BROOKHAVEN NATIONAL LABORATORY

MAGNET DIVISION NOTES

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Title: Tolerances of Alignment of the Measuring Coil During Calibration

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Tolerances of Alignment of the Measuring Coil During Calibration

INTRODUCTION

This note examines the tolerances in alignment of the measuring coil in the magnet used for calibration. If the measurement coil is positioned off center a B_x component appears giving an apparent rotation relative to the angle determined by the gravity sensor. This note determines how much the measurement coil can be positioned off center to give a rotation less than a specified tolerance. Fig. 1 shows a sketch of the calibration magnet with dimensions. A two dimensional analysis was originally performed using PANDIRA[1]. The problem is clearly three dimensional because the axial length of the magnet is less the the transverse lengths. The three dimensional analysis is performed using the TOSCA program[2] to solve Poisson's equations. The yoke is made of low carbon steel. The permanent magnetic material is assumed to be ALNICO(5-7) since the B-H table was readily available. Although this is not a true description of the material, this mainly affects the overall normalization. Since the angular tolerances are related to ratios of the fields the overall normalization is not important. In TOSCA a permanent magnetic material is an anisotropic material with different B-H tables for the easy and hard directions. Furthermore the B-H table for the easy direction has an H_c and B_{mag} implicitly defined by not having a point at B=0, H=0. Because of symmetry only one eighth of the magnet needs to be modeled.

ANALYSIS

Fig. 2 shows $|B|$ along the z-axis. The field falls off quickly when it is outside the iron. It is essentially zero when the distance is three half-lengths of the iron. The field at center of the magnet is only 89% of the 2D field, that is the field that one would obtain if the iron went out to $Z = \infty$. This confirms the supposition that the 2D description would be inadequate. Fig. 3 and Fig. 4 show the field along the x- and y-axes in the symmetry plane at Z=0. Although the field is largely dipole there is a significant amount of sextupole present as can be seen in Fig. 3. Placing the measuring coil off center produces an apparent rotation of the field with respect to the true vertical direction. The apparent rotation is just the ratio of the x-component of the field to the y-component as seen by the measuring coil. If the measuring coil is placed on the midplane axis or on the vertical axis B_x is zero because of symmetry and the apparent rotation is zero. Assuming that only normal even

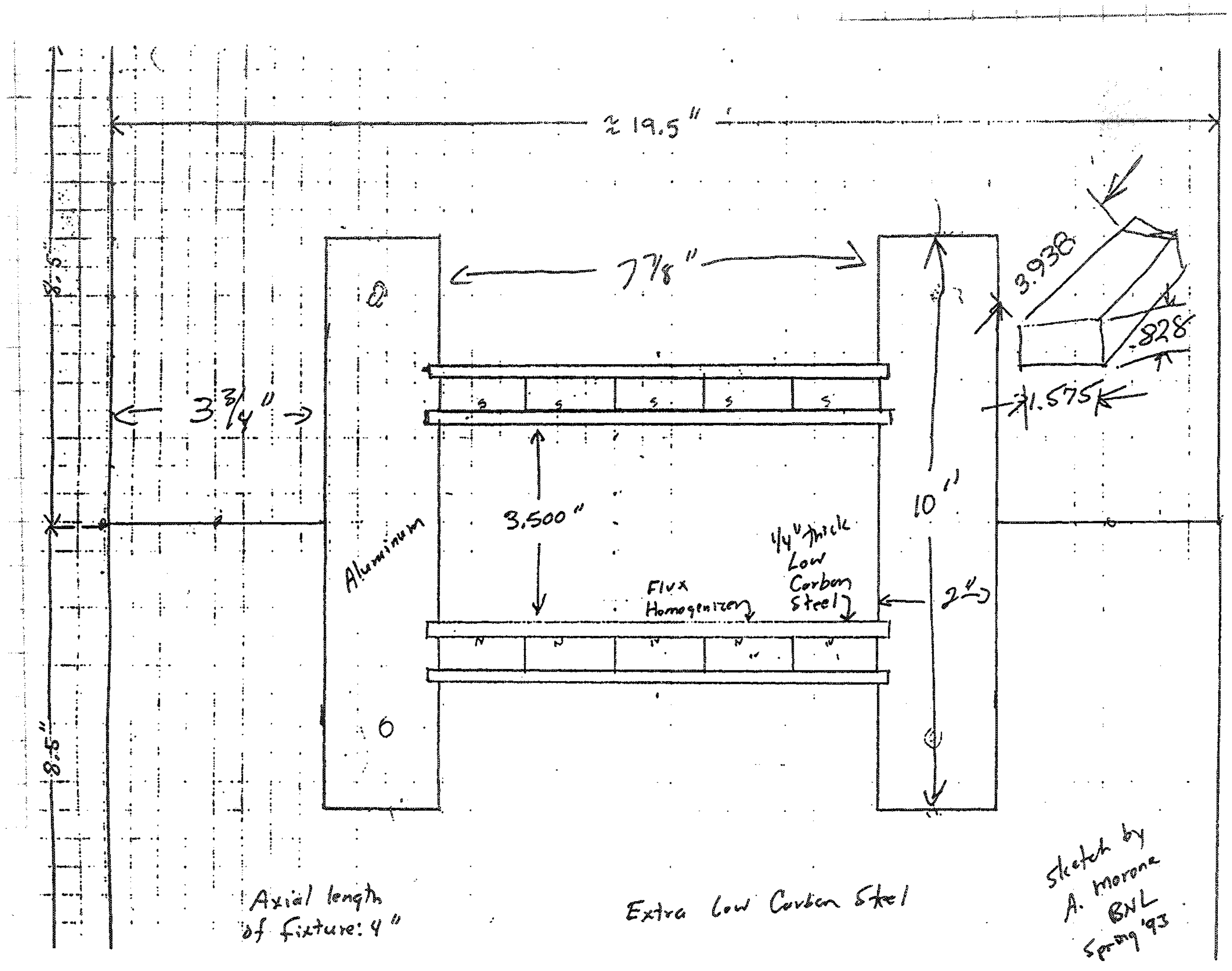

Figure 1: Sketch of cross section of calibration magnet.

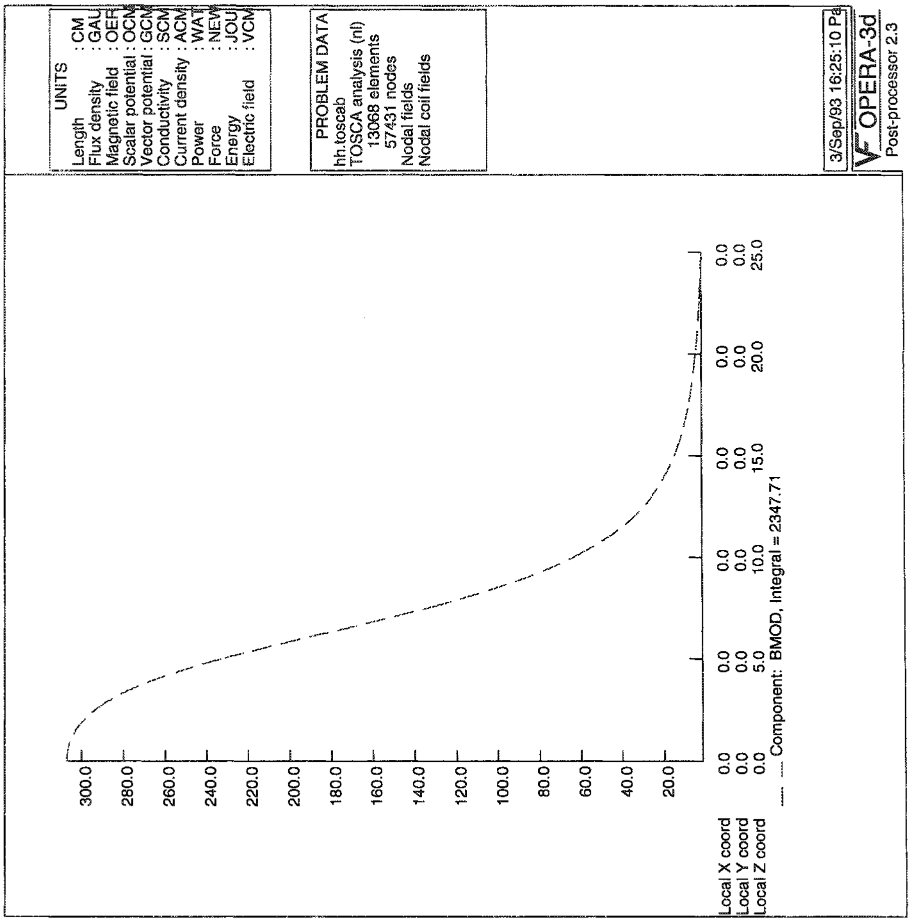

Figure 2: Plot of $|B|$ along the axial direction.

multipoles are present, The standard multipole expansion gives:

$$B_y(x,y) + iB_x(x,y) = \sum_{n=0}^{\infty} B_{2n}\Big(\cos(2n\phi) + i\sin(2n\phi)\Big)\left(\frac{r}{r_o}\right)^{2n}$$

From the equation it can be seen that B_x is maximum on the 45^o line. Furthermore the first allowable term for B_x is due to the sextupole and it grows quadratically with distance from the center.

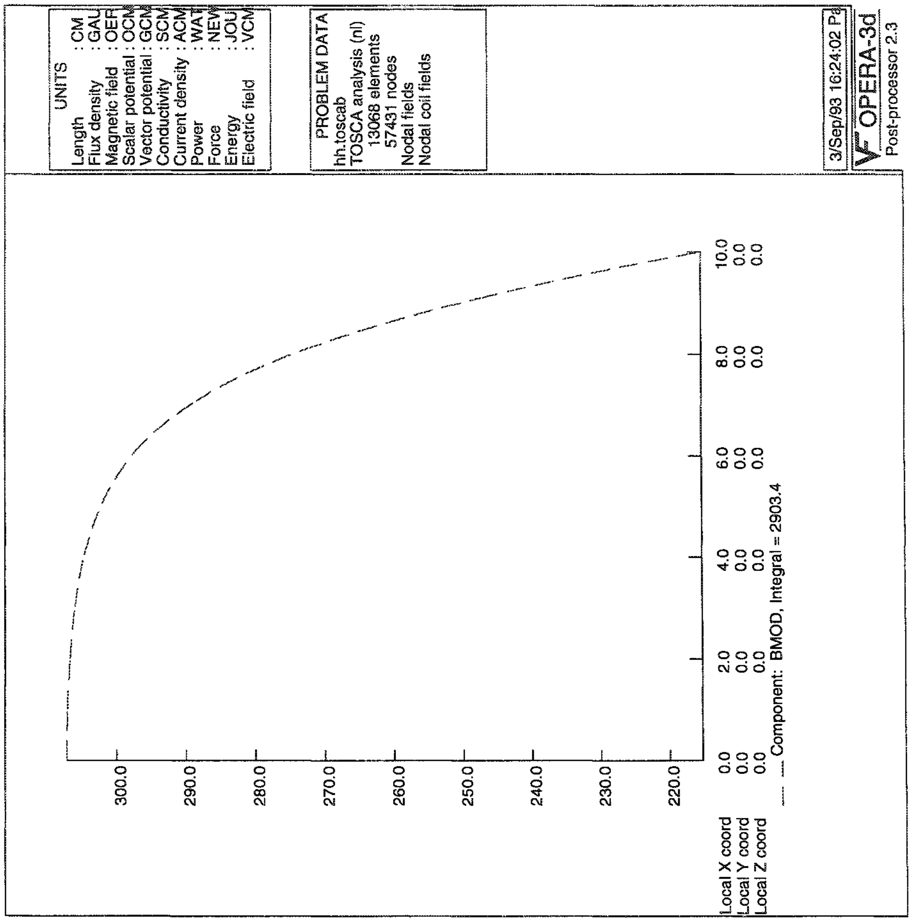

Figure 3: Plot of B_y along the abscissa.

Since the measuring coil is much longer than the length of the calibration magnet it is sensitive to the integral of the field. Table 1 tabulates the results of a calculation of $\int_{-25}^{25} B_x dz$ and $\int_{-25}^{25} B_y dz$ when the measuring coil is parallel to the longitudinal axis of the magnet. The field is evaluated at positions along the 45^o line through the origin which should have the maximum B_x and consequently the maximum apparent rotation. The apparent rotation, $\delta\phi$ is define to be the $arctan(\int_{-25}^{25} B_x dz / \int_{-25}^{25} B_y dz)$. $\delta\phi$ varies very close to quadratic in r as expected for small r. Fig. 5 shows a plot of the limiting radial distance to achieve an apparent rotation of 0.1, 0.3 and 0.5 mrad, respectively.

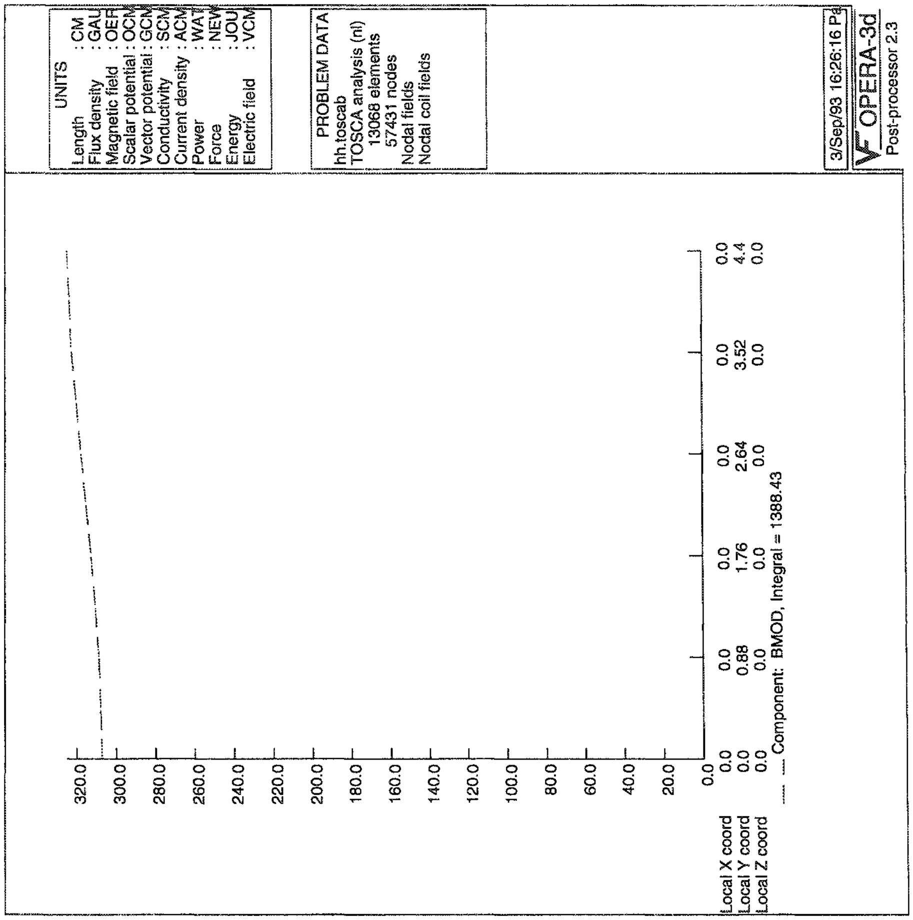

Figure 4: Plot of B_y along the ordinate direction.

We have investigated what happens if the measurement coil is not exactly parallel with the magnet axis. Any general orientation of the measurement coil relative to the magnet axis can be represented by an x-axis rotation followed by a y-axis rotation. Table 2 shows the results for a small rotation about the x-axis. The B_z present for a small rotation about the x-axis would mix with B_y. Since $\int_{-\infty}^{\infty} B_y dz >> \int_{-\infty}^{\infty} B_z dz$, there is only a negligible difference. Table 3 shows the results for a small rotation about the y-axis. The B_z present for a small rotation about the y-axis would mix with B_x, however the $\int_{-\infty}^{\infty} B_z dz$ is small compared to $\int_{-\infty}^{\infty} B_x dz$ for small rotations in the same x-z plane. From these tables it is

Table 1: Integral fields and apparent rotation along the 45^o line when the measurement coil is aligned parallel to the z-axis. Integrated fields are quoted in *gauss-cm*.

r cm	$\int_{-25}^{25} B_x dz$	$\int_{-25}^{25} B_y dz$	$\delta\theta$ $mrad$	$\frac{\delta\theta}{r^2}$
0	0	4695.42	0	-
0.1414	-0.06966	4696.02	-0.0148	-0.74
0.3536	-0.41665	4696.65	-0.0887	-0.71
0.5657	-1.04966	4696.95	-0.2235	-0.70
0.8485	-2.32888	4696.87	-0.4958	-0.69
1.1314	-4.09327	4696.23	-0.8716	-0.68
1.4142	-6.32714	4695.75	-1.3474	-0.67

Table 2: Integral fields and apparent rotation at $r = 0.3536$ and $\phi = 45^o$ when the measurement coil is aligned with a small x rotation ξ from the magnet axis. Integrated fields are quoted in *g-cm*.

ξ $mrad$	$\int_{-25}^{25} B_x dz$	$\int_{-25}^{25} B_y dz$	$\int_{-25}^{25} B_z dz$	$\delta\theta$ $mrad$
1	-1.0497	4696.95	-4.621	-0.2235
5	-1.0495	4696.99	-23.104	-0.2234
10	-1.0488	4697.14	-46.210	-0.2233

Table 3: Integral fields and apparent rotation at $r = 0.3536$ and $\phi = 45^o$ when the measurement coil is aligned with a small y rotation η from the magnet axis. Integrated fields are quoted in *g-cm*.

η $mrad$	$\int_{-25}^{25} B_x dz$	$\int_{-25}^{25} B_y dz$	$\int_{-25}^{25} B_z dz$	$\delta\theta$ $mrad$
5	-1.0497	4697.00	0.0013	-0.2234
10	-1.0499	4697.16	0.0026	-0.2235

evident that the apparent rotation axis is insensitive to a slight angular misalignment the measurement coil to the magnet axis.

REFERENCES

1. PANDIRA is a member of the POISSON group of programs.
2. The TOSCA program is a 3D finite element electromagnetic field program marketed by Vector Fields Limited.

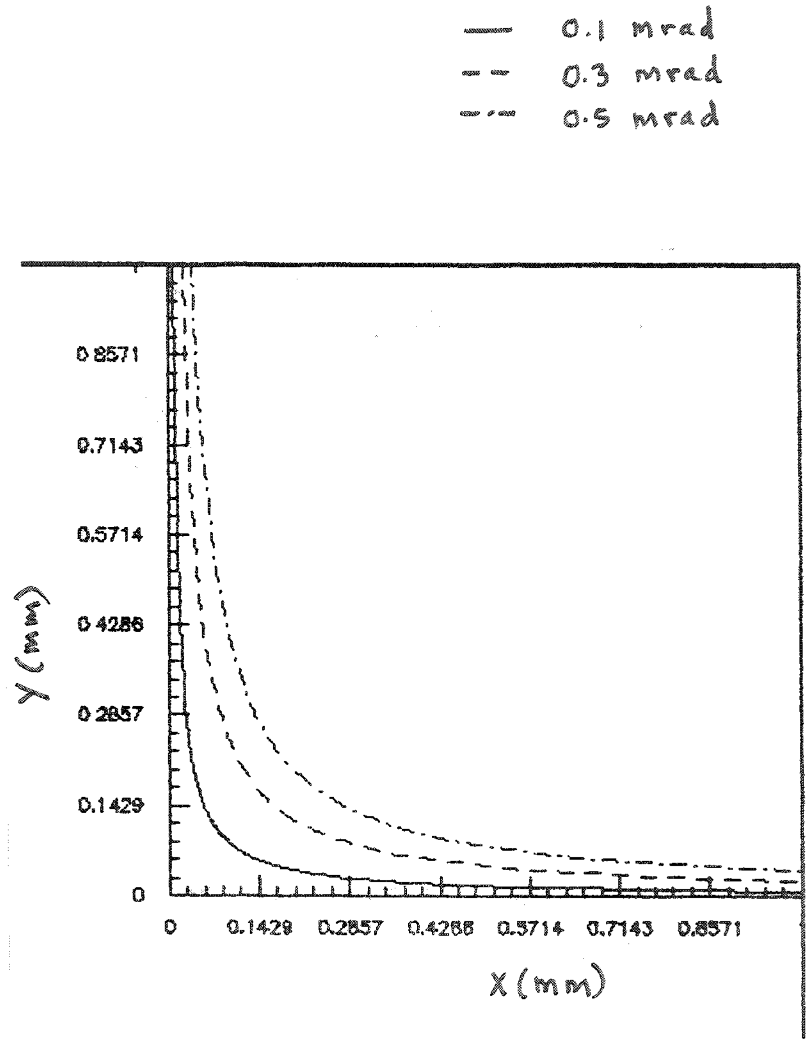

Figure 5: Contour plot of the limiting radial dimension unitsto achieve an apparent rotation of 0.1, 0.3 and 0.5 mrad.