6.536E-03                                |
| 800          | 6.513E-03                                |

| MAGNET<br>NUMBER | OFFSET<br>$[T/M^2] * M/A$<br>$10^{-5}$ |
|------------------|--|
|------------------|--|

|       |      |
|-------|------|
| BMS 1 | 0.9  |
| 2     | -1.1 |
| 3     | 0.5  |
| 4     | -1.5 |
| 5     | 0.4  |
| 6     | 0.1  |
| 7     | -0.1 |
| 8     | 0.4  |
| 9     | -1.4 |
| 10    | -0.6 |
| 11    | -0.0 |
| 12    | 0.6  |
| 13    | 1.8  |
| 14    | 2.7  |
| 15    | 1.8  |
| 16    | 1.4  |
| 17    | 1.6  |
| 18    | 1.6  |
| 19    | -4.6 |
| 20    | -0.6 |
| 21    | -2.1 |
| 22    | 1.8  |
| 23    | 2.4  |
| 24    | 2.3  |
| 25    | -0.8 |
| 26    | 2.8  |
| 27    | -0.8 |
| 28    | -2.2 |
| 29    | -1.5 |
| 30    | 0.0  |
| 31    | -1.9 |
| 32    | -0.8 |
| 33    | -1.6 |
| 34    | 2.2  |
| 35    | -0.9 |
| 36    | -0.2 |
| 37    | -4.5 |
| 38    | 0.7  |
| 39    | 2.0  |
| 40    | -4.3 |
| 41    | 1.8  |
| 42    | -1.9 |
| 43    | -1.8 |
| 44    | 5.3  |
| 45    | 0.6  |
| 46    | 1.7  |

TABLE 2  
STANDARD SEXTUPOLE EXCITATION CURVE

| $[B_2] * L_{eff}$ | $I / \{ [B_2] * L_{eff} \}$ |
|-------------------|-----------------------------|
| $[T/M^2] * M$     | $A / \{ [T/M^2] * M \}$     |
| 0.167             | 149.598                     |
| 0.330             | 151.468                     |
| 0.494             | 151.967                     |
| 0.657             | 152.135                     |
| 1.314             | 152.249                     |
| 1.970             | 152.291                     |
| 2.625             | 152.367                     |
| 3.279             | 152.493                     |
| 3.930             | 152.689                     |
| 4.575             | 152.991                     |
| 5.211             | 153.536                     |

TABLE 4 FIELD SHAPE ANALYSIS  
A. DATA RELATIVE TO B2

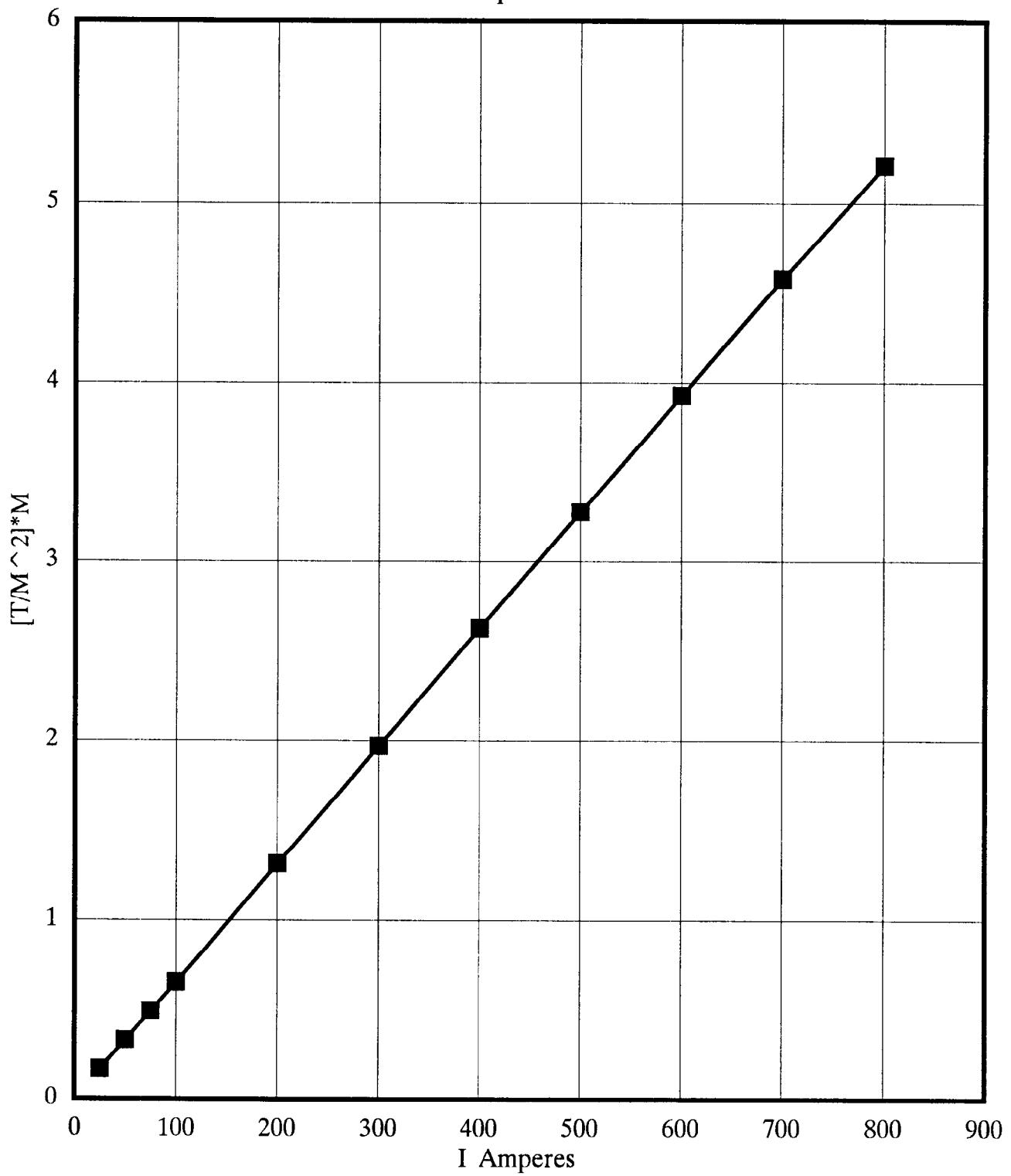
|           | Systematic Errors |              |        | Random Errors |              |            |
|-----------|-------------------|--------------|--------|---------------|--------------|------------|
| Tolerance | Measured          | meas/toler   |        | Tolerance     | Measured     | meas/toler |
|           | $m^{-(n-2)}$      | $m^{-(n-2)}$ |        | $m^{-(n-2)}$  | $m^{-(n-2)}$ |            |
| B0/B2     |                   |              |        | 2.7E-05       | 1.8E-05      | 0.7        |
| B1/B2     |                   |              |        | 3.0E-04       | 2.4E-04      | 0.8        |
| B2        |                   |              |        | 8.9E-03       | 3.4E-03      | 0.4        |
| B3/B2     | 5.9E+00           | 1.3E-02      | 0.002  | 3.0E+00       | 2.0E-02      | 0.007      |
| B4/B2     | 8.9E+00           | -7.2E-01     | -0.08  | 1.8E+01       | 7.5E-01      | 0.04       |
| B5/B2     | 1.2E+05           | 1.9E+01      | 0.000  | 3.0E+02       | 2.3E+01      | 0.08       |
| A0/B2     |                   |              |        | 2.7E-05       | 2.4E-06      | 0.09       |
| A1/B2     |                   |              |        | 3.0E-04       | 2.8E-04      | 0.95       |
| A2/B2     | 8.9E-02           | -2.4E-02     | -0.3   | 8.9E-03       | 2.2E-03      | 0.25       |
| A3/B2     | 5.9E+00           | 2.8E-03      | 0.000  | 3.0E+00       | 2.5E-02      | 0.009      |
| A4/B2     | 8.9E+00           | 1.0E+00      | 0.1    | 1.8E+01       | 8.4E-01      | 0.05       |
| A5/B2     | 1.2E+05           | -1.1E+01     | -0.000 | 3.0E+02       | 1.9E+01      | 0.06       |

B. DATA RELATIVE TO B0

|           | Systematic Errors |            |        | Random Errors |          |            |
|-----------|-------------------|------------|--------|---------------|----------|------------|
| Tolerance | Measured          | meas/toler |        | Tolerance     | Measured | meas/toler |
|           | $m^{-n}$          | $m^{-n}$   |        | $m^{-n}$      | $m^{-n}$ |            |
| b0        |                   |            |        | 9.0E-04       | 6.2E-04  | 0.7        |
| b1        |                   |            |        | 1.0E-02       | 8.2E-03  | 0.8        |
| b2        |                   |            |        | 3.0E-01       | 1.2E-01  | 0.4        |
| b3        | 2.0E+02           | 4.4E-01    | 0.002  | 1.0E+02       | 6.6E-01  | 0.007      |
| b4        | 3.0E+02           | -2.4E+01   | -0.08  | 6.0E+02       | 2.5E+01  | 0.04       |
| b5        | 4.0E+06           | 6.5E+02    | 0.000  | 1.0E+04       | 7.6E+02  | 0.08       |
| a0        |                   |            |        | 9.0E-04       | 8.1E-05  | 0.09       |
| a1        |                   |            |        | 1.0E-02       | 9.5E-03  | 0.95       |
| a2        | 3.0E+00           | -8.2E-01   | -0.3   | 3.0E-01       | 7.4E-02  | 0.25       |
| a3        | 2.0E+02           | 9.3E-02    | 0.000  | 1.0E+02       | 8.5E-01  | 0.009      |
| a4        | 3.0E+02           | 3.4E+01    | 0.1    | 6.0E+02       | 2.8E+01  | 0.05       |
| a5        | 4.0E+06           | -3.8E+02   | -0.000 | 1.0E+04       | 6.2E+02  | 0.06       |

# [B2]\*Leff vs I

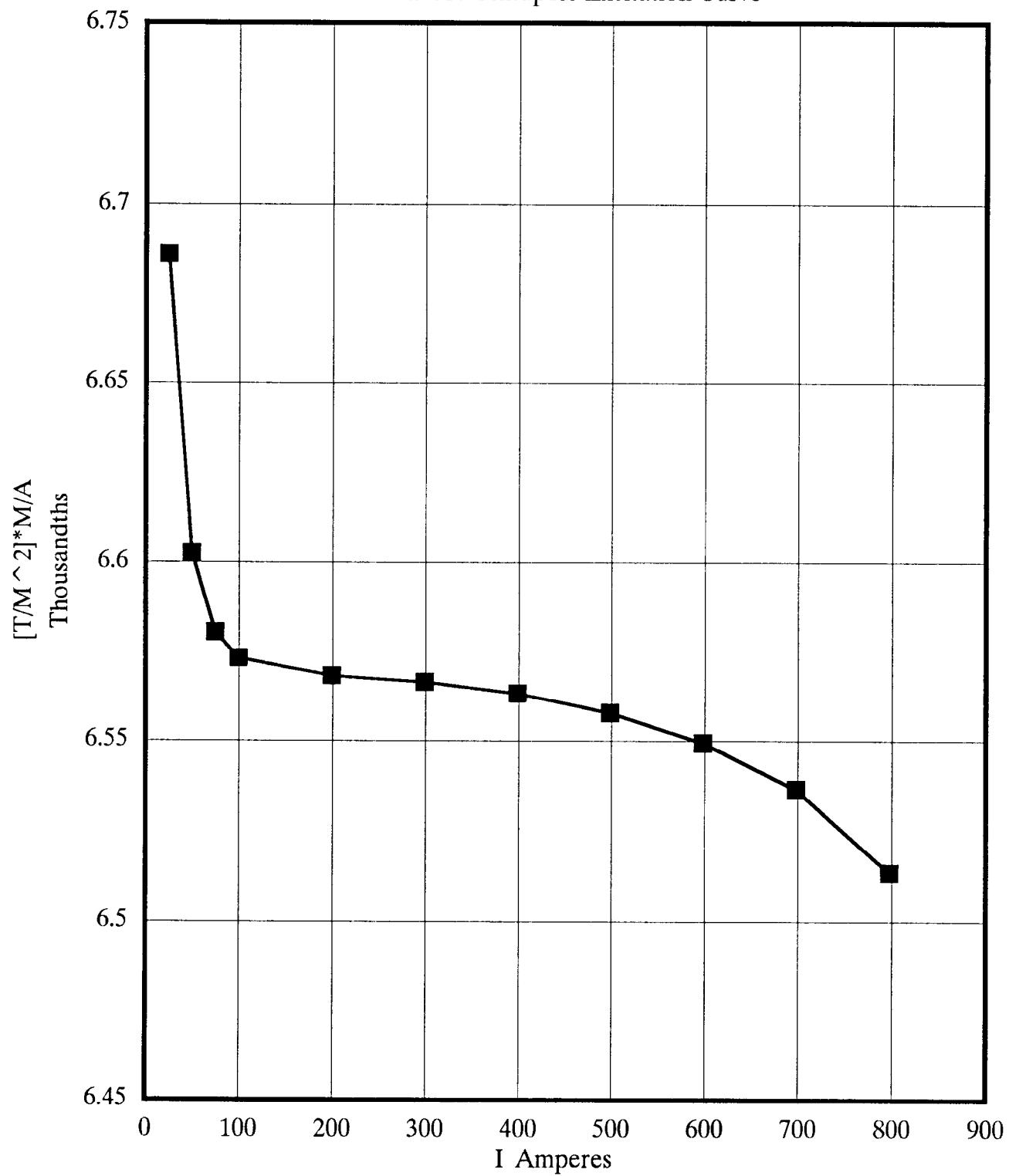
Standard Sextupole Excitation Curve



Averaged over 52 Sextupole Magnets  
08-Mar-91

# [B2]<sup>\*</sup>L<sub>eff</sub>/I vs I

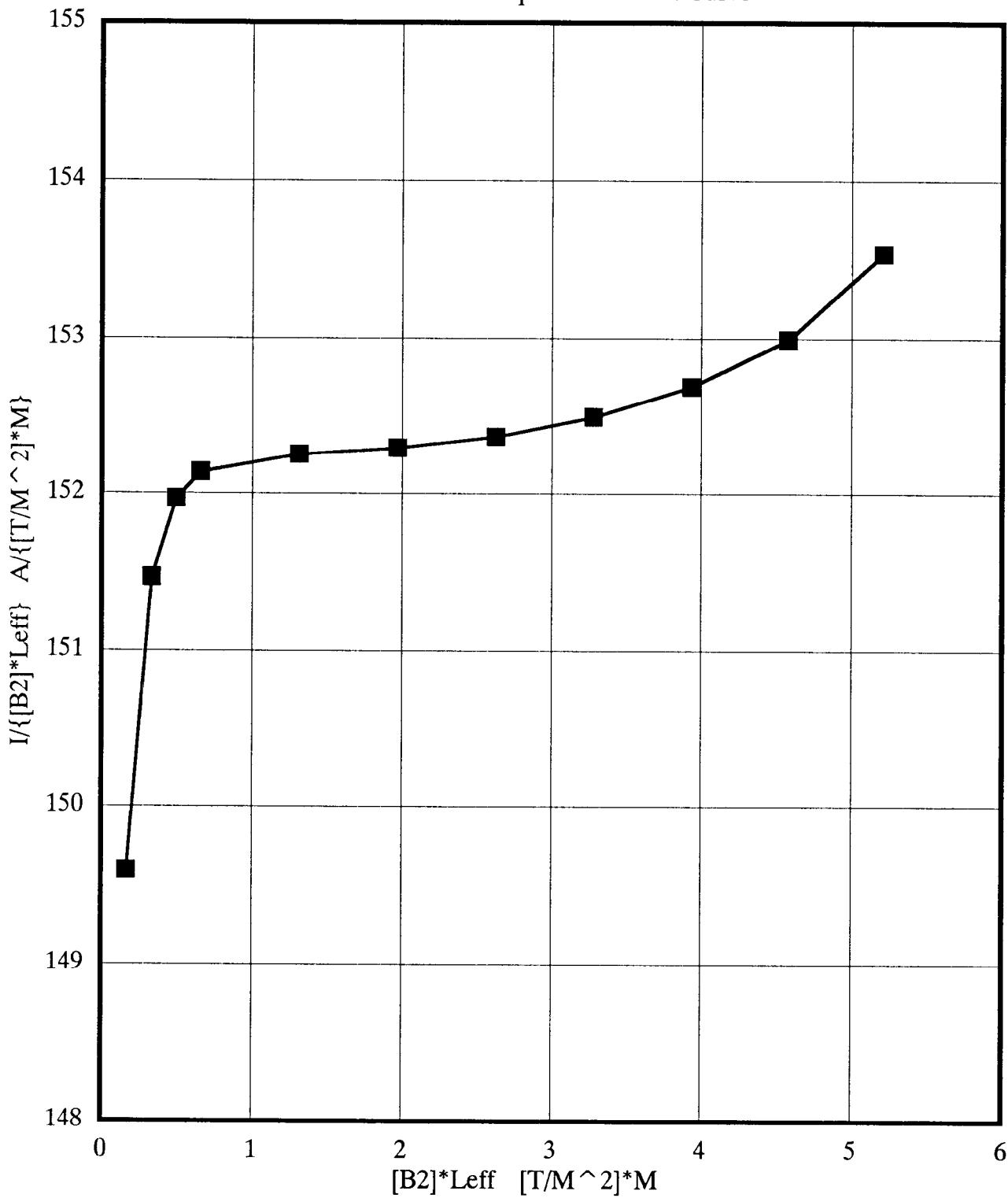
Standard Sextupole Excitation Curve



Averaged over 52 Sextupole Magnets  
08-Mar-91

# $I/\{[B_2]^*L_{eff}\}$ VS $[B_2]^*L_{eff}$

Standard Sextupole Excitation Curve

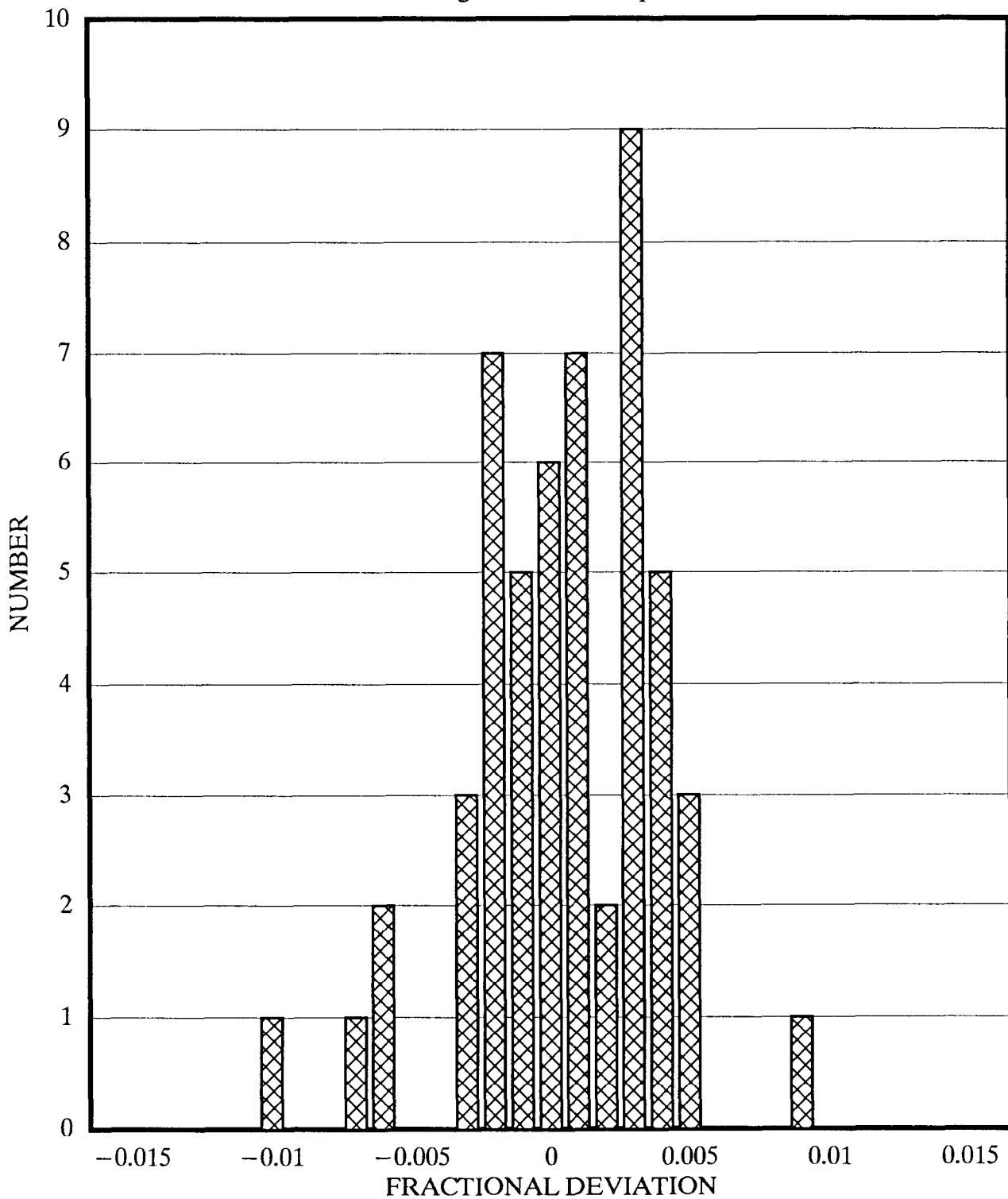


AVERAGED OVER 52 SEXTUPOLE MAGNETS

08-Mar-91

# DEVIATIONS from the MEAN for [B2]\*Leff/I

Histogram of 52 Sextupoles



STD = 0.0035

08-Mar-91

## ANALYSIS of FIELD SHAPE MEASUREMENTS

|                     |                   |
|---------------------|-------------------|
| MAGNET TYPE         | BOOSTER SEXTUPOLE |
| MAGNET NUMBER       | BMS025            |
| RUN NUMBER          | BMS025.101(raw)   |
| DATE of MEASUREMENT | 2 Aug 90 15:25:15 |
| DATE of ANALYSIS    | 20-Feb-91         |

## SHORT SUMMARY of MAGNET QUALITY

### SUMMARY of PRIMARY FIELD RESULTS

|                             |                      |
|-----------------------------|----------------------|
| $B_2 * L_{eff} / I @ 400 A$ | 0.00656 (T/M^2) *M/A |
| $B_2 * L_{eff} / I @ 800 A$ | 0.00651 (T/M^2) *M/A |

|                   |        |
|-------------------|--------|
| SATURATION EFFECT | 1.0076 |
|-------------------|--------|

### SUMMARY of HARMONIC CONTENTS

|           | AVG       | STD DEV | UNITS |
|-----------|-----------|---------|-------|
| $B_0/B_2$ | -7.27E-05 | 5.1E-07 | M^2   |
| $A_0/B_2$ | 1.18E-06  | 2.0E-07 | M^2   |
| $B_3/B_2$ | 2.00E-02  | 3.4E-03 | M^-1  |
| $A_3/B_2$ | -5.98E-03 | 2.4E-03 | M^-1  |
| $B_4/B_2$ | -5.24E-01 | 5.0E-02 | M^-2  |
| $A_4/B_2$ | 4.59E-01  | 4.4E-02 | M^-2  |
| $B_5/B_2$ | 2.0E+01   | 2.7E+00 | M^-3  |
| $A_5/B_2$ | -8.6E+00  | 1.3E+00 | M^-3  |

### SUMMARY of ALIGNMENT PARAMETERS

|                |                    |                |                   |
|----------------|--------------------|----------------|-------------------|
| x <sub>o</sub> | 5.90E-05<br>2.3    | 1.4E-06<br>0.1 | M<br>0.001 INCHES |
| y <sub>o</sub> | -4.75E-04<br>-18.7 | 3.7E-06<br>0.1 | M<br>0.001 INCHES |
| Theta          | -7.19E-03          | 1.2E-05        | radians           |

### SUMMARY of RESIDUAL FIELDS

|                 |          |            |
|-----------------|----------|------------|
| $B_0 * L_{eff}$ | 1.4E-04  | T*M        |
| $A_0 * L_{eff}$ | -2.9E-06 | T*M        |
| $B_2 * L_{eff}$ | 5.8E-03  | (T/M^2) *M |
| $A_2 * L_{eff}$ | -1.9E-04 | (T/M^2) *M |

## BASIC MEASUREMENT RESULTS

---

|    | I<br>AMPS | B2*Leff<br>(T/M^2)*M | Bo*Leff<br>T*M | B1*Leff<br>(T/M)*M | B3*Leff<br>(T/M^3)*M | B4*Leff<br>(T/M^4)*M | B5*Leff<br>(T/M^5)*M |
|----|-----------|----------------------|----------------|--------------------|----------------------|----------------------|----------------------|
| 1  | 0.002     | 0.006                | 1.4E-04        | 5.2E-05            | -5.7E-03             | -1.2E-02             | -2.79E-01            |
| 2  | 24.593    | 0.165                | 1.3E-04        | 6.5E-05            | 3.0E-03              | -2.5E-01             | -6.43E+00            |
| 3  | 49.54     | 0.327                | 1.2E-04        | 8.1E-05            | 9.0E-03              | -2.1E-01             | 3.89E+00             |
| 4  | 74.486    | 0.490                | 1.1E-04        | 1.0E-04            | 8.2E-03              | -2.0E-01             | 1.15E+01             |
| 5  | 99.409    | 0.653                | 9.5E-05        | 1.2E-04            | 6.6E-03              | -2.2E-01             | 8.07E+00             |
| 6  | 199.16    | 1.307                | 4.7E-05        | 2.0E-04            | 2.9E-02              | -7.7E-01             | 2.35E+01             |
| 7  | 298.804   | 1.960                | 6.7E-07        | 2.8E-04            | 3.6E-02              | -8.5E-01             | 4.95E+01             |
| 8  | 398.534   | 2.613                | -4.6E-05       | 3.7E-04            | 3.7E-02              | -1.3E+00             | 4.38E+01             |
| 9  | 498.326   | 3.264                | -9.4E-05       | 4.5E-04            | 5.0E-02              | -1.8E+00             | 6.94E+01             |
| 10 | 598.144   | 3.913                | -1.4E-04       | 5.0E-04            | 6.9E-02              | -2.2E+00             | 7.71E+01             |
| 11 | 697.713   | 4.555                | -1.9E-04       | 5.7E-04            | 8.4E-02              | -2.4E+00             | 9.18E+01             |
| 12 | 797.507   | 5.188                | -2.5E-04       | 6.7E-04            | 7.4E-02              | -3.1E+00             | 1.14E+02             |

|    | I<br>AMPS | A2*Leff<br>(T/M^2)*M | Ao*Leff<br>T*M | A1*Leff<br>(T/M)*M | A3*Leff<br>(T/M^3)*M | A4*Leff<br>(T/M^4)*M | A5*Leff<br>(T/M^5)*M |
|----|-----------|----------------------|----------------|--------------------|----------------------|----------------------|----------------------|
| 1  | 0.002     | -0.000               | -0.000         | 1.7E-04            | 7.2E-04              | -1.5E-01             | -6.152234            |
| 2  | 24.593    | -0.004               | -0.000         | 2.9E-05            | 1.3E-03              | -1.1E-01             | -11.48617            |
| 3  | 49.54     | -0.007               | -0.000         | -1.2E-04           | -5.0E-03             | -4.3E-02             | -8.852036            |
| 4  | 74.486    | -0.010               | -0.000         | -2.6E-04           | -3.1E-03             | 2.2E-01              | -5.013184            |
| 5  | 99.409    | -0.014               | -0.000         | -4.1E-04           | 8.0E-04              | 2.9E-01              | -4.467261            |
| 6  | 199.16    | -0.028               | -0.000         | -1.1E-03           | -7.2E-03             | 5.6E-01              | -16.37456            |
| 7  | 298.804   | -0.042               | -0.000         | -1.7E-03           | -1.8E-02             | 6.8E-01              | -21.53754            |
| 8  | 398.534   | -0.056               | -0.000         | -2.3E-03           | -1.9E-02             | 1.1E+00              | -26.65769            |
| 9  | 498.326   | -0.070               | 0.000          | -2.9E-03           | -1.5E-02             | 1.3E+00              | -42.37914            |
| 10 | 598.144   | -0.085               | 0.000          | -3.6E-03           | -2.4E-02             | 1.5E+00              | -34.3978             |
| 11 | 697.713   | -0.098               | 0.000          | -4.2E-03           | -7.3E-03             | 1.8E+00              | -49.0289             |
| 12 | 797.507   | -0.112               | 0.000          | -4.8E-03           | -2.4E-02             | 2.1E+00              | -52.22543            |

## GRADIENT and POSITION ANALYSIS

### Residual Field Subtracted

|            | I<br>AMPS | B2*Leff/I<br>(T/M^2)*M/A | Theta<br>A2/(3*B2)<br>radians | xo<br>B1/(2*B2)<br>M | yo<br>A1/(2*B2)<br>M |
|------------|-----------|--------------------------|-------------------------------|----------------------|----------------------|
| 1          | 0.002     |                          |                               |                      |                      |
| 2          | 24.593    | 0.00669                  | 0.00646                       | -7.38E-03            | 4.07E-05             |
| 3          | 49.54     | 0.00660                  | 0.00649                       | -7.34E-03            | 4.49E-05             |
| 4          | 74.486    | 0.00658                  | 0.00650                       | -7.04E-03            | 5.18E-05             |
| 5          | 99.409    | 0.00657                  | 0.00651                       | -7.04E-03            | 4.89E-05             |
| 6          | 199.16    | 0.00656                  | 0.00653                       | -7.20E-03            | 5.82E-05             |
| 7          | 298.804   | 0.00656                  | 0.00654                       | -7.19E-03            | 5.90E-05             |
| 8          | 398.534   | 0.00656                  | 0.00654                       | -7.20E-03            | 6.08E-05             |
| 9          | 498.326   | 0.00655                  | 0.00654                       | -7.19E-03            | 6.09E-05             |
| 10         | 598.144   | 0.00654                  | 0.00653                       | -7.20E-03            | 5.78E-05             |
| 11         | 697.713   | 0.00653                  | 0.00652                       | -7.17E-03            | 5.73E-05             |
| 12         | 797.507   | 0.00651                  | 0.00650                       | -7.21E-03            | 5.99E-05             |
| AVG(2-700) |           | 6.55E-03                 | 6.53E-03                      | -7.19E-03            | 5.90E-05             |
| STAND DEV  |           | 1.2E-05                  | 7.1E-06                       | 1.2E-05              | 1.4E-06              |
|            |           |                          |                               |                      | 3.7E-06              |

HARMONIC CONTENT

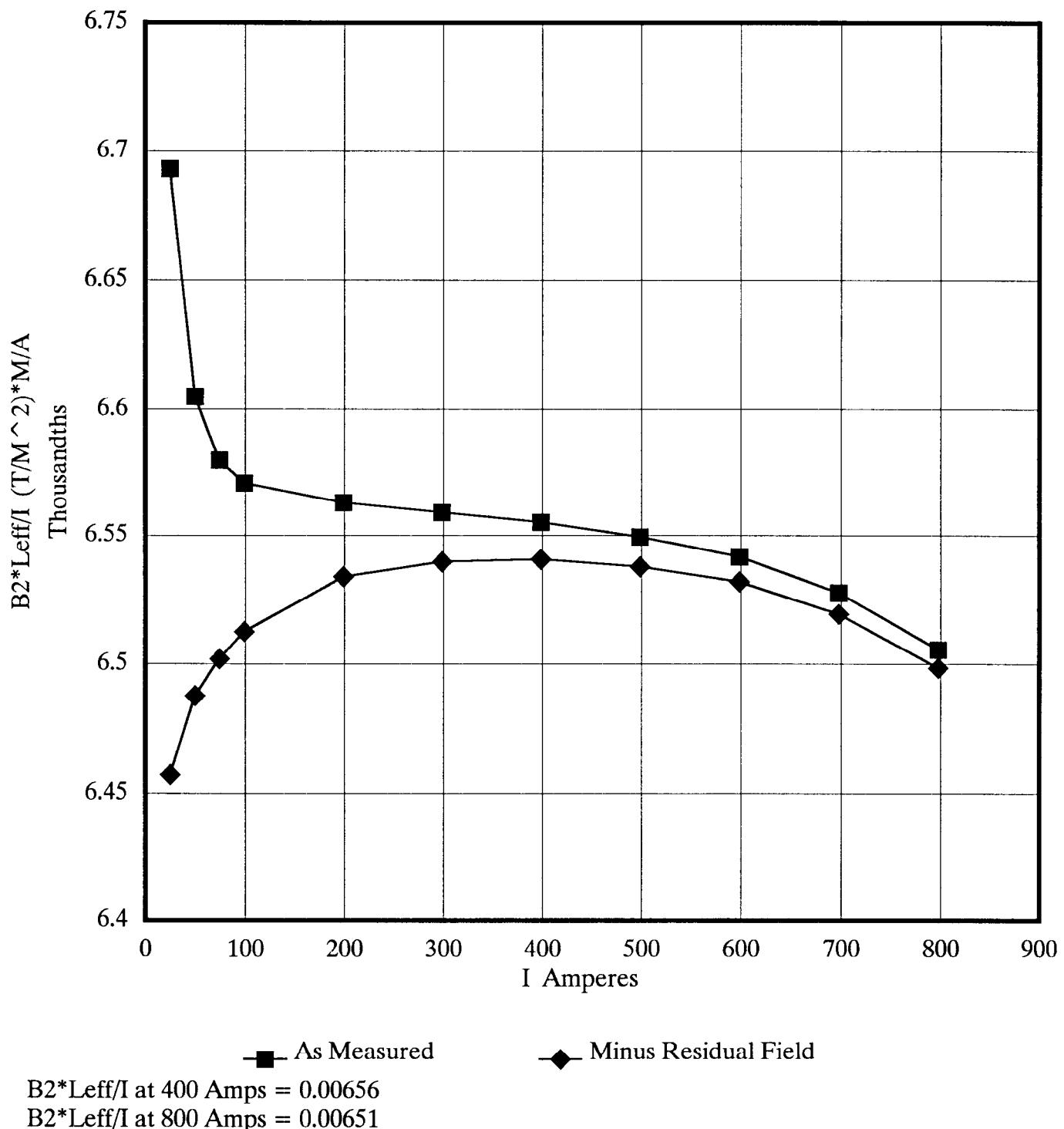
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|            | I<br>AMPS | B2*Leff/I<br>(T/M^2)*M/A | Bo/B2<br>M^2 | B1/B2<br>M | B3/B2<br>M^-1 | B4/B2<br>M^-2 | B5/B2<br>M^-3 |
|------------|-----------|--------------------------|--------------|------------|---------------|---------------|---------------|
| 1          | 0.002     |                          |              |            |               |               |               |
| 2          | 24.593    | 6.693E-03                | -6.89E-05    | 8.14E-05   | 5.52E-02      | -1.5E+00      | -3.9E+01      |
| 3          | 49.54     | 6.605E-03                | -7.24E-05    | 8.98E-05   | 4.59E-02      | -6.1E-01      | 1.3E+01       |
| 4          | 74.486    | 6.580E-03                | -7.26E-05    | 1.04E-04   | 2.88E-02      | -3.8E-01      | 2.4E+01       |
| 5          | 99.409    | 6.571E-03                | -7.24E-05    | 9.78E-05   | 1.91E-02      | -3.2E-01      | 1.3E+01       |
| 6          | 199.16    | 6.563E-03                | -7.29E-05    | 1.16E-04   | 2.66E-02      | -5.8E-01      | 1.8E+01       |
| 7          | 298.804   | 6.559E-03                | -7.23E-05    | 1.18E-04   | 2.13E-02      | -4.3E-01      | 2.5E+01       |
| 8          | 398.534   | 6.555E-03                | -7.20E-05    | 1.22E-04   | 1.65E-02      | -5.1E-01      | 1.7E+01       |
| 9          | 498.326   | 6.550E-03                | -7.24E-05    | 1.22E-04   | 1.70E-02      | -5.6E-01      | 2.1E+01       |
| 10         | 598.144   | 6.542E-03                | -7.29E-05    | 1.16E-04   | 1.91E-02      | -5.5E-01      | 2.0E+01       |
| 11         | 697.713   | 6.528E-03                | -7.35E-05    | 1.15E-04   | 1.97E-02      | -5.1E-01      | 2.0E+01       |
| 12         | 797.507   | 6.506E-03                | -7.56E-05    | 1.20E-04   | 1.54E-02      | -5.9E-01      | 2.2E+01       |
| AVG(2-700) |           | 6.55E-03                 | -7.27E-05    | 1.18E-04   | 2.00E-02      | -5.24E-01     | 2.03E+01      |
| STAND DEV  |           | 1.2E-05                  | 5.1E-07      | 2.8E-06    | 3.4E-03       | 5.0E-02       | 2.7E+00       |

|            | I<br>AMPS | A2/B2<br>M^2 | Ao/B2<br>M^2 | A1/B2<br>M | A3/B2<br>M^-1 | A4/B2<br>M^-2 | A5/B2<br>M^-3 |
|------------|-----------|--------------|--------------|------------|---------------|---------------|---------------|
| 1          | 0.002     |              |              |            |               |               |               |
| 2          | 24.593    | -2.2E-02     | -1.83E-06    | -8.66E-04  | 3.42E-03      | 2.5E-01       | -3.4E+01      |
| 3          | 49.54     | -2.2E-02     | -4.52E-07    | -8.80E-04  | -1.79E-02     | 3.5E-01       | -8.4E+00      |
| 4          | 74.486    | -2.1E-02     | 4.82E-07     | -8.73E-04  | -7.88E-03     | 7.8E-01       | 2.4E+00       |
| 5          | 99.409    | -2.1E-02     | 5.41E-07     | -8.92E-04  | 1.21E-04      | 6.9E-01       | 2.6E+00       |
| 6          | 199.16    | -2.2E-02     | 7.93E-07     | -9.39E-04  | -6.08E-03     | 5.5E-01       | -7.9E+00      |
| 7          | 298.804   | -2.2E-02     | 1.35E-06     | -9.40E-04  | -9.58E-03     | 4.3E-01       | -7.9E+00      |
| 8          | 398.534   | -2.2E-02     | 1.03E-06     | -9.49E-04  | -7.39E-03     | 4.7E-01       | -7.9E+00      |
| 9          | 498.326   | -2.2E-02     | 1.31E-06     | -9.54E-04  | -4.81E-03     | 4.6E-01       | -1.1E+01      |
| 10         | 598.144   | -2.2E-02     | 1.28E-06     | -9.57E-04  | -6.24E-03     | 4.3E-01       | -7.2E+00      |
| 11         | 697.713   | -2.2E-02     | 1.32E-06     | -9.56E-04  | -1.77E-03     | 4.2E-01       | -9.4E+00      |
| 12         | 797.507   | -2.2E-02     | 1.08E-06     | -9.54E-04  | -4.74E-03     | 4.4E-01       | -8.9E+00      |
| AVG(2-700) |           | -2.16E-02    | 1.18E-06     | -9.49E-04  | -5.98E-03     | 4.59E-01      | -8.56E+00     |
| STAND DEV  |           | 3.54E-05     | 2.04E-07     | 7.38E-06   | 2.39E-03      | 4.38E-02      | 1.32E+00      |

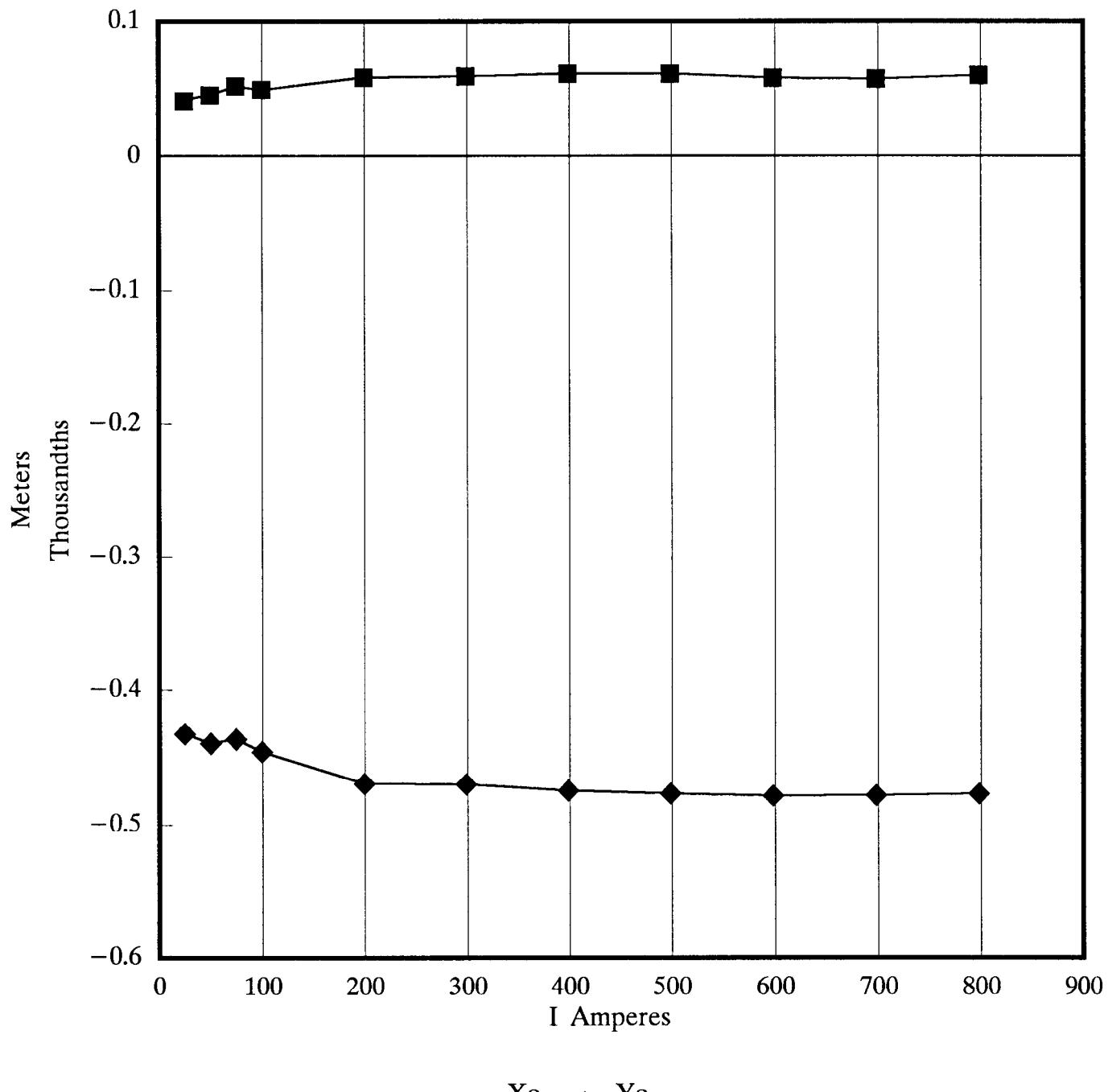
# B2\*Leff/I vs I, BMS025

20-Feb-91



# Xo, Yo vs I, BMS025

20–Feb–91



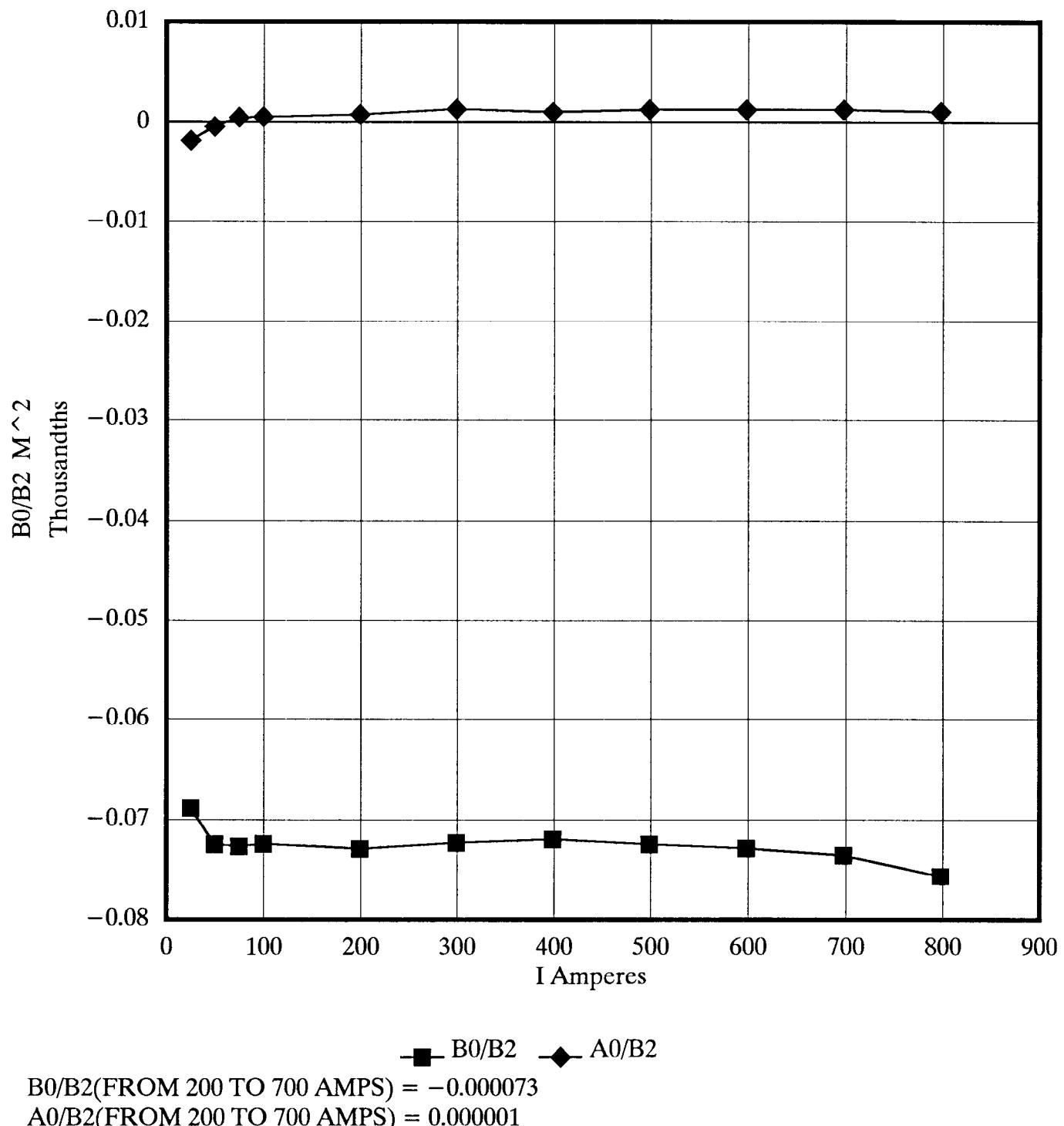
■  $X_o$  ◆  $Y_o$

$X_o = 0.0023$  inches

$Y_o = -0.0187$  inches

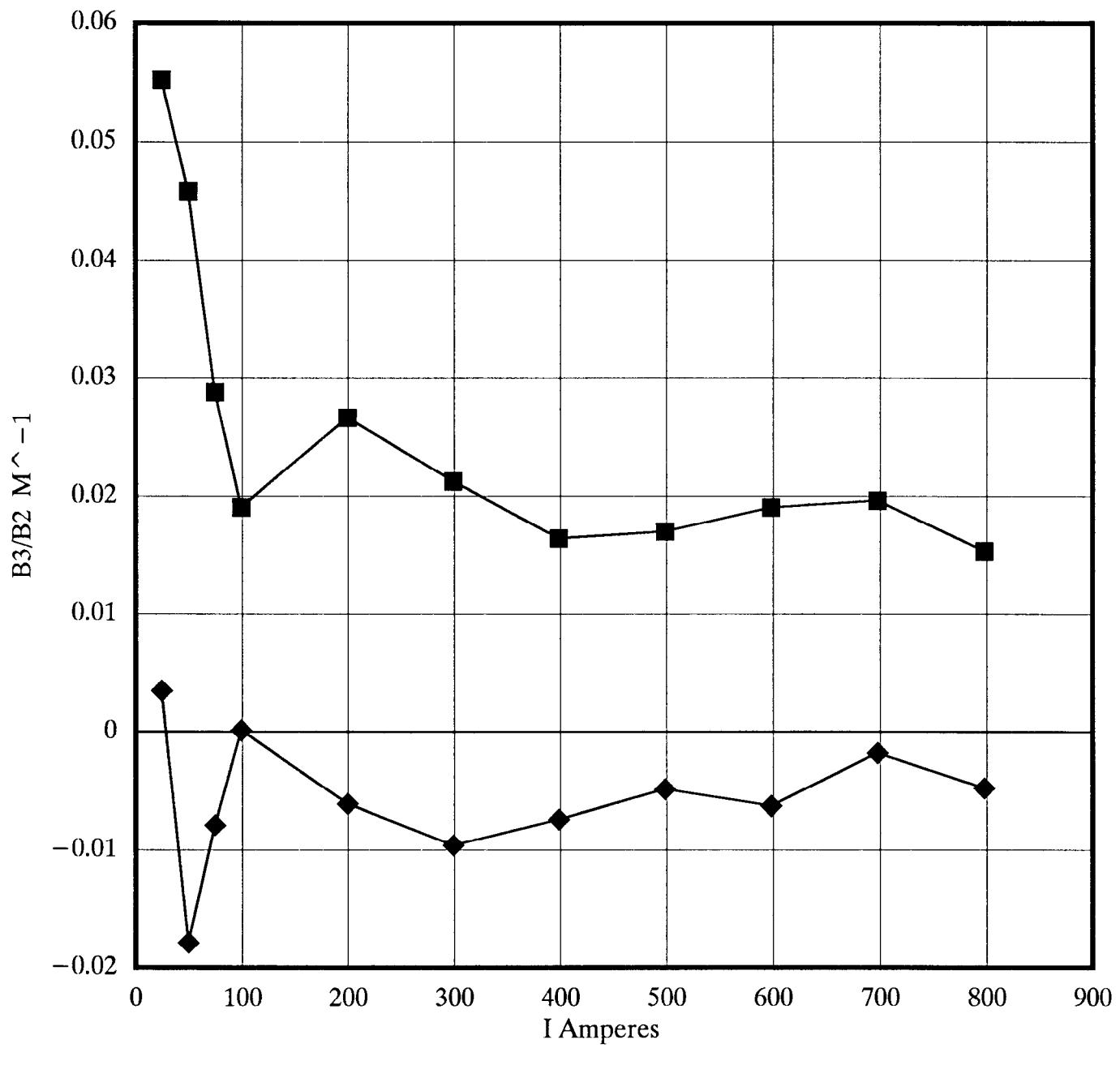
# B0/B2, A0/A2 VS I, BMS025

20-Feb-91



# B3/B2, A3/B2 VS I, BMS025

20-Feb-91



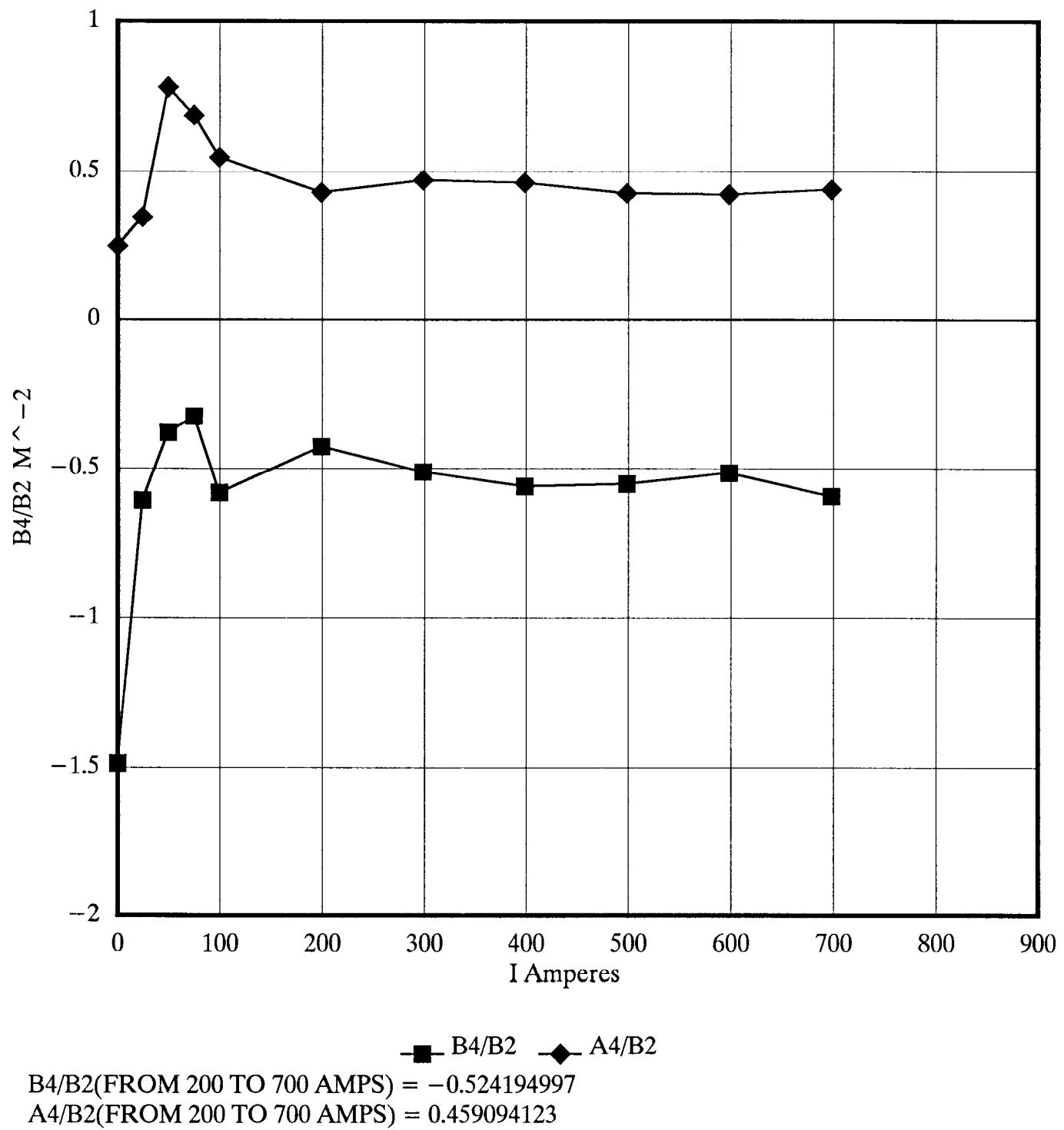
■ B3/B2      ♦ A3/B2

B3/B2(FROM 200 TO 700 AMPS) = 0.020019

A3/B2(FROM 200 TO 700 AMPS) = -0.005981

## B4/B2, A4/B2 VS I, BMS025

20-Feb-91



# PARAMETER SHEET FOR BOOSTER SEXTUPOLE

Issued February 21, 1991

**PROTOTYPE NAME**  
**MAGNET CLASS**  
**NUMBER OF MAGNETS**  
**VENDOR**

**BMS (BOOSTER MAIN SEXTUPOLE)**  
**SEXTUPOLE**  
**48 PLUS 4**  
**Everson Electric-Complete Magnet**

|                     | INCHES         | METERS    | OTHER | REF |
|---------------------|----------------|-----------|-------|-----|
| <b>MECHANICAL</b>   |                |           |       |     |
| <b>CORE</b>         |                |           |       |     |
| Lamination Length   | 3.000          | 76.2 E-3  |       | a   |
| Tolerance Specified | 0.005          | 0.137 E-3 |       | a   |
| Tolerance Measured  | 0.011          | 0.28 E-3  |       | e   |
| Structural Length   | 3.5            | 89. E-3   |       | a   |
| Coil Length         | 5.2            | 132       |       | a   |
| Overall Length      | 8.5            | 216       |       | a   |
| Aperture Shape      | Round          |           |       |     |
| Radius at Pole Tip  | 3.250          | 82.55 E-3 |       | a   |
| Tolerance Specified | 0.002          | 0.05 E-3  |       | d   |
| Tolerance Measured  | 0.001          | 0.02 E-3  |       | e   |
| Pole Width          | 2.45           | 62.2 E-3  |       | a   |
| Core Height         | 8.89           | 226. E-3  |       | a   |
| Core Width          | 8.89           | 226. E-3  |       | a   |
| <b>LAMINATIONS</b>  |                |           |       |     |
| Material            | Armco M-36     |           |       | a   |
| Coating             | AISI Type - C5 |           |       | a   |
| Coating Thickness   | 0.0002         | 0.005 E-3 |       | a   |
| Overall Thickness   | 0.025          | 0.6 E-3   |       | a   |

|                        | INCHES      | METERS    | OTHER | REF |
|------------------------|-------------|-----------|-------|-----|
| Approx. Lams Per Block | 120         |           |       |     |
| Block Weight           | NA          | NA        |       |     |
| Tolerance Specified    | NA          | NA        |       |     |
| Tolerance Measured     | NA          | NA        |       |     |
| <b>VACUUM PIPE</b>     |             |           |       |     |
| Height - Outside       | 6           | 152 E-3   |       | b   |
| Width - Outside        | 6           | 152 E - 3 |       | b   |
| Wall Thickness         | 0.063       | 1.6 E-3   |       | b   |
| Tolerance Specified    | 0.003       | 0.1 E-3   |       | b   |
| Tolerance Measured     | NA          | NA        |       |     |
| Half Height - Inside   | 2.937       | 74.6 E-3  |       |     |
| Half Width - Inside    | 2.937       | 74.6 E-3  |       |     |
| Material               | Inconel 625 |           |       | b   |
| Resistivity            | 1.29 E-6    |           | Ohm-m | b   |
| Tolerance Specified    | 0.02 E-6    |           | Ohm-m | b   |
| Tolerance Measured     | NA          |           |       |     |

|                             | INCHES              | METERS   | OTHER          | REF |
|-----------------------------|---------------------|----------|----------------|-----|
| <b>MAIN COIL</b>            |                     |          |                |     |
| <b>COIL</b>                 |                     |          |                |     |
| Turns per Pole              | 8                   |          |                |     |
| Poles per Magnet            | 6                   |          |                |     |
| Resistance per Magnet       | 7.58 E-3            |          | Ohms           | f   |
| Inductance Per Magnet - DC  | 0.37 E-3            |          | Henry          | f   |
| Inductance Per Magnet - 1 k | 0.37 E-3            |          | Henry          | f   |
| <b>CONDUCTOR</b>            |                     |          |                |     |
| Material                    | Copper - Alloy 0102 |          |                | a   |
| Shape                       | Square              |          |                |     |
| Width                       | 0.315               | 8.0 E-3  |                | a   |
| Height                      | 0.315               | 8.0 E-3  |                | a   |
| Cooling Hole Diameter       | 0.197               | 5.0 E-3  |                | a   |
| Area                        | 0.067               | 43 E-6   |                | a   |
| Length per Pole             | 126                 | 3.2      |                | a   |
| Length per Magnet           | 756                 | 19.2     |                |     |
| <b>INSULATION</b>           |                     |          |                |     |
| Material                    | Epoxy Fiberglas     |          |                | a   |
| Thickness                   | 0.04                | 1. E-3   |                | a   |
| Tolerance                   | 0.01                | 0.25 E-3 |                | a   |
| Ground Test                 | 2000                |          | Volts          | c   |
| Impulse Test                | 1500                |          | Volts          | c   |
| <b>COOLING</b>              |                     |          |                |     |
| Circuits per Magnet         | 2                   |          |                | a   |
| Flow Rate per Magnet        | 0.6                 |          | Gallons/Minute | a   |
| Input Pressure              | 50                  |          | PSI            | a   |
| Temp Rise @ RAMP to Imax    | 20                  |          | Degrees F      | a   |
| <b>CURRENT</b>              |                     |          |                |     |
| Imax (PS Limit)             | 300                 |          | Amperes        | c   |
| Current Density @ Imax      | 4500                | 7 E+6    | Amperes/Area   |     |
| DC Power @ Imax             | 680                 |          | Watts          |     |
| Stored Energy @ Imax        | 17                  |          | Joules         |     |

|                           | INCHES            | METERS   | OTHER        | REF |
|---------------------------|-------------------|----------|--------------|-----|
| <b>ONE TURN TRIM COIL</b> |                   |          |              |     |
| <b>COIL</b>               |                   |          |              |     |
| Turns per Pole            | 1                 |          |              | a   |
| Poles per Magnet          | 6                 |          |              |     |
| Resistance per Magnet     | 7.93 E-3          |          | Ohms         | g   |
| Inductance per Magnet-DC  | 0.01 E-3          |          | Henry        | g   |
| Inductance per Magnet-1 k | 0.01 E-3          |          | Henry        | g   |
| <b>CONDUCTOR</b>          |                   |          |              |     |
| Material                  | Copper - ETP #110 |          |              | a   |
| Shape                     | Round #8 Wire     |          |              | a   |
| Width                     | 0.129             | 3.28 E-3 |              | a   |
| Height                    | 0.129             | 3.28 E-3 |              | a   |
| Cooling Hole Diameter     | None              | None     |              |     |
| Area                      | 0.013             | 8.4 E-6  |              |     |
| Length per Pole           | 16                | .41      |              | a   |
| Length per Magnet         | 136               | 3.45     |              |     |
| <b>INSULATION</b>         |                   |          |              |     |
| Material                  | Epoxy - Fiberglas |          |              | a   |
| Thickness                 | 0.06              | 1.5 E-3  |              | a   |
| Tolerance                 | NA                | NA       |              |     |
| Ground Test               | 1000              |          | Volts        | c   |
| Impulse Test              | NA                |          |              |     |
| <b>COOLING</b>            |                   |          |              |     |
| Circuits per Magnet       | None              |          |              |     |
| Flow Rate per Magnet      | None              |          |              |     |
| Input Pressure            | None              |          |              |     |
| Temp Rise @ RAMP to Imax  | NA                |          |              |     |
| <b>CURRENT</b>            |                   |          |              |     |
| Imax (PS Limit)           | 50                |          | Amperes      | c   |
| Current Density @ Imax    | 3826              | 6 E+6    | Amperes/Area |     |
| DC Power @ Imax           | 20                |          | Watts        |     |
| Stored Energy             | 0.013             |          | Joules       |     |

|                             | INCHES            | METERS   | OTHER        | REF |
|-----------------------------|-------------------|----------|--------------|-----|
| <b>TWO TURN TRIM COIL</b>   |                   |          |              |     |
| <b>COIL</b>                 |                   |          |              |     |
| Turns per Pole              | 2                 |          |              | a   |
| Poles per Magnet            | 6                 |          |              |     |
| Resistance per Magnet       | 11 E-3            |          | Ohms         | f   |
| Inductance per Magnet - DC  | 17 E-6            |          | Henry        | f   |
| Inductance per Magnet - 1 k | 17 E-6            |          | Henry        | f   |
| <b>CONDUCTOR</b>            |                   |          |              |     |
| Material                    | Copper - ETP #110 |          |              | a   |
| Shape                       | Round #8 Wire     |          |              | a   |
| Width                       | 0.129             | 3.28 E-3 |              | a   |
| Height                      | 0.129             | 3.28 E-3 |              | a   |
| Cooling Hold Diameter       | None              | None     |              |     |
| Area                        | 0.013             | 8.43 E-6 |              |     |
| Length per Pole             | 32                | 0.813    |              |     |
| Length per Magnet           | 222               | 5.64     |              |     |
| <b>INSULATION</b>           |                   |          |              |     |
| Material                    | Epoxy - Fiberglas |          |              | a   |
| Thickness                   | 0.033             | 0.84 E-3 |              | a   |
| Tolerance                   | NA                |          |              |     |
| DC Test                     | 1000              |          | Volts        | c   |
| 1 kHz Test                  | NA                |          |              | c   |
| <b>COOLING</b>              |                   |          |              |     |
| Circuits per Magnet         | None              |          |              |     |
| Flow Rate per Magnet        | None              |          |              |     |
| Temp Rise @RAMP to Imax     | NA                |          |              |     |
| <b>CURRENT</b>              |                   |          |              |     |
| Imax (PS Limit)             | 50                |          | Amperes      | c   |
| Current Density @ Imax      | 3826              | 6 E+6    | Amperes/Area |     |
| DC Power @ Imax             | 28                |          | Watts        |     |
| Stored Energy               | 0.021             |          | Joules       |     |

| MAGNETIC PROPERTIES OF THE MAIN COIL     |           |          |                                 |                         |     |
|--|-----------|----------|---------------------------------|-------------------------|-----|
| FIELD SHAPE                              |           |          |                                 |                         |     |
| $b_n = B_n/B_0$ , $a_n = A_n/B_0$        |           |          | B <sub>0</sub> from main dipole |                         |     |
| SYSTEMATIC TOLERANCES                    |           |          |                                 |                         |     |
|  | SPECIFIED | MEASURED |                                 | UNITS                   | REF |
|  |           | $b_n$    | $a_n$                           |                         |     |
| n = 2                                    | 3         | --       | - 0.83                          | $m^{-2}$                | d,e |
| n = 3                                    | 200       | 0.32     | 0.022                           | $m^{-3}$                | d,e |
| n = 4                                    | 300       | - 28     | 31                              | $m^{-4}$                | d,e |
| n = 5                                    | 4.0 E+06  | 540      | -330                            | $m^{-5}$                | d,e |
| n = 6                                    | 3.0 E+04  | NA       | NA                              | $m^{-6}$                | d   |
| RANDOM TOLERANCES                        |           |          |                                 |                         |     |
|  |           | $b_n$    | $a_n$                           |                         |     |
| n = 0                                    | 9.0 E-4   | --       | --                              |                         | d   |
| n = 1                                    | 1.0 E-02  | 7.5E-03  | 9.4 E-03                        | $m^{-1}$                | d,e |
| n = 2                                    | 0.3       | 0.11     | 0.058                           | $m^{-2}$                | d,e |
| n = 3                                    | 100       | 0.59     | 0.79                            | $m^{-3}$                | d,e |
| n = 4                                    | 600       | 0.24     | 0.28                            | $m^{-4}$                | d,e |
| n = 5                                    | 1.0 E+04  | 7.3E+02  | 6.0 E+02                        | $m^{-5}$                | d,e |
| n = 6                                    | 3.0 E+05  | NA       | NA                              | $m^{-6}$                | d   |
| EXCITATION FUNCTION                      |           |          |                                 |                         |     |
| TYPICAL DC MEASUREMENTS                  |           |          | MEASURED                        | UNITS                   | REF |
| B <sub>2</sub> *L <sub>eff</sub> @ I = 0 |           |          | 6.4E-03                         | (T/m <sup>2</sup> )*m   | e   |
| B <sub>2</sub> *L <sub>eff</sub> /I      |           |          |                                 |                         |     |
| @ 100 AMPS                               |           |          | 6.572E-03                       | (T/m <sup>2</sup> )*m/A | e   |
| @ 200 AMPS                               |           |          | 6.566E-03                       | (T/m <sup>2</sup> )*m/A | e   |
| @ 600 AMPS                               |           |          | 6.561E-03                       | (T/m <sup>2</sup> )*m/A | e   |
| @ 800 AMPS                               |           |          | 6.511E-03                       | (T/m <sup>2</sup> )*m/A | e   |
| Saturation Effect                        |           |          |                                 |                         |     |
| 800/400                                  |           |          | 0.76%                           |                         |     |

| CALCULATIONS   |  | CALCULATED | UNITS                   | REF |
|--|--|------------|-------------------------|-----|
| B2/I   |  | 0.10722    | (T/m <sup>2</sup> )*m   | e   |
| <b>Leff</b>  |  |            |                         |     |
| @ 100 AMPS   |  | .0613      | (T/m <sup>2</sup> )*m/A | e   |
| @ 200 AMPS   |  | .0612      | (T/m <sup>2</sup> )*m/A | e   |
| @ 400 AMPS   |  | .0612      | (T/m <sup>2</sup> )*m/A | e   |
| @ 800 AMPS   |  | .0607      | (T/m <sup>2</sup> )*m/A | e   |
| <b>Pole Tip Field</b>                                |  |            |                         |     |
| @ 100 AMPS   |  | 0.0731     | Tesla                   |     |
| @ 200 AMPS   |  | 0.1461     | Tesla                   |     |
| @ 400 AMPS   |  | 0.2923     | Tesla                   |     |
| @ 800 AMPS   |  | 0.5845     | Tesla                   |     |
| <b>MAGNETIC PROPERTIES OF THE ONE TURN TRIM COIL</b> |  |            |                         |     |
| Typical DC Measurements                              |  |            |                         |     |
| B2*Leff/I  |  | 8.22 E-04  | (T/m <sup>2</sup> )*m/A |     |
| Calculations   |  |            |                         |     |
| B2/I   |  | 1.34 E-02  | (T/m <sup>2</sup> )/A   |     |
| <b>MAGNETIC PROPERTIES OF THE TWO TURN TRIM COIL</b> |  |            |                         |     |
| Typical DC Measurements                              |  |            |                         |     |
| B2 Leff/I  |  | 1.64 E-03  | (T/m <sup>2</sup> )*m/A |     |
| Calculations   |  |            |                         |     |
| B2/I   |  | 2.68 E-02  | (T/m <sup>2</sup> )/A   |     |

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- a. J. Koehler, Private Communication
- b. H. C. Hseuh, Private Communication
- c. A. Soukas, Private Communication
- d. A. Ruggiero, Memo to W. Weng, 1/23/90
- e. E. Bleser