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Field Measurements on a Booster Synchrotron F-Magnet

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Measurements of the dc relative gradient have been completed on a booster synchrotron F-magnet (F-47). These measurements include data at seven equally spaced intervals covering approximately $\frac{1}{2}$ of the 10 foot magnet length at currents of 37 A (injection), 75 A, 300 A, and 500 A (extraction).[1] These data are used to determine the internal relative gradient, and the integrated relative gradient which includes the end effects. The data were taken using the standard search coil integrator technique. A special fixture was constructed to position the 10 inch long coil used for the measurements at various radial positions on the horizontal midplane of the magnet. The effect of finite coil size and magnet curvature on the field gradient measurements is discussed.

The coils used to measure the field gradient are 10 in. long with a .244 x .244 square cross-section. They are wound with a single layer of .004 in. diameter wire containing 60 turns.[2] Two such coils are mounted side by side with a space of .3125 in. between centers. The coils are electrically connected so that they measure the field difference at a point. A second stationary pair of bucked coils were placed in the opposite end of the magnet to buck out the signal from the measuring coils. This technique is used to essentially eliminate errors due to power supply drift. The magnet was powered with a Transrex power supply. The current levels were determined with a shunt whose accuracy is ±0.25%. A small Hewlett Packard power supply was used for the measurements at injection (I = 37 A). The points at which the horizontal gradient was measured are shown in Figure 1.

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1 These data which amount to several thousand points were taken by J. Pachnik with assistance from A. Tanner.

2 The construction and winding of these coils were completed by R. Remsbottom at the U. of Wisconsin Engineering Science Facility.

The coils described above were mounted in a positioning fixture which is shown schematically in Figure 2. This fixture consists of a fixed platform which indexes off the pole tip and a moving platform on which the coil is mounted. With this arrangement the measurements are always made along a radius regardless of the z position. The fixed platform is held in place by air pressure[3] applied to rubber diaphrams which expand against the upper pole tips. The total travel allowed by the movable slide of 4.157 in. allows measurements on the midplane from x = -2.044 in. to x = +2.113 in. The negative direction is toward the center of the radius of curvature (the low field side of the F magnet). The x coordinate was determined relative to the magnet centerline with an accuracy of ±0.03 in., but was reproducible for successive runs at a given z position to ±0.01 in. A linear potentiometer connected by means of a string and pulley system to the moving platform provided a voltage proportional to the x coordinate of the coils. Of course the fixture could not be used to measure the fringe field, so for z = -6, and +4 in. the coils were mounted on a lathe, which was positioned so that it moved the coils perpendicular to the tangent of the bending arc at z = 0 (z = 0 marks the end of the magnet steel). This tangent makes an angle of 2.02 degrees with the normal to the end plate of the magnet. Using the lathe to do the fringe field allowed accurate positioning in the z direction so that one 10 in. measuring interval began precisely where the other one left off. However, the absolute error in locating the coil center with respect to the end of the magnet steel at z = 0 is estimated to be ±0.1 in. Accurate positioning in z for measurements inside the magnet is not required. The z = +4 position was measured using both the fixture and the lathe. In so doing a 0.3 in. shift was discovered between the x = 0 positions of the lathe and fixture. This was taken into account, of course, in the analysis of the data. The remaining uncertainty between the x = 0 positions of these two positioning devices is approximately ±0.05 in.

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3 This technique was suggested by J. Michelassi.

The average internal gradient is given in Figure 3 at the various currents. The quantity plotted is $[B'(x) - B'(0)]/B'(0)$ in percent. The data at z = 14, 24, 34, 44, and 54 in. were averaged to give the curves shown in Figure 3. The average deviations in these data are ±0.15 at I = 300 A and 500 A, ±0.25 at I = 75 A, and ±0.3 at I = 37 A. One can ask what effect the finite coil size has on the data. There is also the fact that the coils are straight while the magnet is curved to be considered. Figure 4 shows the relative gradient calculated from a measured lamination profile. The solid curve is the calculated result.[4] Using these calculated results a correction for finite coil size and magnet curvature was applied. The results of this correction are shown in the dashed curve. The difference between these curves is mostly due to finite coil size. If the coils are not well matched, additional errors can result, the nature of which in this case would be to further reduce the peaks in the gradient. In comparing Figures 3 and 4, one notes that the slope in the measured gradient is already steeper than what is calculated from the measured profile.

Figure 5 shows the integrated relative gradient which is the quantity $[\int B'(x)dz - \int B'(0)dz]/\int B'(0)dz$ in percent. The data at I = 37 A are determined from fringe field measurements at z = 0, and +10 inches instead of z = -6 and +4 inches. This was done because the signal at z = -6 inches at this low current was so small as to be essentially lost in the drift of the integrator. The average deviations in these data are essentially the same as those for the internal gradient data (figure 3).

The magnet (F-47) used for these measurements is one which was taken from the spare magnet supply for the booster synchrotron. It had never been operated in the booster ring nor pulsed at the booster operating frequency of 15 Hz. The high current measurements were completed first thereby establishing the remnant field. In fact a measurement was done at 1000 A (equivalent to 2000 A in booster ring) prior to the injection field

4 The field calculations used here were supplied by S. Snowden. The measured profile of booster F magnet lamination # 706 is the contour used in making these calculations.

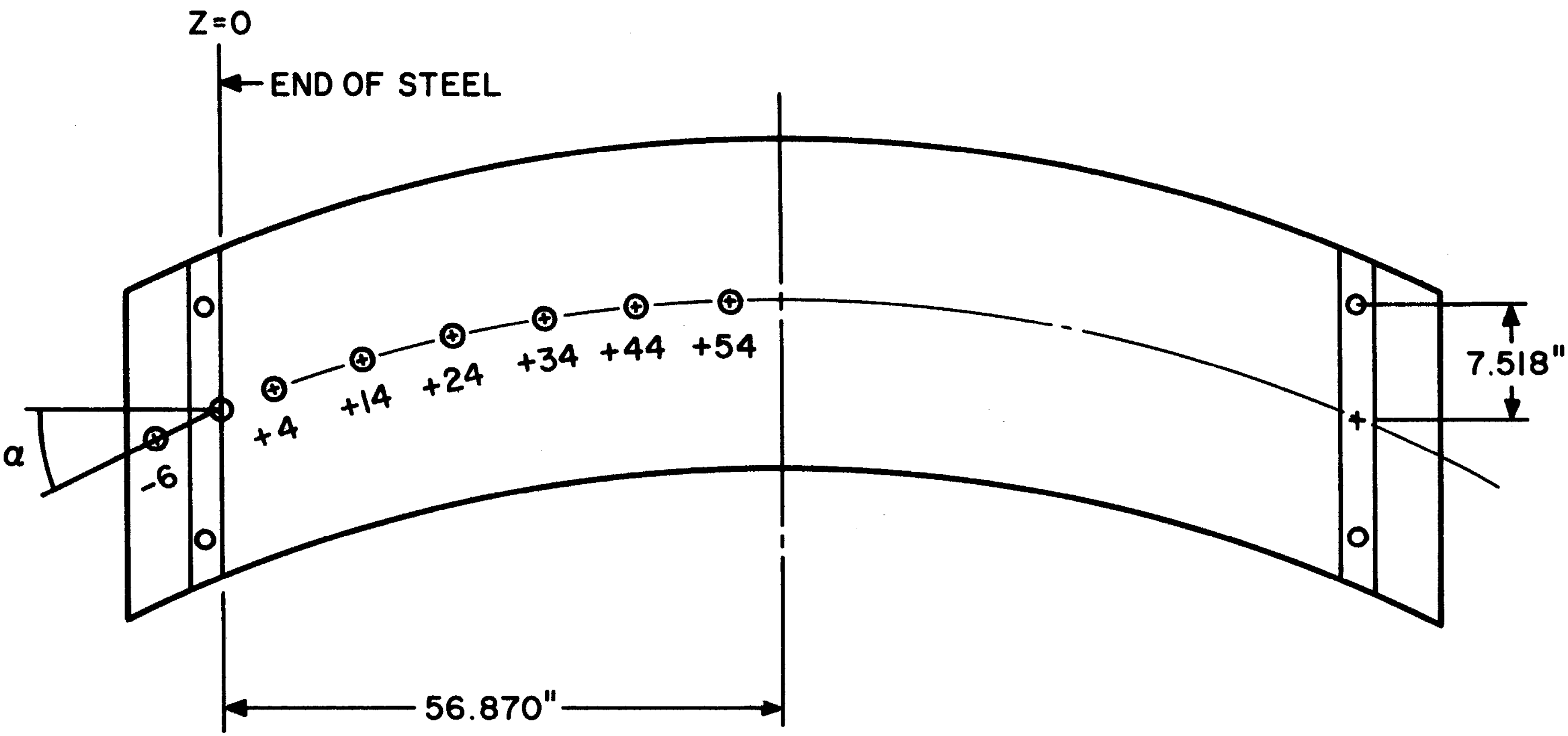
measurements. The remanent field in this magnet is approximately 7.5 gauss near x = 0. This would mean that the remanent field should comprise ~ 1.4% of the gradient at injection (central injection field being ~ 526 gauss).

Since two different power supplies were used for the measurements, one for injection field and one for the higher field measurements, one questions whether the polarity might not have been reversed during the change from one supply to the other. To guard against this, the cables were verified as being + or - and marked accordingly along with the mating plates (which remained fixed to the magnet) before their removal. Then the small supply power cables were connected and checked for polarity. Finally, it is noted that data for all runs were taken using the same coils, integrator, and integrator settings. Two different techniques were used to produce a flux change in the measuring coils. In one case the coils were moved across the gap while holding the current constant and in the other the coils were held stationary while the magnet was pulsed from I = 0 to a particular level. These results agree within measuring error.

Another effect of the finite width of the measuring coils can be seen from Figure 4. The good field width appears narrower for the corrected data than for the calculated data without correction. In particular, a decrease in good field width of approximately 0.2 in. is evident, so that the quantity $\Delta G/G$ peaks at x = ±1.8 in. This is in agreement with the measured results as can be seen in Figure 3. Finally, the gradient lengths $L_G(x) = \int B'(x)dz / B'(0)$ have been calculated and are given here at x = 0 as follows:

I (A)	$L_G(0)$ (in.)
37	114.8
75	114.5
300	113.7
500	113.7

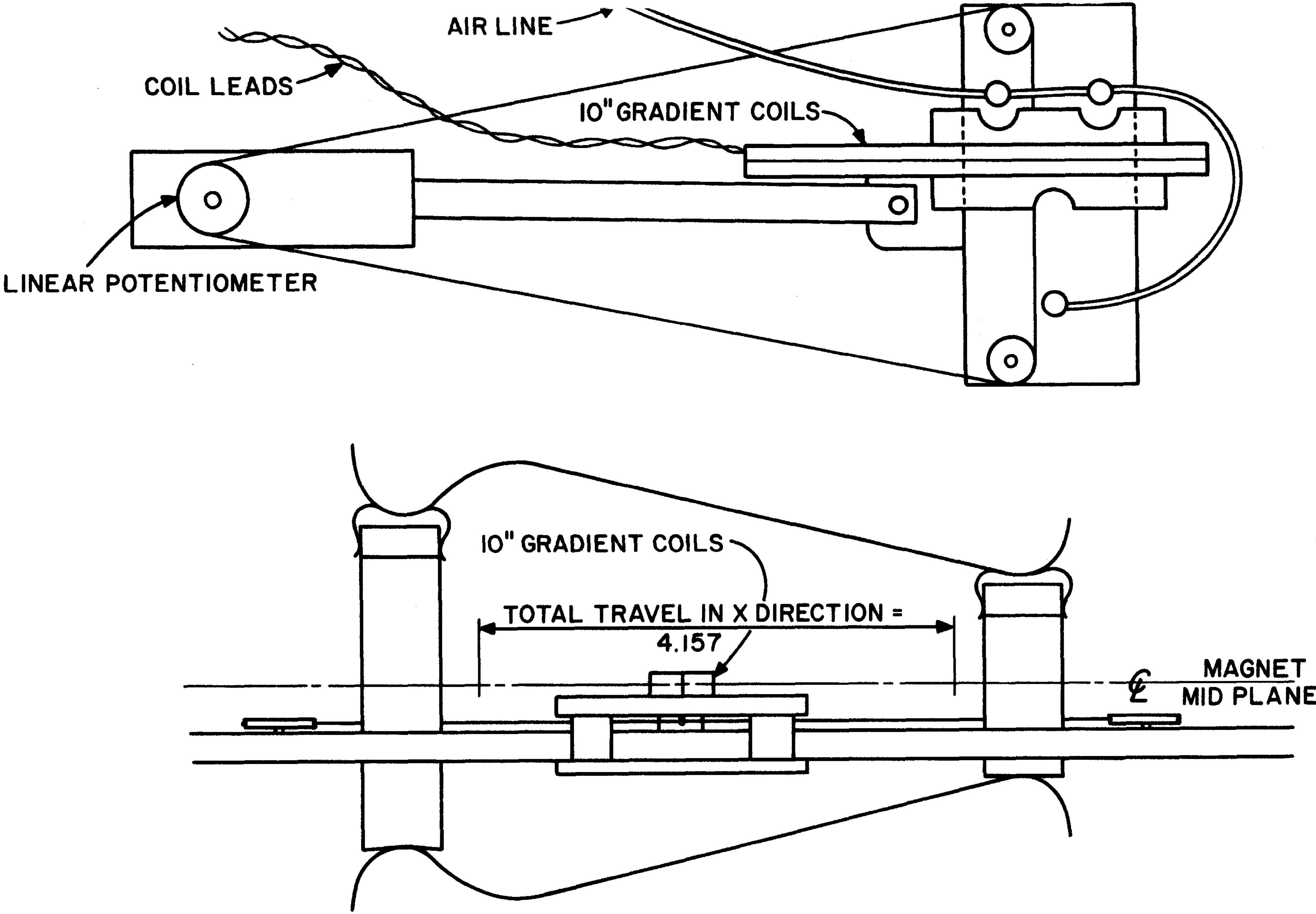
The error in $L_G(0)$ is estimated to be ±0.25 in.



RADIUS OF CURVATURE = 1608.15"
ANGLE α = 2.02°

PLAN VIEW OF BOOSTER "F" MAGNET SHOWING THE Z POSITION OF THE FIELD MEASUREMENTS

FIG. 1



SCHEMATIC DIAGRAMS OF COIL POSITIONING FIXTURE
FIG. 2

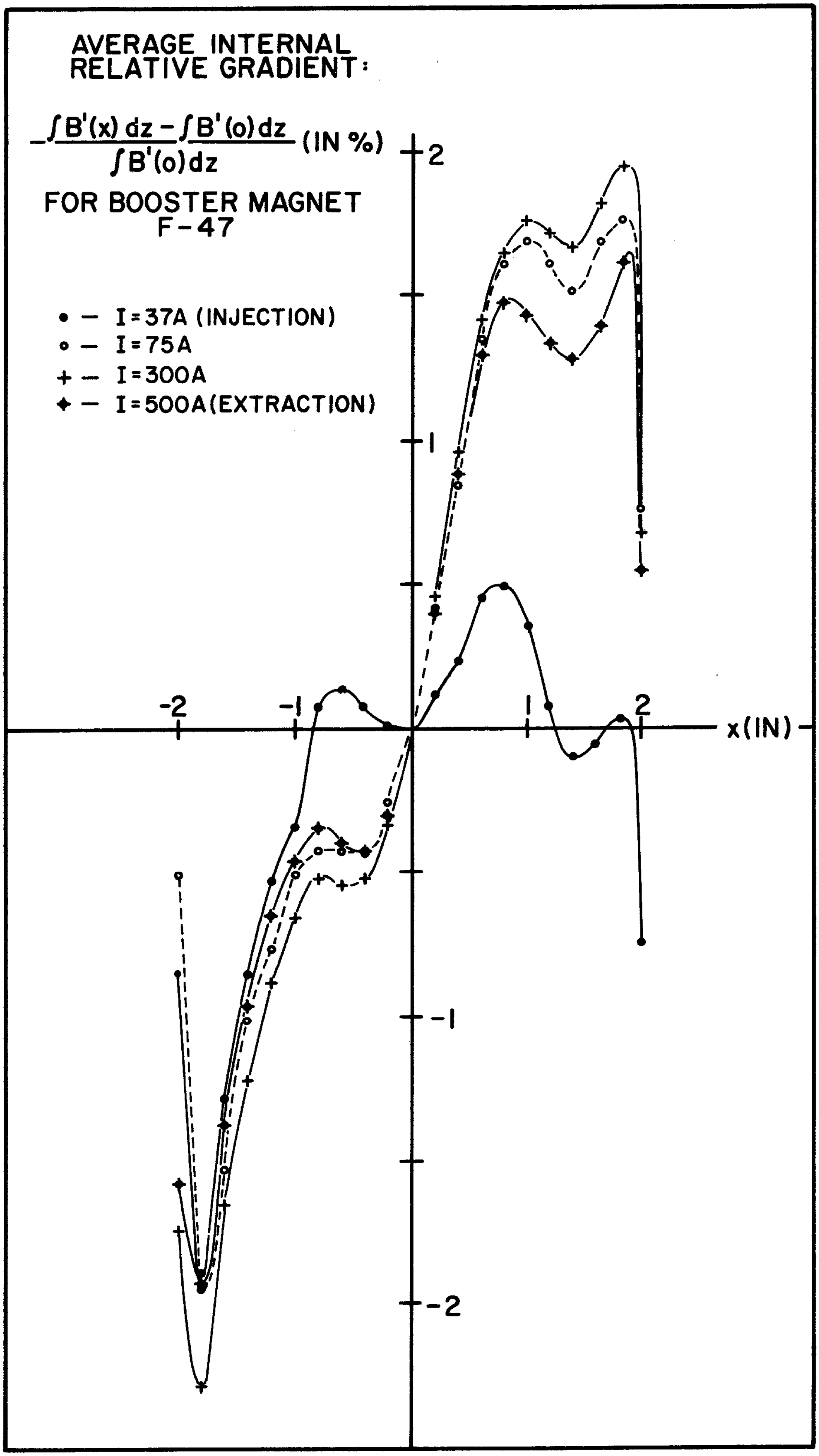

AVERAGE INTERNAL RELATIVE GRADIENT:
$-\frac{\int B'(x)\,dz - \int B'(o)\,dz}{\int B'(o)\,dz}$ (IN %)
FOR BOOSTER MAGNET F-47
• — I=37A (INJECTION)
○ — I=75A
+ — I=300A
✦ — I=500A(EXTRACTION)
2
1
-1
-2
-2
-1
1
2
x(IN)

FIG.3

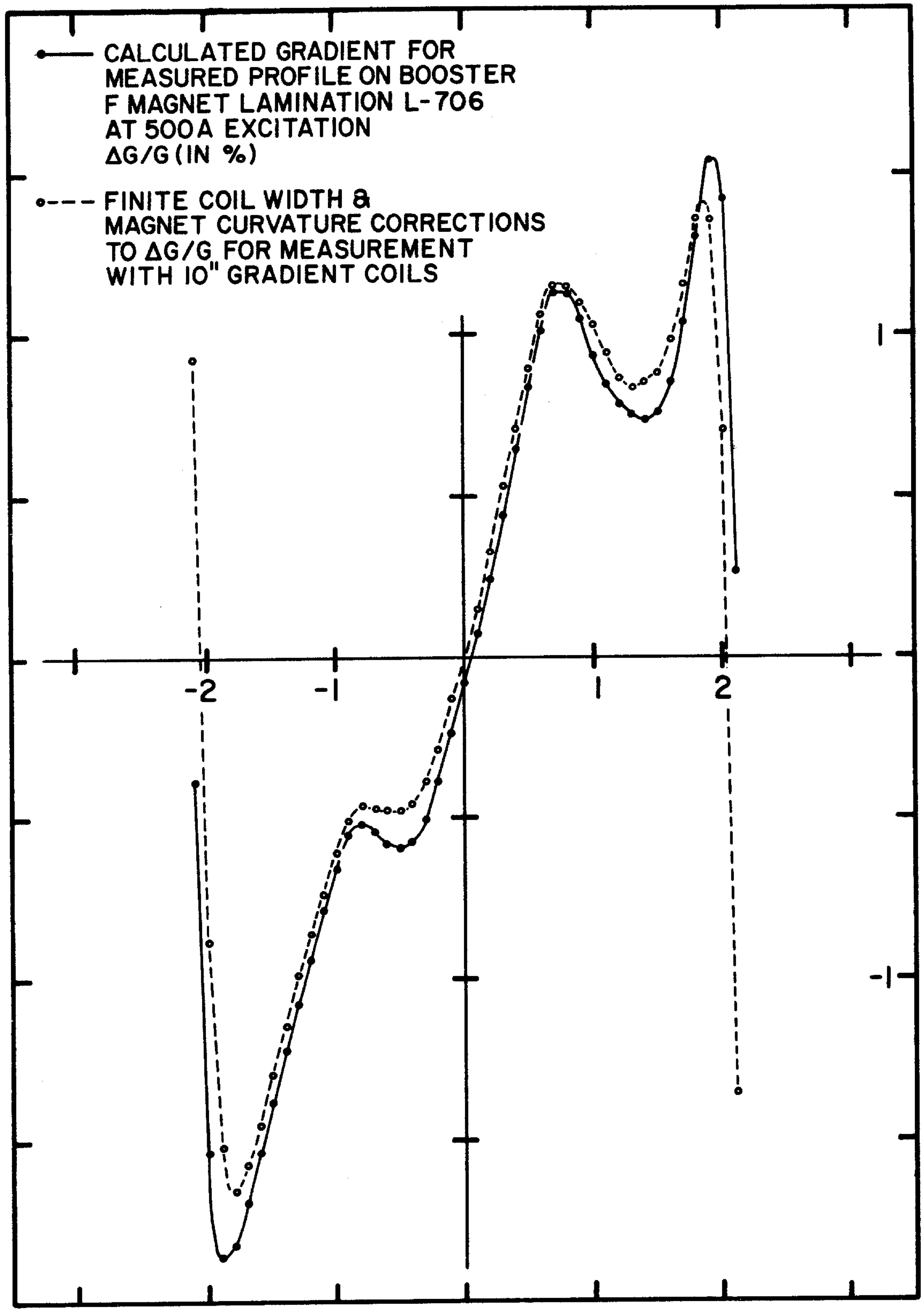

CALCULATED GRADIENT FOR
MEASURED PROFILE ON BOOSTER
F MAGNET LAMINATION L-706
AT 500A EXCITATION
ΔG/G (IN %)
FINITE COIL WIDTH &
MAGNET CURVATURE CORRECTIONS
TO ΔG/G FOR MEASUREMENT
WITH 10" GRADIENT COILS
-2
-1
1
2
1
-1

FIG.4

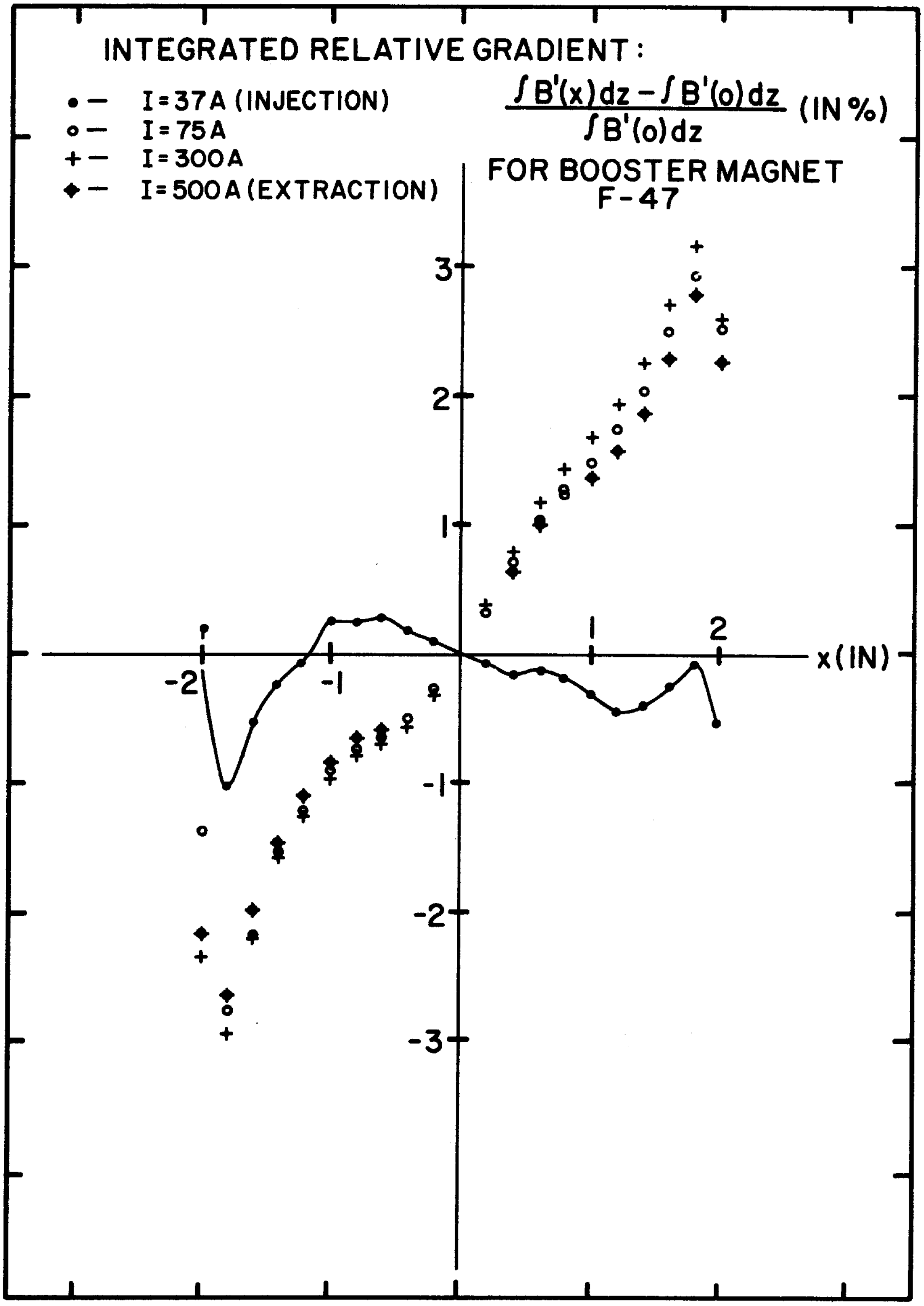

INTEGRATED RELATIVE GRADIENT:
$\frac{\int B'(x)dz - \int B'(o)dz}{\int B'(o)dz}$ (IN %)
FOR BOOSTER MAGNET
F-47
• — I=37A (INJECTION)
o — I=75A
+ — I=300A
◆ — I=500A (EXTRACTION)
3
2
1
-1
-2
-3
-2
-1
1
2
x(IN)

FIG. 5