Hall Probe Measurements of DS0309
Non-lead End External Magnetic Field*

TS-SSC 90-097
November 30, 1990
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Hall probe measurements of $\sqrt{[B_x^2+B_y^2]}$ and B_y have been made at 30 degree increments in azimuthal angle just outside the stainless steel end can (outer radius = 7.937cm) at the non-lead end of short SSC 1 m model dipole magnet DS0309. Readings were taken 0, 5, 10, 15, 20, and 25 cm from the yoked portion of the coil. All of these data were taken following cold-testing of the magnet in Lab 2, during which the magnet was excited to currents above 6000 A.

Figure 1a shows how the measurments were done. A tape measure was placed around the inner edge of the magnet shell, and the linear values corresponding to various azimuthal angles were calculated. A piece of string could be stretched across the shell aperture at the approriate tape measure values for each azimuthal angle.

The coordinate system chosen has the x axis pointing horizontally to the right when looking from the non-lead end of the magnet toward the lead end. The y axis points vertically up. (The magnet was positioned azimuthally so that this would correspond to the vertical symmetry axis of the coil package.) The z coordinate was defined to be the distance from the yoked portion of the magnet, with z value increasing toward the non-lead end of the magnet. (See **Figure 1b.**)

An aluminum tube was placed at the desired azimuthal position so that its ends abutted against the magnet yoke and the stretched string, and so that it ran along the edge of the end can. A Hall probe was inserted in the aluminum tube and positioned at the desired z coordinate (the non-sensitive portion of the probe had been marked off previously with marks that could be read at the end of the aluminum tube visible to the measurer.)

The azimuthal resolution obtained with this technique was about ± 5 degrees, and the z resolution was about ± .2 cm[1].

The probe was rotated inside the aluminum tube until a maximal reading was obtained. That reading was recorded as $\sqrt{[B_x^2+B_y^2]}$. The probe was also rotated until it was sensitive to the field along the y axis (a less precise measurement depending on the measurer's sense of holding the probe's broader surface horizontally within the tube), and this reading was recorded as B_y.

Table 1 gives the field magnitude at r = 7.94 cm at various azimuthal angles and distances (z coordinate values) from the end of the yoke. Only data taken at z values up to 15 cm are shown in Table 1, since beyond this value the field from the coils is comparable to the earth's field and the remnant field of the yoke.

Table 2 compares the field magnitude at 90 degrees azimuth for 10 A and 0 A. Some yoke remnant field is seen at 0 A. The remnant field seems to have a maximum near z = 7 cm.

*** I would like to thank Butch Bianchi and Dean Validis of the Fermilab Magnet Test Facility for their help with these measurements.**

Figures 2a - 2d show the field magnitude at r = 7.94 cm as a function of azimuthal angle at four different distances from the non-lead end yoke. Some sharp variations in field with azimuth are seen, in particular for z = 0 cm at 0 and 180 degrees azimuth.[2]

Figure 3 shows the magnetic field magnitude as a function of position at 90 degrees for 10 A and 0 A current.

Figure 4 shows the field magnitude vs. azimuthal angle at z = 5 cm, scaled up to represent the field at 7000 A magnet current. It is seen that the field strength outside the end can will not be much more than one Tesla when the magnet is operating at full field.

Table 1. Magnetic Field Magnitude $\sqrt{(Bx^2 + By^2)}$ (Gauss) at Various Distances from End of Yoked Section

Angle (degrees)	0 cm	5 cm	10 cm	15 cm
0	8.4	6.4	5.7	2.8
30	1.8	7.2	6.0	2.8
60	2.8	10.2	7. 9	3.3
90	2.7	11.1	8.2	3.3
120	2.7	10.5	7.9	3.3
150	1.8	7.3	6.1	2.7
180	9.6	6.2	5.6	2.7
210	1.9	9.0	6.5	2.5
240	2.7	10.6	9.3	3.5
270	2.5	11.9	8.8	3.6
300	2.0	10.5	7.9	3.2
330	2.0	8.4	6.5	2.6

Table 2. Magnetic Field Magnitude $\sqrt{(Bx^2 + By^2)}$ (Gauss) at Various Distances from End of Yoked Section (Comparing 10 A and 0 A at 90 degrees)

	0.0 cm	2.5 cm	5.0 cm	7.5 cm	10.0 cm	12.5 cm	15.0 cm
10 A	2.6	8.5	10.9	10.6	8.3	5.7	3.3
0 A	0.8	0.5	1.0	1.3	0.8	0.5	0.4

Notes

1. Error Analysis: The random string positioning error was about ±.2 cm, and the inner circumference of the magnet shell was 83 ± .5 cm. (The ± .5 cm represents possible systematic error in setting up the tape measure. The angular resolution due to the string technique alone was therefore

.2 cm * (360 degrees / 83 cm) = .87 degrees combined with a possible

systematic error from the initial tape measure setup of

.5 cm * (360 degrees / 83 cm) = 2.17 degrees

Probably a more significant source of random error was the difficulty of positioning the aluminum tube at a given azimuthal angle. To do this, the hidden end of the tube was forced to be perpendicular to the yoke surface, and the tube was then brought up against the end can and taped into place, making sure that the exposed end of the tube was centered on the string marking the azimuthal angle. All of these errors are of comparable size, and a reasonable estimate of random + systematic error is ± 5 degrees.

The z resolution depended on the accuracy of the marks on the Hall probe and the repeatability of positioning the probe at a given z. Two sets of measurements at 90 degrees azimuth, taken many hours apart, and therefore with different settings-up of the string/aluminum tube arrangement) give the following results:

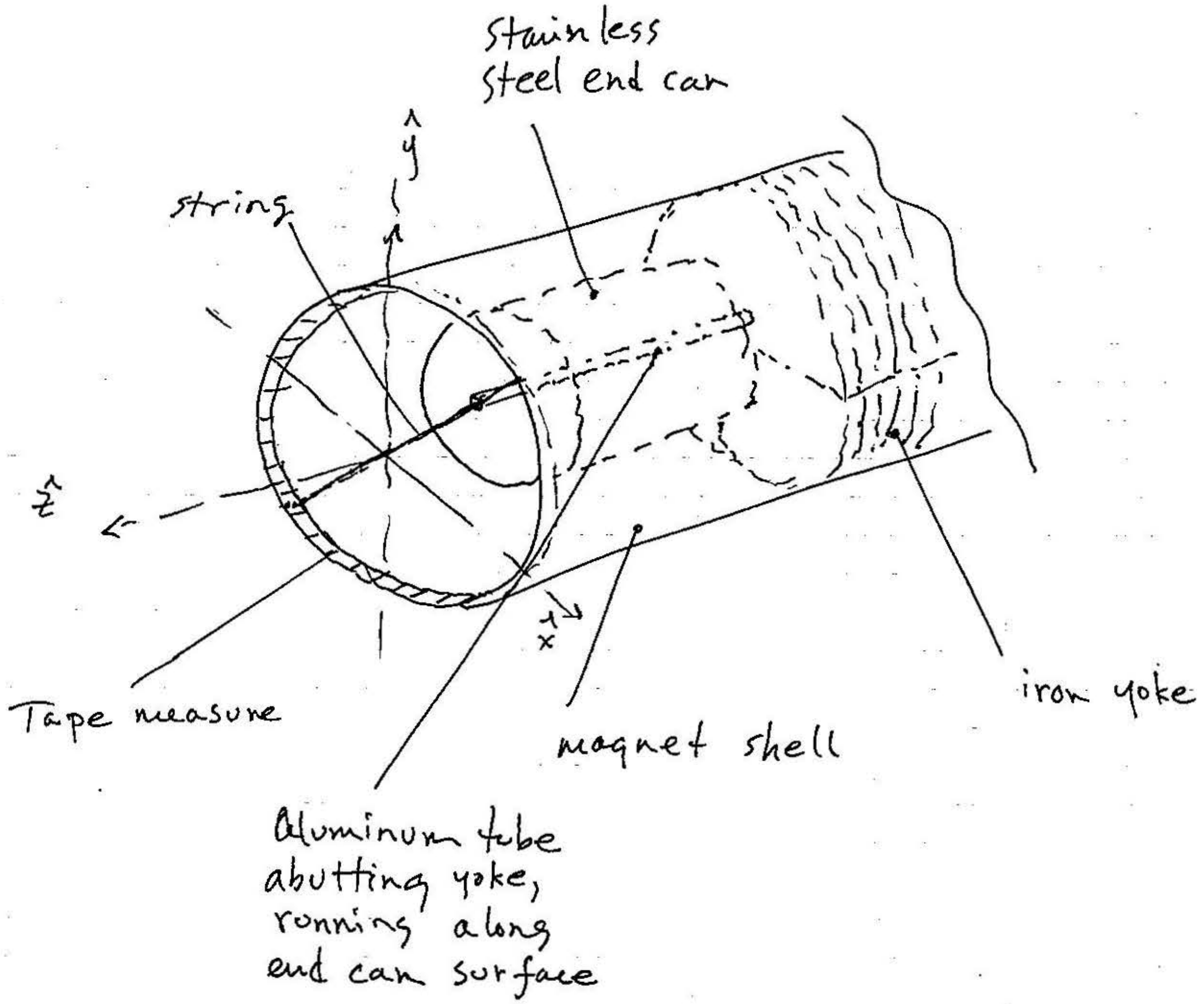
1) 2.7, 11.0, 8.3, 3.3, 0.0 Gauss
(readings taken at 0, 5, 10, 15, 20 cm respectively)
2) 2.7, 11.1, 8.2, 3.3, 0.1 Gauss

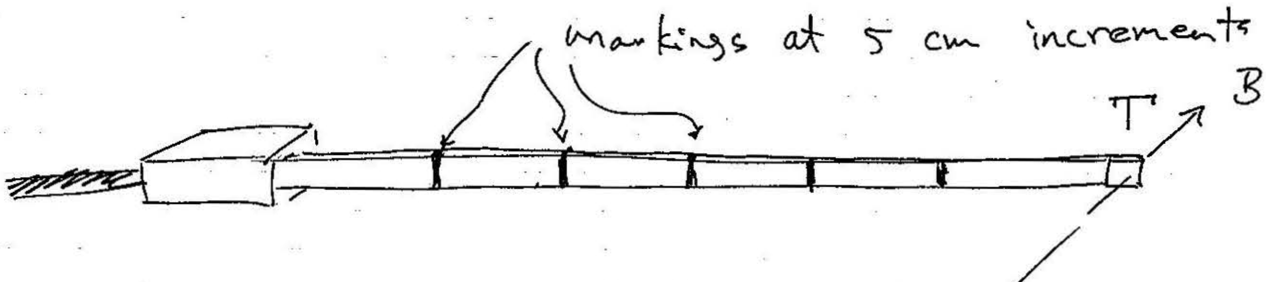
2. For the nth harmonic of a "two-dimensional" field which can be represented for example by the complex field iBx + By, no azimuthal dependence is expected for the quantity $\sqrt{[B_x{}^2+B_y{}^2]}$ outside the current windings. This is because the nth harmonic has the behavior

$1 / (x + iy)^{n+1}$ (e.g., the dipole falls off like $1/r^2$ and so the *magnitude* of

this quantity is just $1/r^{\,n+1}$. However, some azimuthal dependence of $\sqrt{[B_x{}^2+B_y{}^2]}$ could result if there are non-negligable contributions from the remnant field of the yoke and from the current in the coil ends, neither of which are expected to be "two-dimensional." The large spikes in the z = 0 cm data are most likely due to a yoke effect, while the more gentle variations with azimuth for z = 5, 10, and 15 cm are probably due to the coil ends.

Figure 1a. Hall Probe Measurement Setup





Hall Probe, sensitive only at tip T to magnetic field perpendicular to wide dimension

The probe is inserted in the aluminum tube, which may be placed at various azimuthal angles, and which serves to keep the probe rigid and at a well-defined position.

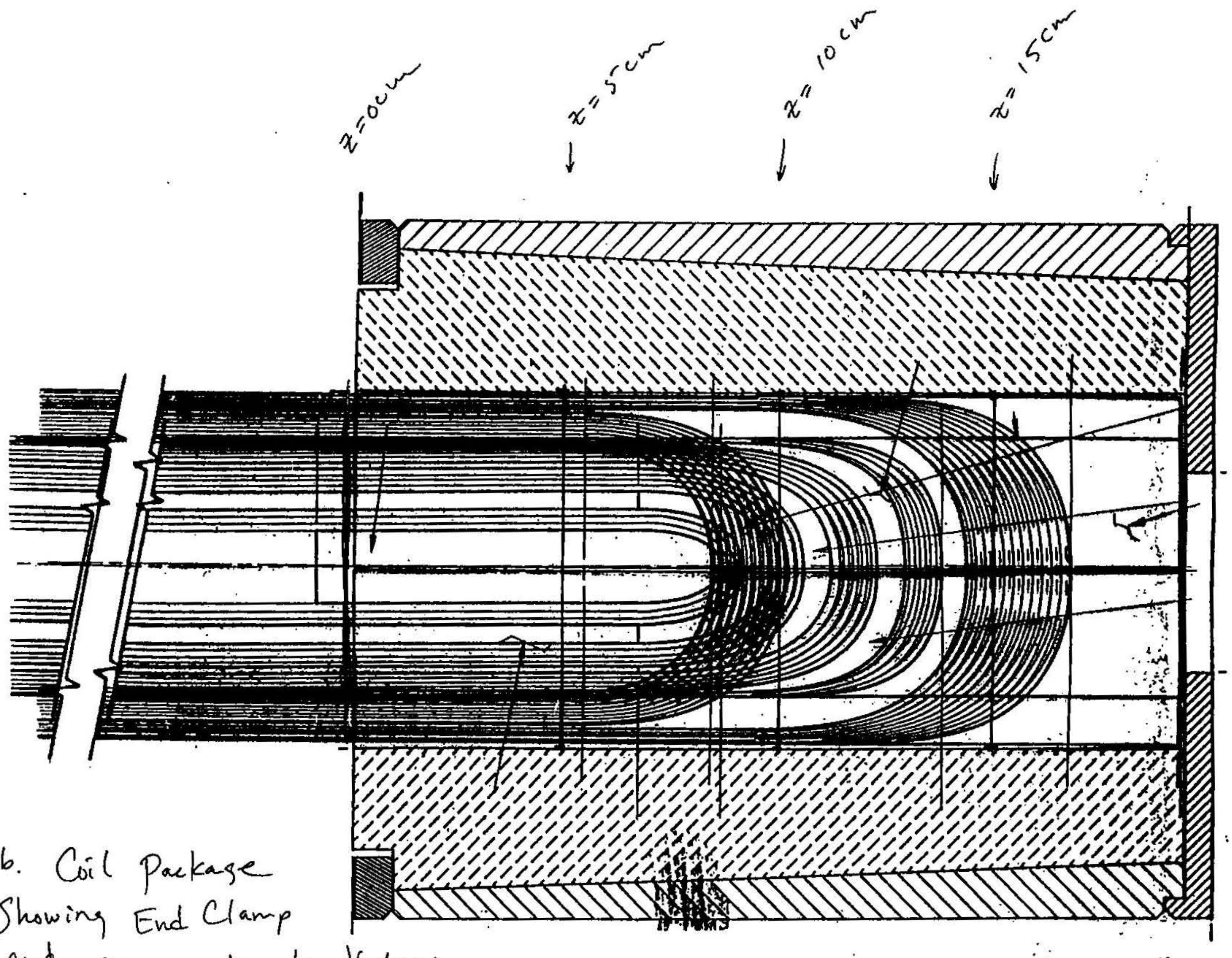


Figure 1b. Coil Package
Showing End Clamp
and z-coordinate Values.

DS0309 Hall Probe Measurement

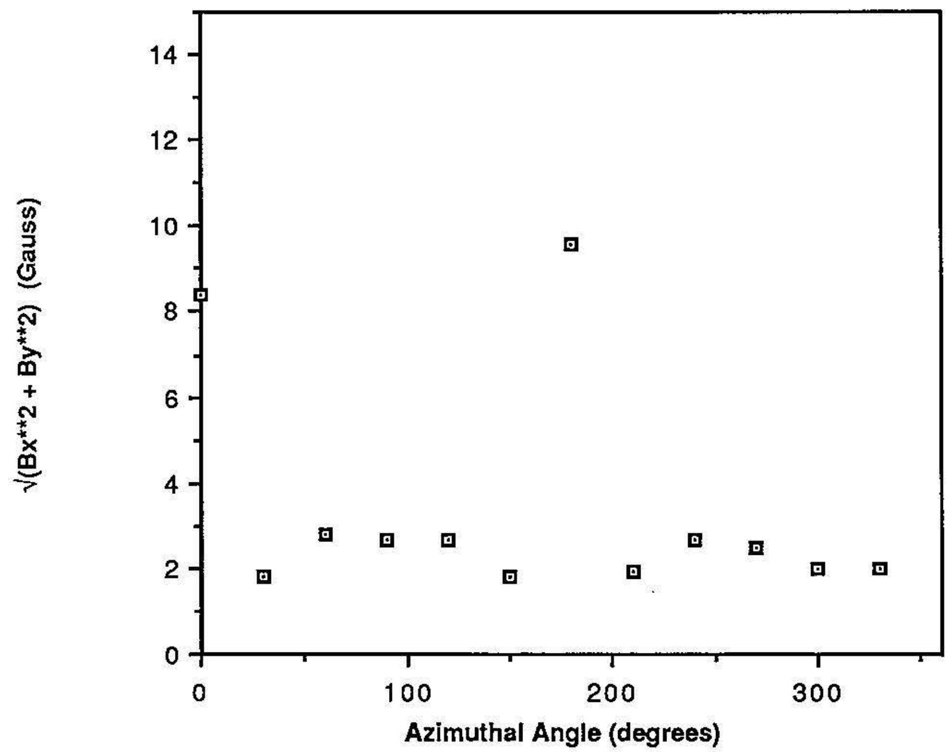


Figure 2a. Magnetic Field Magnitude 0 cm from Yoke

DS0309 Hall Probe Measurement

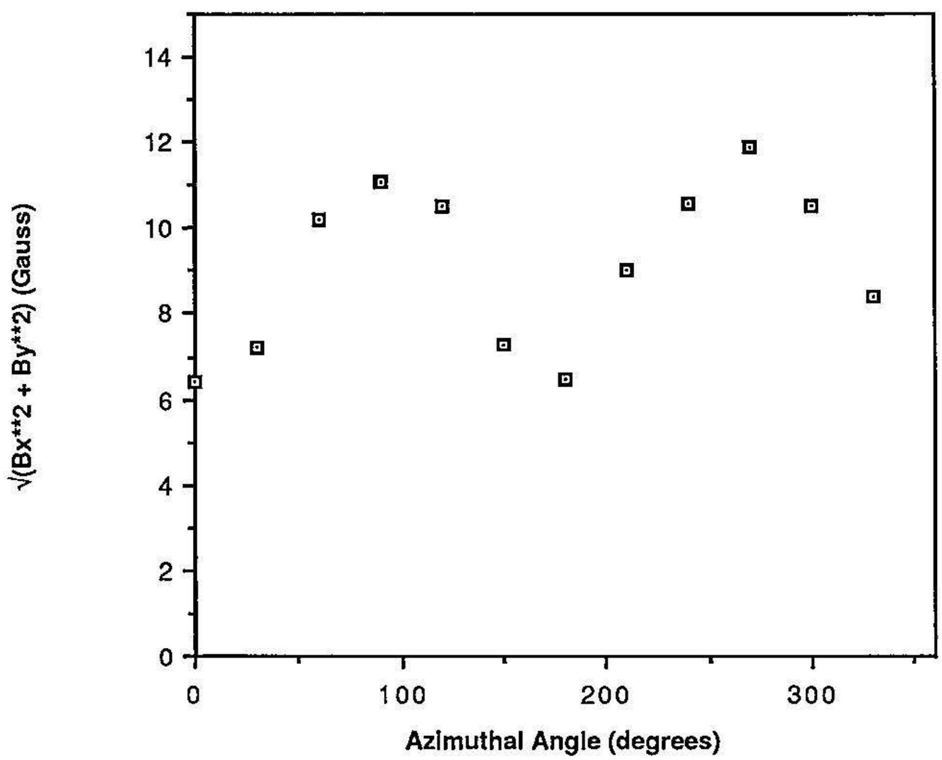


Figure 2b. Magnetic Field Magnitude 5 cm from Yoke

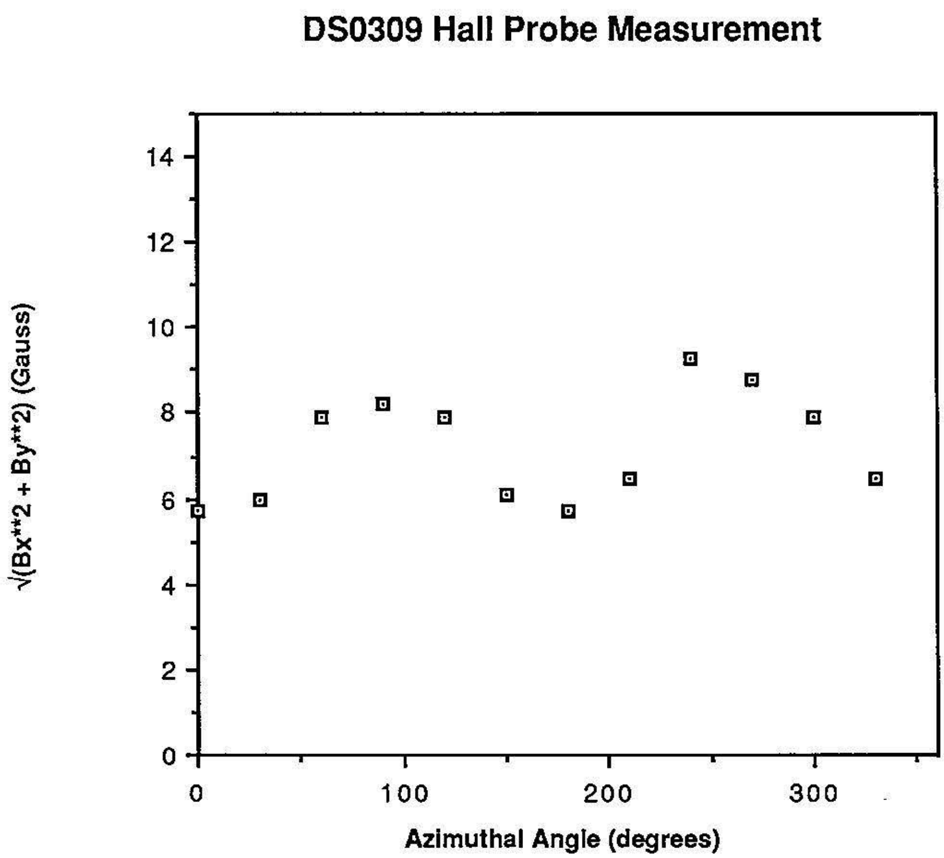


Figure 2c. Magnetic Field Magnitude 10 cm from Yoke

DS0309 Hall Probe Measurement

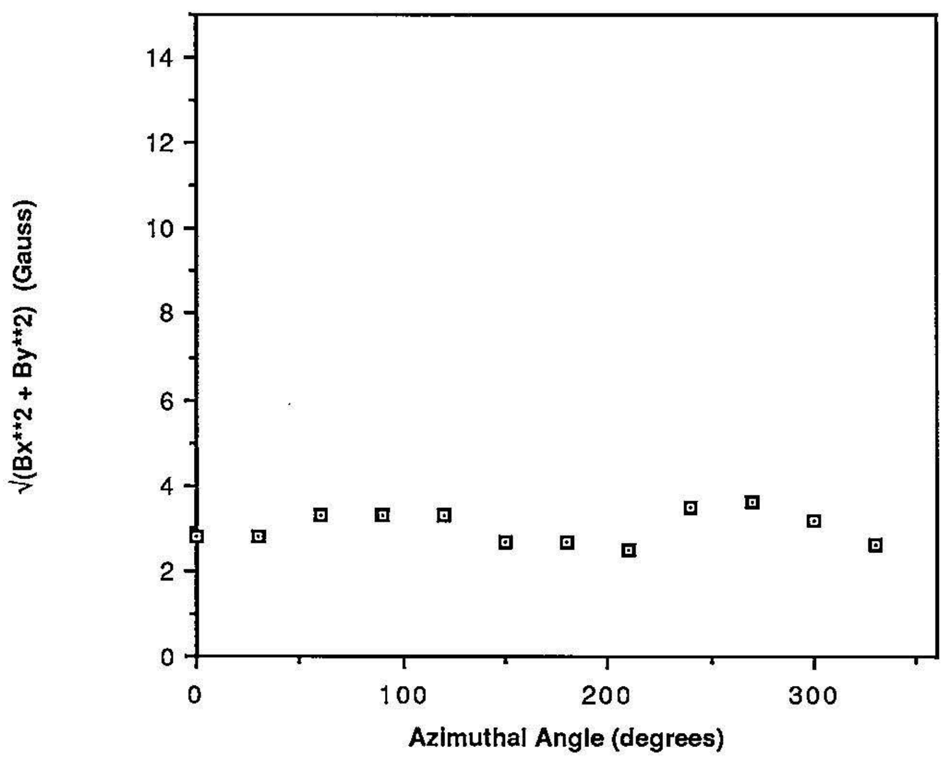


Figure 2d. Magnetic Field Magnitude 15 cm from Yoke

DS0309 Hall Probe Measurement

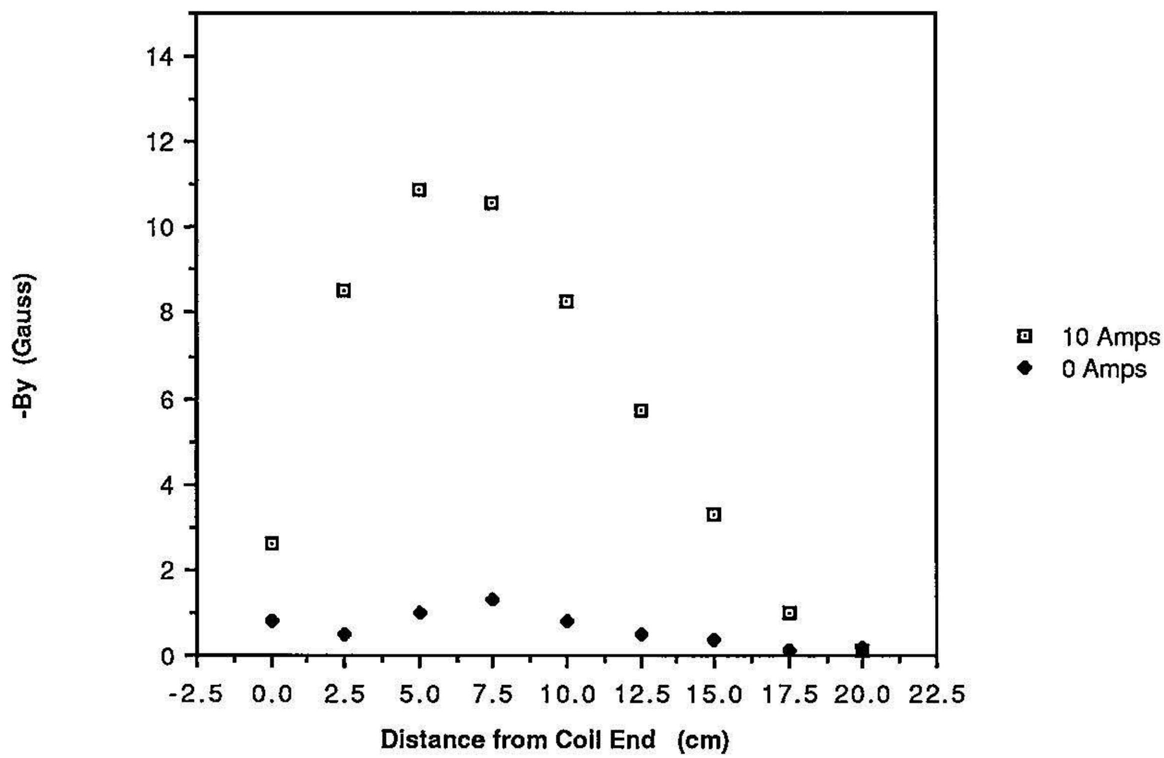


Figure 3. Magnetic Field Magnitude at 90 degrees

DS0309 Hall Probe Measurement

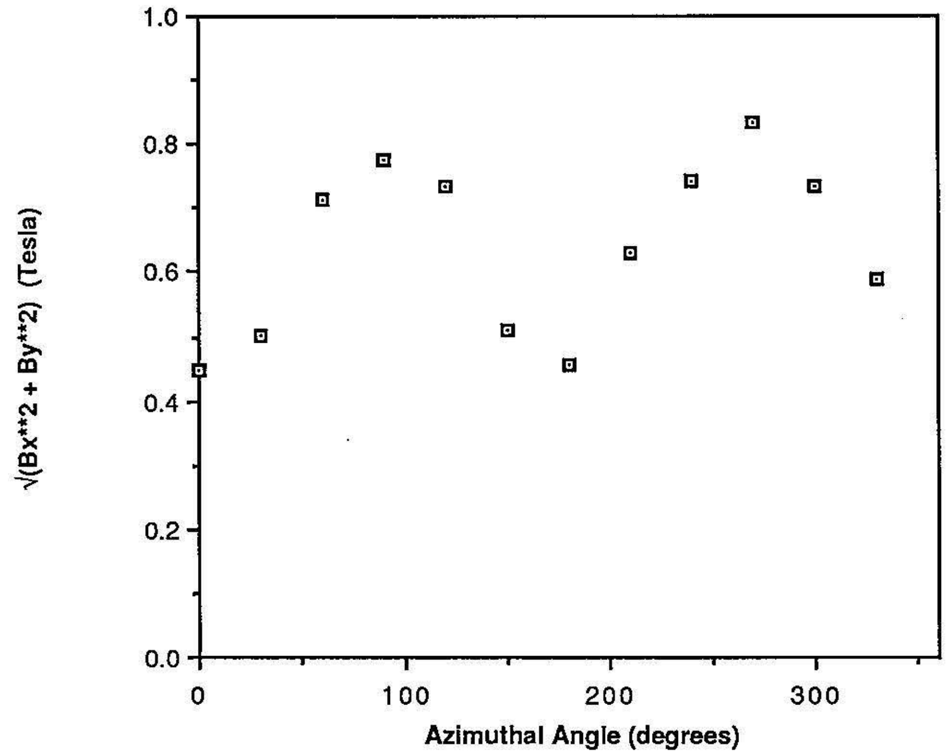


Figure 4. Magnetic Field Magnitude at 5 cm from Yoke, Scaled to 7000 A

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