TM-695
0321.000

BOOSTER MAGNET D-48 FIELD MEASUREMENT

E. Gray

October, 1976

The only ac measurements that were made on booster ring magnets consisted of accurately placing a turn of wire in each magnet and pulsing a standard current through the magnet coils.[1] The voltage produced on the inserted wire showed a very high degree of consistancy between magnets. Other measurements made on F47 and D51 were all made under dc conditions.[2,3] They included (among others) central body gradient, magnetic length, and gradient length in the central plane as functions of horizontal position. It was decided to repeat some of the measurements on a spare magnet connected into the booster ring and thus operating in the standard ac cycle.

This paper is a report of the ac measurements made on booster magnet D-48. The ac and dc measurements are in basic agreement.

Technique of Measurement

Magnet D-48 was placed on a stand in the West Gallery and connected to the magnet circuit of the Booster.

Mechanical fixtures were made that centered a transit between the two magnet alignment pins at one end of the magnet. At the other end (the electrical connection end) of the magnet a sighting point fixture allowed the transit to be placed on a line of sight between

*Operated by Universities Research Association Inc. Under Contract with the Energy Research and Development Administration

the centers of both ends of the magnet. A motorized lathe bed was then placed at the end of the magnet such that the line of travel of the coil mount was at the half angle of the magnet bend from the perpendicular line of the magnet alignment pins.

Two sets of matched coils were on hand (3/8x1/2x2 inches and 1/2x5/8x24 inches). The longer one was used for effective length measurements and the shorter one for the body gradient data.

The coil signals are added (or subtracted), integrated, put in a sample and hold, and then finally read on a triggered digital voltmeter. Because the fields are a biased sinusoid one is also measuring a dc component. The result is that one must zero the integrator with the coil outside the field and integrate into the field. Thus the body gradient data was taken by zeroing the integrator with the coil outside, moving the coil into the field, and reading the voltage. Then to get a variation with horizontal position, the voltage is read, the probe quickly stepped in the horizontal direction, and a new reading is taken. The differences are used to minimize the effect of integrator drift.

Effective length data was taken by zeroing the integrator with the coil probe outside the fields, moving the probe into the fields, and reading the voltage and lathe position. A new voltage reading is taken just before stepping the probe farther into the magnet and again reading the voltage and position. After retracting the coils a final voltage reading is taken. The difference in the initial and and final voltage reading gives the total integrator drift over the measurement made at each horizontal position. Integrator drift was the single most important limitation on the reproducibility of the effective length measurement. Only after a modification was made to the original integrator circuit was I able to get some measure of consistancy on good days with constant attention to the voltage adjustment. This modification was suggested by Ed Higgins and gave roughly a factor of three decrease in drift.

Body Gradient Measurements

Figure 1 shows the result of recording the integrator voltage as a function of longitudinal position for the short coil. This information is used to establish how far into the magnet one must go to get away from end effects. The shape of these curves is as expected.[4]

Figures 2, 3 and 4 show the present measurements of body gradient plotted on copies of similar measurements taken dc by R. Yamada.[3] The large points are the present measurements. The curves of the earlier measurements are marked by a dc current value corresponsing to running all the magnet coils in series. One must double these to get the corresponding current in normal booster operating mode. These currents span the range from injection to 8 GeV. Figures 2 and 3 show the data at four different times in the booster cycle going from injection to 8 GeV. The new data show less scatter on the plus coordinate side than R. Yamada's original data. In particular the injection level values stayed down with the other later time data.

Two sets of data were taken with the booster magnets running dc, the magnets were cycled to ac and then back to dc, and then three sets of body gradient data were taken. Figure 4 shows these data.

There seems to be increased scatter in the points and somewhat lower values on the negative axis side. With the spread in values as well as an estimate of overall error of the order of a few tenths of percent the data are seen to be in basic agreement with the earlier dc measurement.

Effective Length Measurements

The effective length edge position at one end of the magnet (either magnetic or gradient) can be written:

$$L = \frac{(V_1 - V_{01}\ (Z_2 - Z_p) - (V_2 - V_{02})\ (Z_1 - Z_p)}{(V_2 - V_1')}$$

where subscript 1 and 2 correspond to the first and second position of the probe. Z_p is the calibration of the lathe bed scale with reference to the coil position relative to the end of the magnet. V_{01} and V_{02} are the integrator drift values needed at the time of reading the corresponding voltage to get the correct integrated value. Since one can not measure these they must be estimated from the before and after measurement readings of the voltage with the coils outside the magnet. The term $(V_2 - V_1')$ is the difference in voltage in stepping from position one to two. These voltages are read as close together as possible to minimize the integrator drift.

Of several ways of estimating V_{01} and V_{02} (the drifted zero values), the one used consisted of using V_1 and V_1' difference as the difference between V_{01} and V_{02} and centering these values between the initial and final zero readings.

As an estimate of error limit the square root of the sum of the squares of the errors in length were calculated for each point assuming:

$$\Delta Z_1 = \Delta Z_2 \approx .02''$$

$$\Delta Z_p \approx .01''$$

$$\Delta (V_2 - V_1{}^1) \approx 1\text{mv}$$

$$\Delta V_1 = \Delta V_2 \approx \text{half of zero drift}$$

The error due to the zero integrator reading drift dominates such that for injection gradient length with

$$V_1 \approx 28\text{mv}$$

$$V_2 \approx 38\text{mv}$$

a few millivolts of drift gives an error of the order of 1 to 2 tenths of an inch. Drifts of up to 20 millivolts give a limit of almost an inch. Half of the drift value should be an over estimate of error.

Figure 5 shows a comparison of R. Yamada's magnetic and gradient length with the present measurements. Those labeled "Grad Lengths" were taken in the same way for three conditions: dc injection, ac injection, and 10 msec level. The consistancy of these data seem to indicate no significant variation within the measurement accuracy for the different conditions. In trying to explain the shifts between the curves of the present and past measurements, length data was taken at the center position with the coil turned over. No effect was noticed in the magnetic length but the gradient length shifted by 0.9 in. The two matched coils in the probe do not seem to be matched well enough. By shifting one coil first 1/16 and then

1/8 in. and measuring the gradient lengths for both probe orientations, an estimate of such an offset required to give 0.9 in. difference in the gradient measurement turns out to be of the order of .02 in. To eliminate this effect each X position is measured twice at each coil orientation and an average taken. The result is the curved marked Av. Grad in Fig. 5. Now notice that the shift between this curve and R. Yamada's gradient length is approximately the same as the difference in the magnetic length curves. This difference is either a probe zero position error in one of the measurement sets or a true difference in the two magnets D-51 and D-48. I suspect it is an error in one of the measurements.

Conclusion

In general the body gradients seem to be that of the earlier measurement with little variation ac to dc. Likewise the effective length data appear similar enough to the previous measurements that no significance can be attributed to the variation. The question remains do these fields explain the Booster aperture limitation?

Acknowledgments

Many people helped in this effort. The magnet measuring group under R. Yamada provided the integrator circuit and coils with special thanks to assistance from Ed Schmidt. John Dinkel provided the sample and hold circuit and the connections to the triggered DVM. Dave Cosgrove provided mechanical assistance including alignment fixtures and coil probe mounts. Jim Garvey and the Booster group installed the magnet in the electrical and water circuits. Harland Gerzevske assisted with the survey alignment. Lee Teng provided some useful discussion about the meaning of the data. To these and others who helped I wish to express my thanks.

References

1. Private Communication R. Peters
2. R. Juhala, TM-471 (1974) FNAL Internal Report
3. R. Yamada, J. Pachnik, and P. Price, "Magnetic Field Measurements on Booster Synchrotron Magnets", April 5, 1974 unpublished.
4. Private Communication S. Snowdon

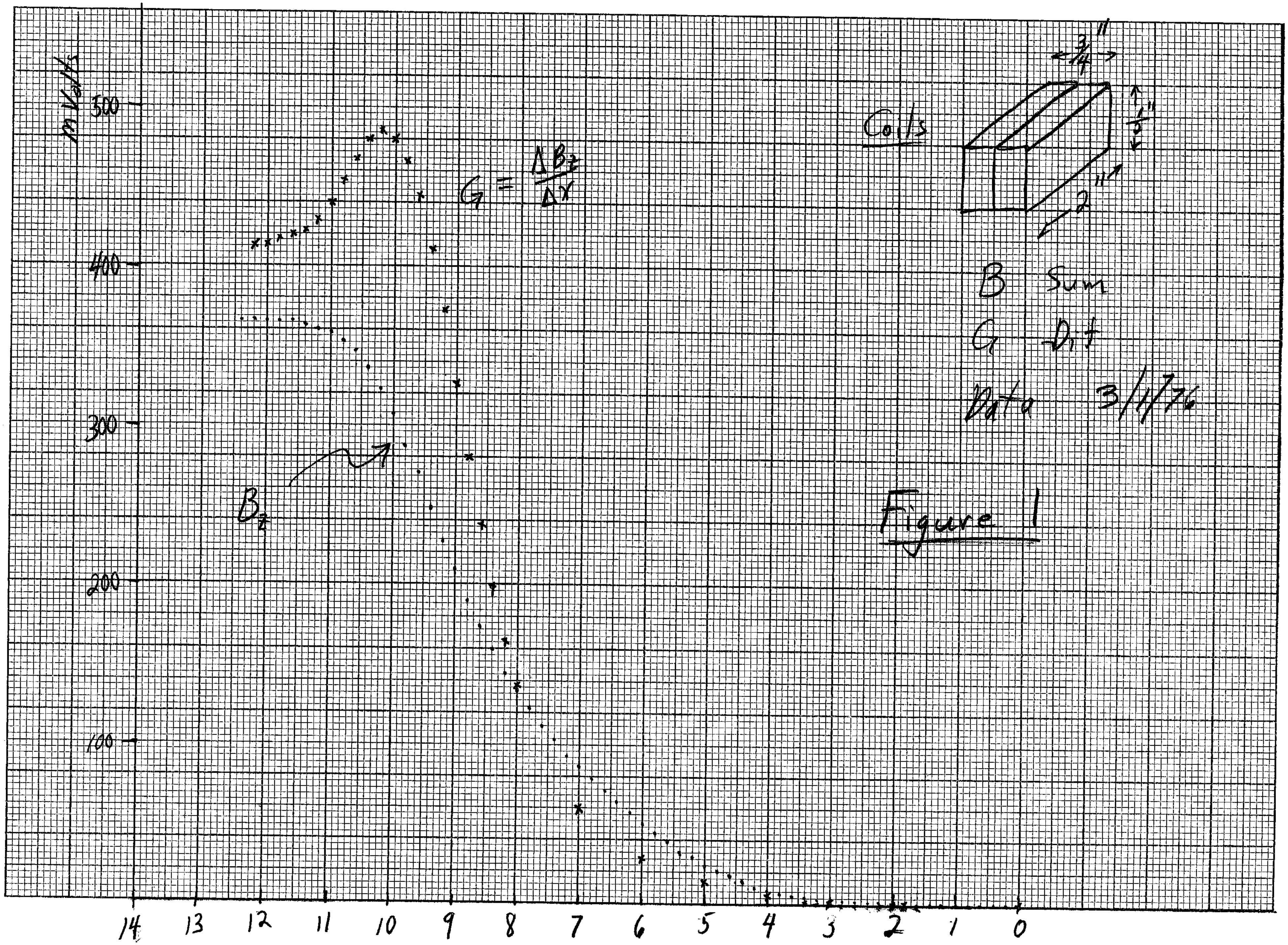

mVolts
500
400
300
200
100
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
$G = \frac{\Delta B_z}{\Delta x}$
B_z
Coils
3/4"
1/2"
2"
B Sum
G Dif
Data 3/1/76

Figure 1

Fig 6

Booster Magnet D51 Gradient Distribution z = 14 in

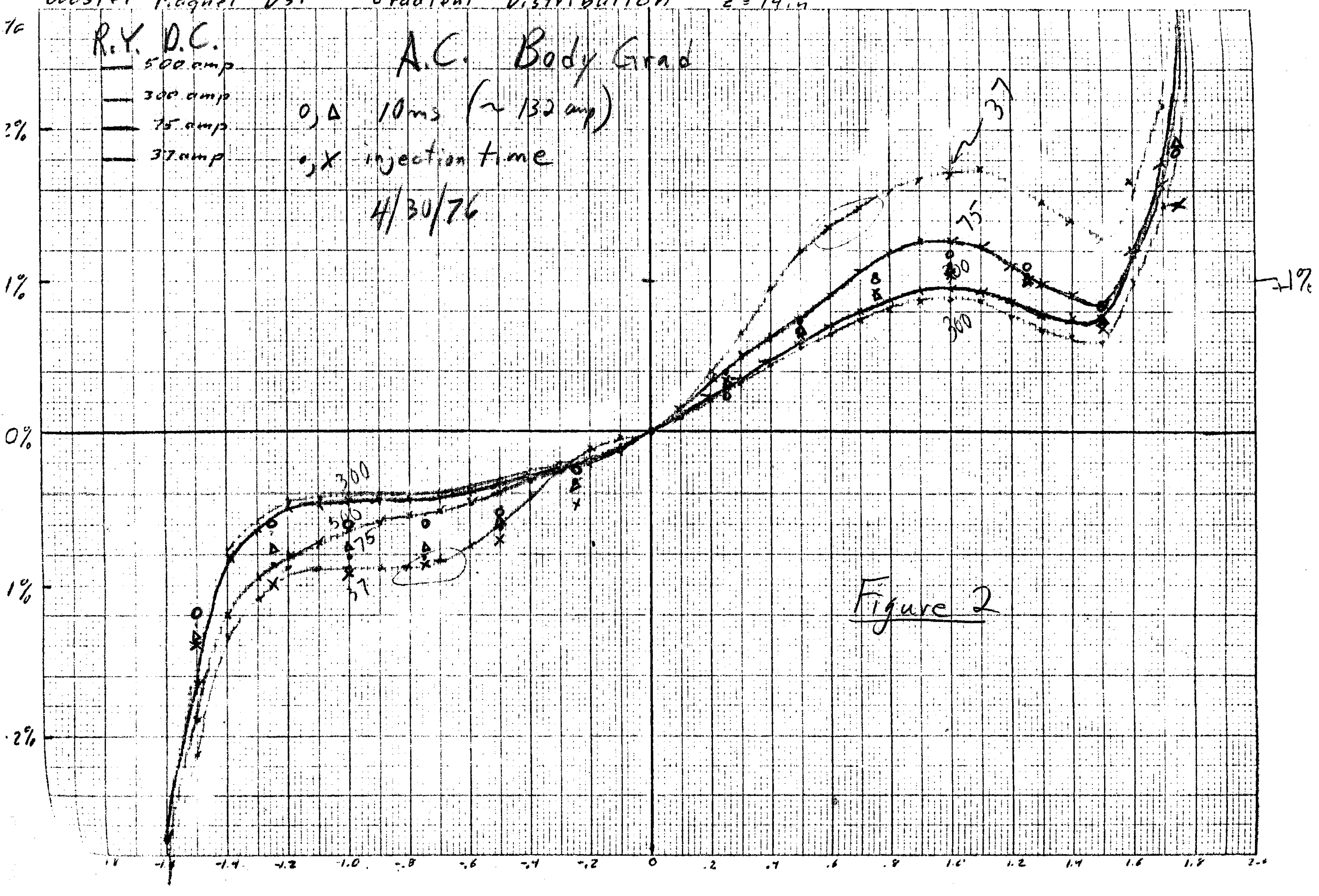


Figure 2

Fig 6

Booster Magnet D51 Gradient Distribution z = 14 in

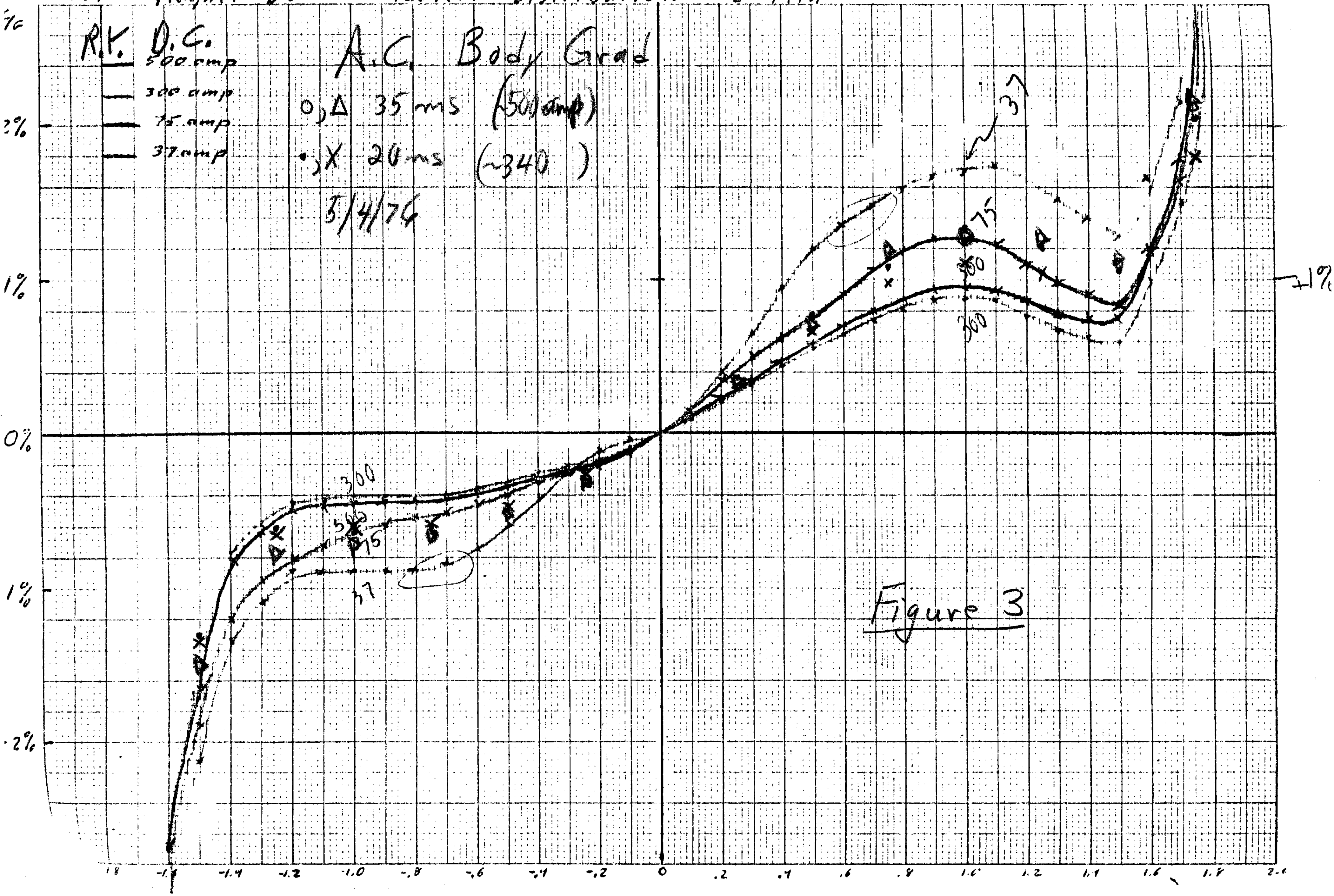
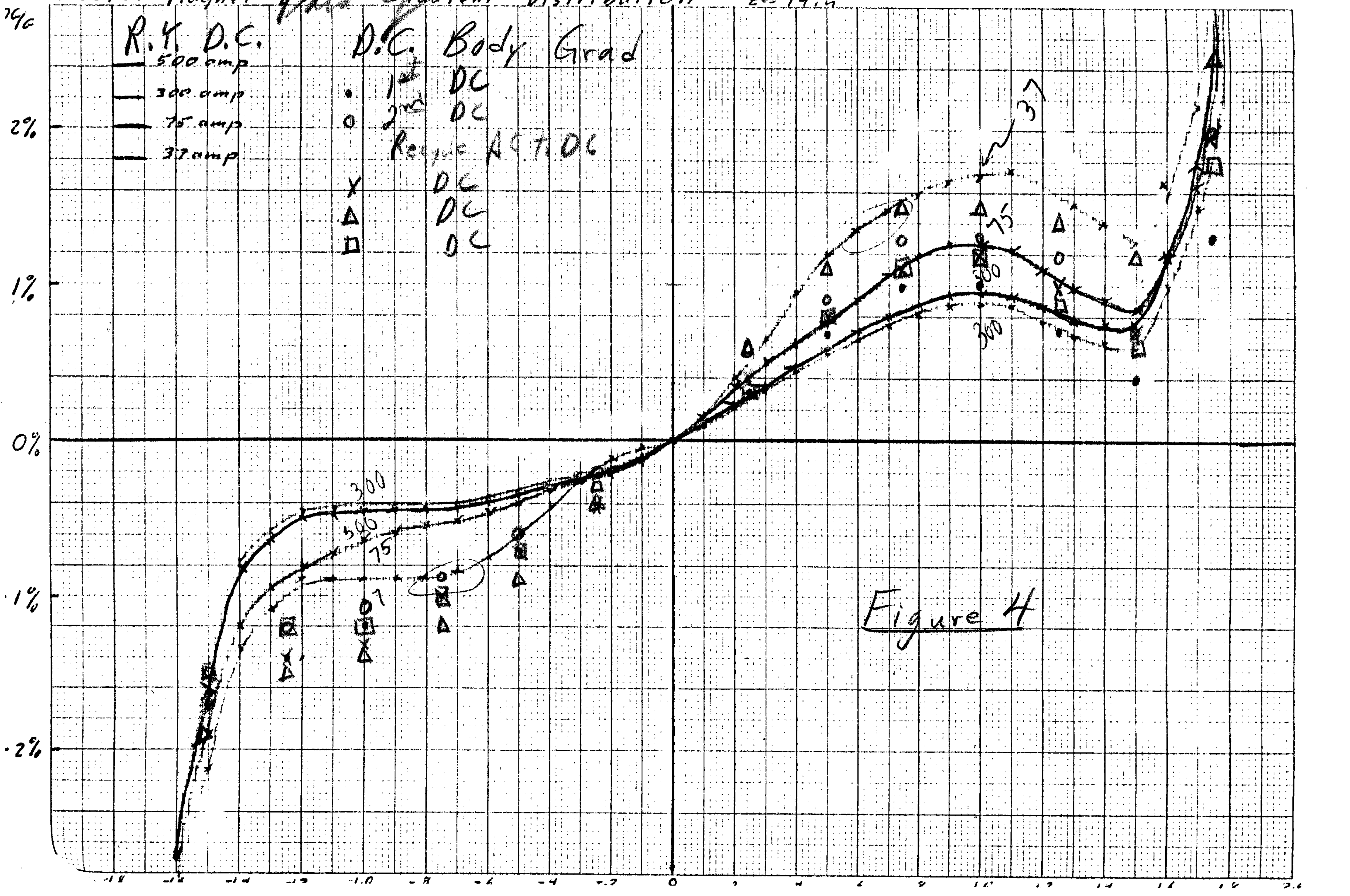
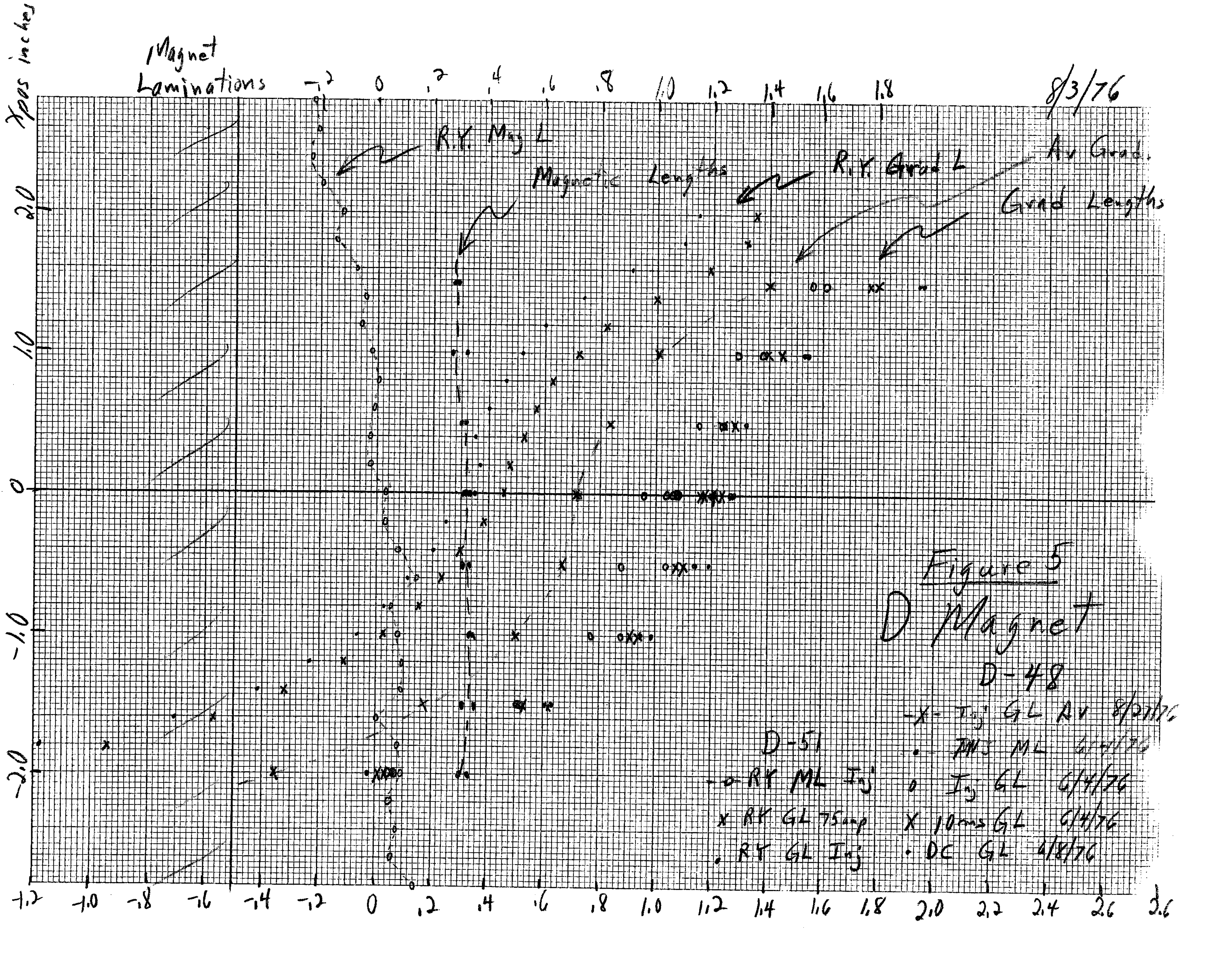


Figure 3

Fig 6

Booster Magnet Delta of Gradient Distribution z=14in 6/8/76 DC Mag




8/3/76
Magnet Laminations
Xpos inches
R.Y. Mag L
Magnetic Lengths
R.Y. Grad L
Av Grad.
Grad Lengths
Figure 5
D Magnet
D-48
D-51
-x- Inj GL Av
• ML
o Inj GL 6/4/76
X 10ms GL 6/4/76
• DC GL 4/8/76
-o- RY ML Inj
x RY GL 75amp
• RY GL Inj

Fermilab

BOOSTER MAGNET D-48 FIELD MEASUREMENT-ADDENDUM

E.R. Gray

November 18, 1976

It was suggested by S. Ohnuma that the measurement data of the original report be plotted as a normalized gradient compared to Figure 9-5 of the accelerator design report. Since Figure 5 of the original report reproduced so poorly an improved version is included here.

Figure 6 shows the injection body gradient data of R. Yamada for the F and D magnet and the present data for the D magnet. Figure 7 shows the same data taken later in the cycle. These data are plotted on a copy of Figure 9-5 of the accelerator design report. However since the original design did not have special "end packs" on the magnets the same data is replotted in Figures 8 and 9 as a normalized body gradient-gradient length product. Also plotted in Figure 9 is a horizontal scale with numbers 10 to 90. This scale is found by taking a momentum spread of ±.1% that is doubled by RF capture (i.e. ±.2%) with the largest beta and X_p for each magnet from a SYNCH run for the Booster and calculating the extremum of the position for each emittance 10π mm mr to 90π mm mr:

$$X = (\beta\varepsilon)^{\frac{1}{2}} + X_p \frac{\Delta p}{p} .$$

From this viewpoint an AC measurement of an F magnet would have been more interesting than that of a D magnet since the F seems to be more restricted. If the parallel lines do indeed have some relation to a useable aperture, an observed aperture less than 90π seems very reasonable.

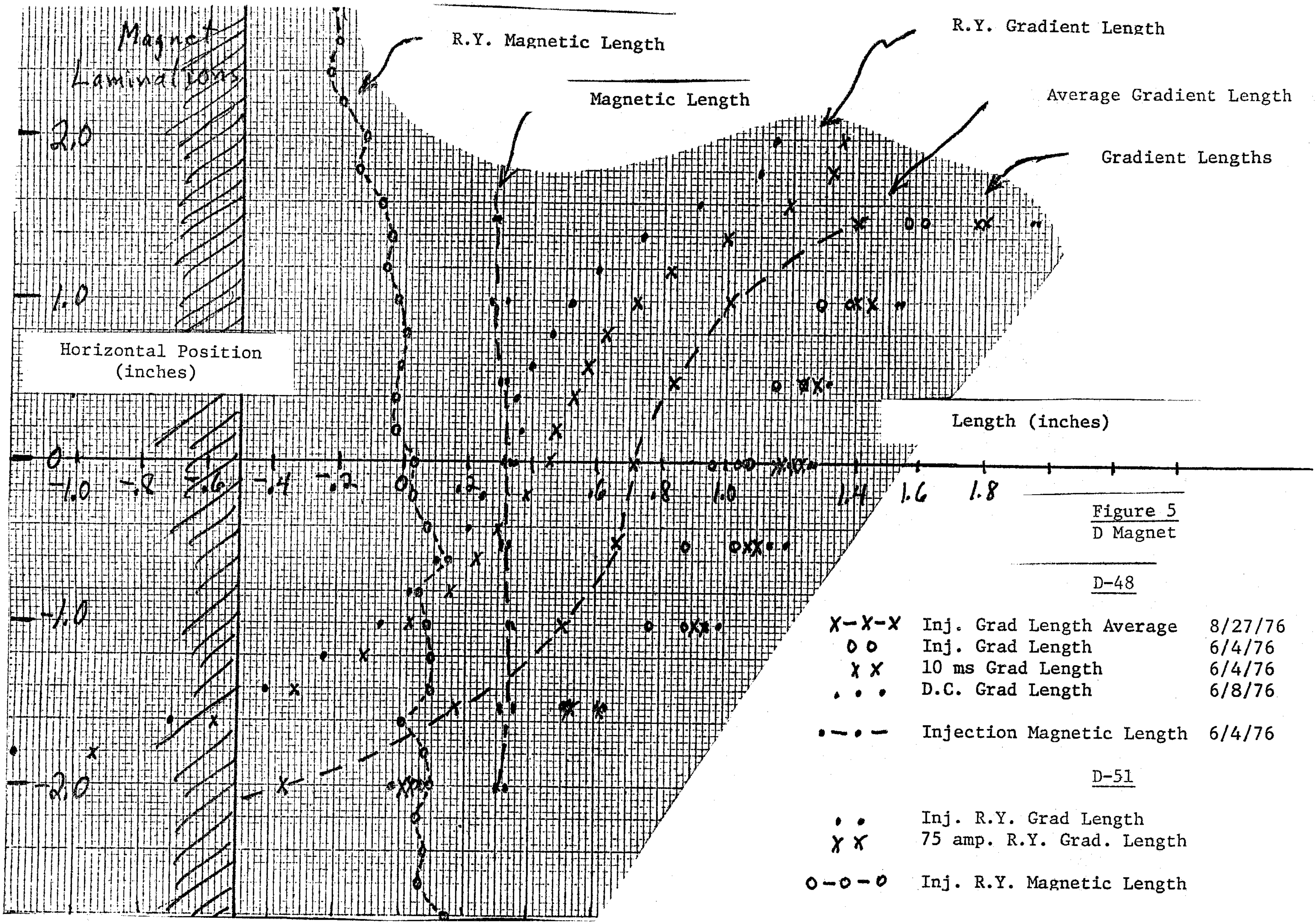


Figure 5
D Magnet

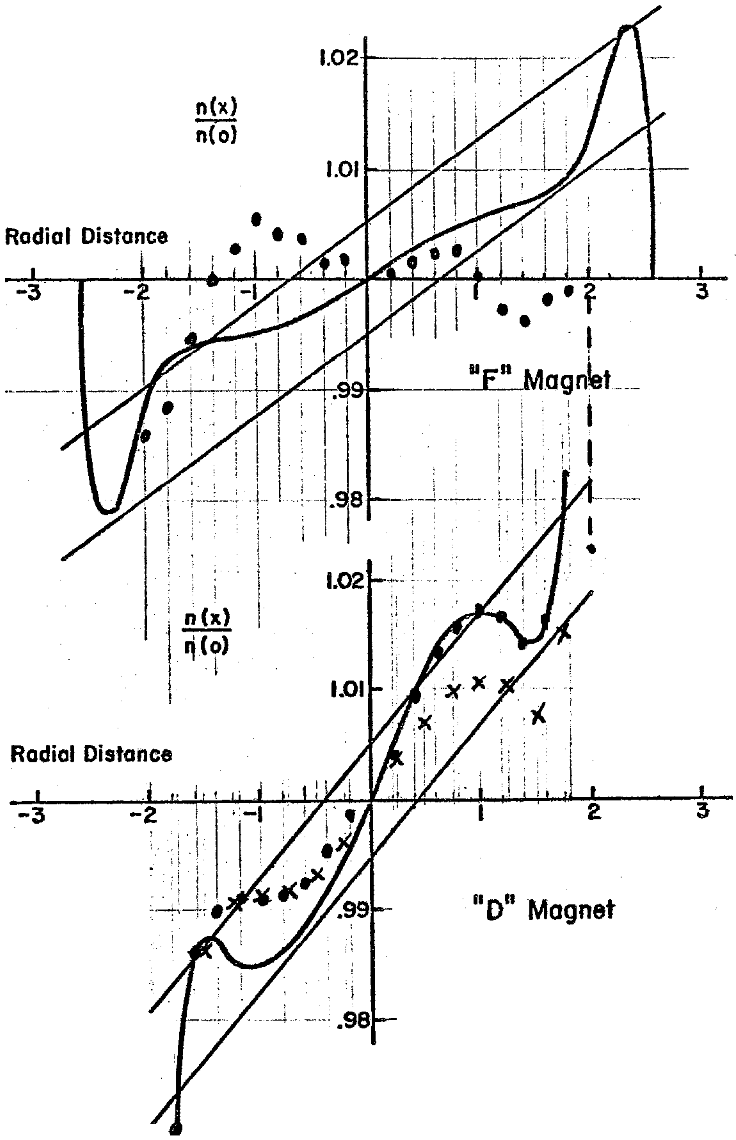


Figure 6

Injection Normalized Gradient

• • R.Y. data

X X Present data

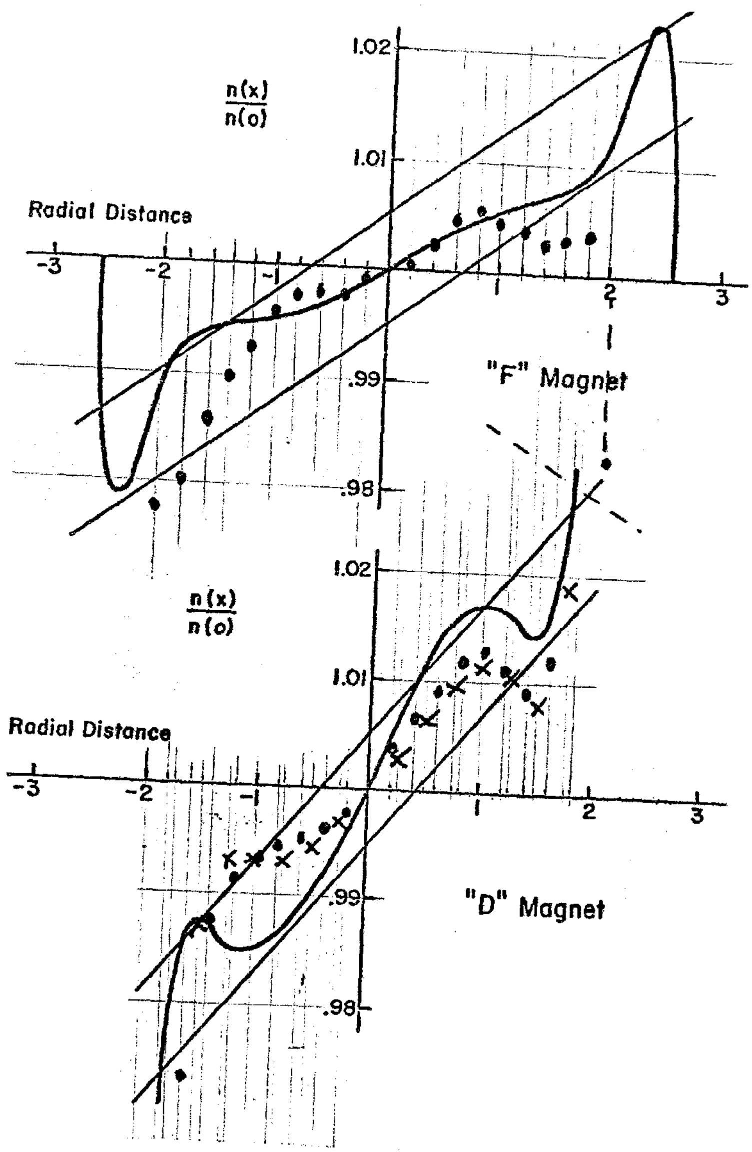


Figure 7

Normalized Gradient

• • 6 ms. R.Y. data
X X 10 ms. Present data

x

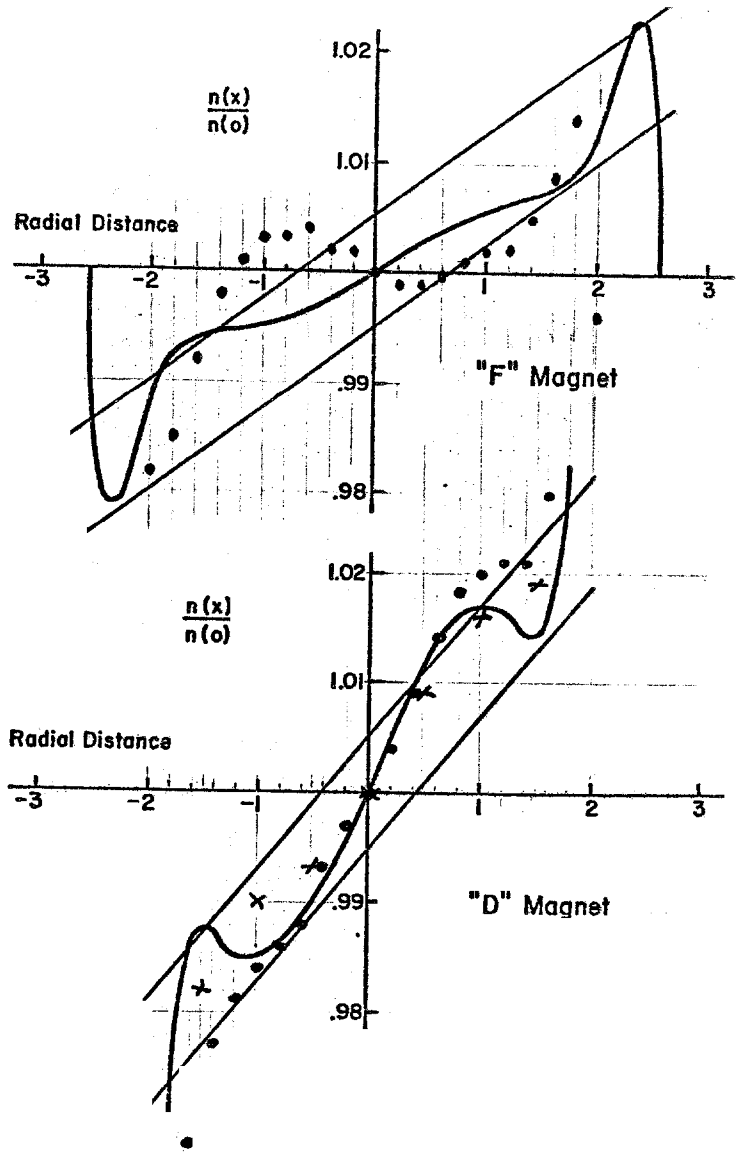


Figure 8

Injection Normalized Gradient*Gradient Length

• • R.Y. data

X X Present data

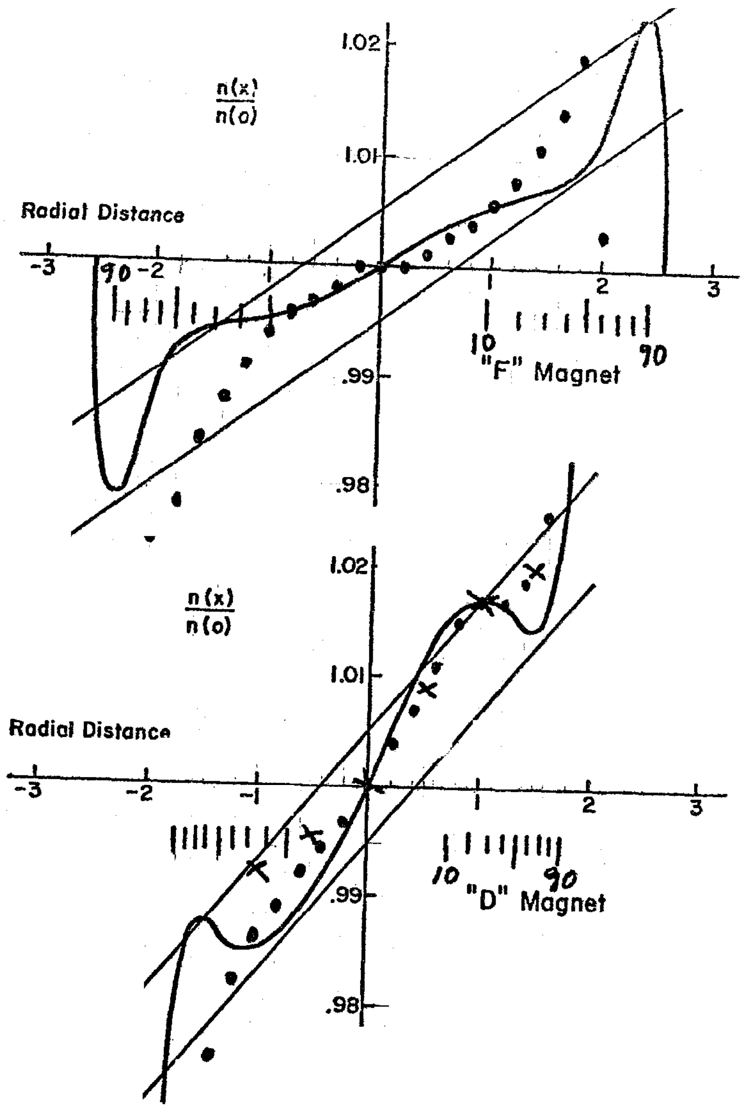


Figure 9

Normalized Gradient*Gradient Length

•• 6 ms. R.Y. data

XX 10 ms. Present data