3-D NUMERICAL FIELD CALCULATIONS OF CESR'S UPGRADED SUPERCONDUCTING MAGNETS

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Abstract

A 3-D numerical code BST.c was used to calculate the spatial magnetic fields generated by a current carrying wire. In particular, the code calculates the fields of wire loops wrapped on a pipe similar to superconductive magnet structures. The arrangement and dimensions of the loops can be easily modified to create dipoles, quadrupoles, skew magnets etc., and combinations of the above. In this paper we show the calculated 3-D fields of ironless superconducting quadrupole dipole combination designed for CESR phase III upgrade (which will be manufactured by TESLA). Since the magnet poles are made of loops, the fields at the edges are not only distorted but have a component, B_z, in the z direction as well. This B_z field can cause X-Y coupling of the beam. In order to calculate the coupling, the particle trajectories through the whole magnet were computed. The code is also used to calculate local fields errors due to possible manufacturing imperfections. An example of a rotational error of one pole is shown.

1 INTRODUCTION

3-D Numerical magnetic field calculation code BST.c was developed in order to study the possible problems associated with the rounded ends of the wire loops of the superconductive magnets, planned for CESR upgrade III. The algorithm and details of the code BST.c are described in CBN 97-10 [1]. The code calculates the spatial magnetic field surrounding current carrying wire loops.

2 *QUADRUPOLES*

Each one of the superconducting quadrupoles, to be installed next to the interaction point, for CESR upgrade III [2] is made out of four loops of wire ribbons which are wrapped on a pipe. The loops touch each other and create four poles. (The current flows in opposite direction in each loop). All the consecutive ribbon layers have the same perimeter. The straight part of the loops (ideal magnet) lies along the z axis for $-z_m < z < z_m$ .The ends of the loops are elliptical causing magnetic field distortion at the ends including a component of magnetic field, B_z, in the z direction. In order to suppress the field distortion (higher order multipoles), created at the rounded ends of the loops, each loop is divided into three sub concentric loops. The fields of this magnet, calculated by the 3-D code BST.c, are shown in Figures 1-5. Figure 1 shows the field components B_r, B_θ, B_z along the z axis for $r = 0.055,\ \theta = 10°$, with pipe radius $a = 0.092\ m$. Figures 2,3 show the field

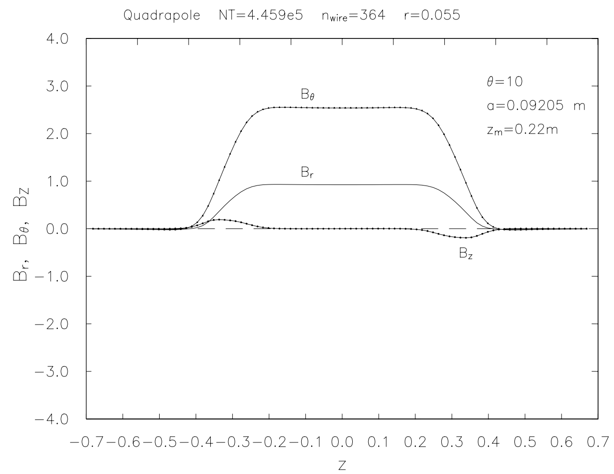

Figure 1: Magnetic Field of the TESLA Quadrupole for $r < a$

components at the end $(z = 0.33\ m)$ along the r and θ axis correspondingly. Figures 4,5 show 3D presentation of B_r and B_z along z and r axis, $0 < r < 1.5a$, $\theta = 0$. Since the superconducting magnet does not have iron, the field calculated for $r > a$ is the field outside the magnet. This field is not small, as can be seen in Figures 4,5. Its effect on the nearby interaction point detector may be significant. Note, despite the subdivision of each loop, there is still a component, B_z at the ends for $-z_m < z < (z_m = 0.23)$ which increases with r, as can be seen in Figures 2,3,5. Also, there is some distortion left in B_r and B_θ at the ends which will introduce higher order multipoles.

3 HIGHER ORDER MULTIPOLES

In order to find the extent of the parasitic multipoles we expand the field component $B_r(\theta) = \sum_{m=1}(A_m \cdot \sin(m\theta) + B_m \cdot \cos(m\theta))$. $A_2 \sin(2\theta)$ is the ideal quadrupole component where $A_{(m,m\neq 2)}$ is the m multipole amplitude and B_m is the m sqew pole amplitude. The normalized amplitude A_m/A_2 of the multipoles, obtained by Fourier transformation, at the end of the magnet $(z = 0.33\ m)$ and very large displacement $(r = 0.8a)$, is shown in Figure 6. The expanded scale (right side axis) shows that the strongest remaining multipole $m = 6$ is less than 3% of the quadrupole strength at this location. The other multipoles $m = 10$ is less than 2% and $m = 14$ is less than 1%. The total effect of each multipole is obtained by integration of each multipole intensity along the whole length of the magnet.

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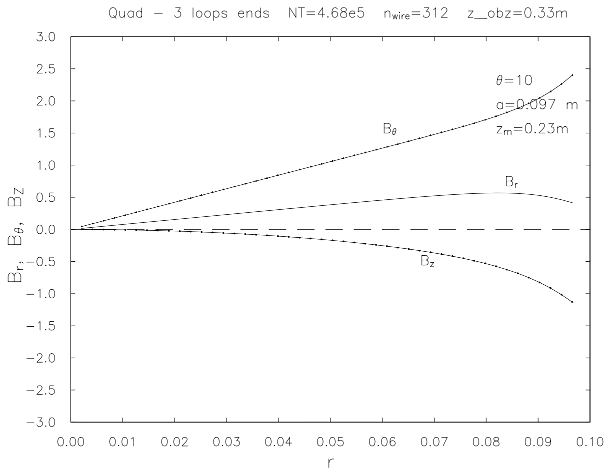

Figure 2: Magnetic Field of the Quadrupole along r

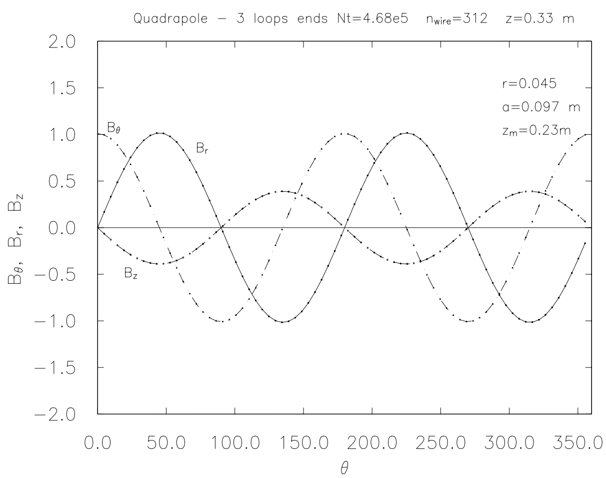

Figure 3: Magnetic Field of the Quadrupole along θ

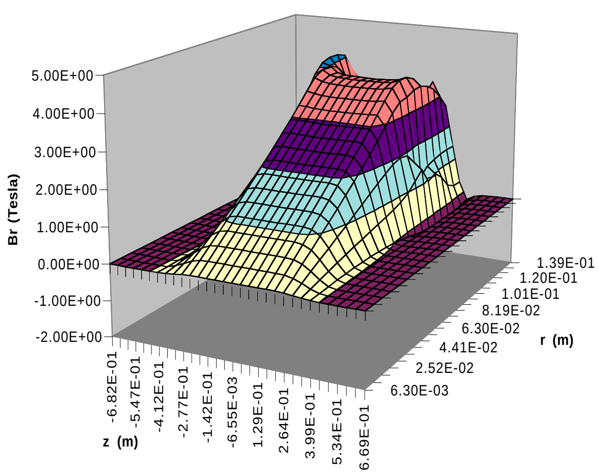

Figure 4: Magnetic Field B_r of the TESLA Quadrupole along z for $0 < r < 1.5a$

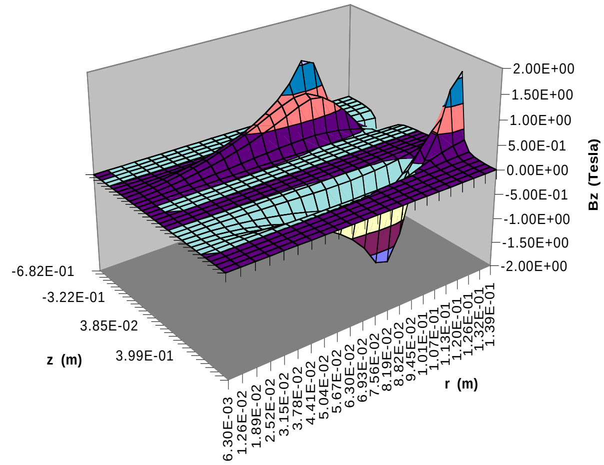

Figure 5: Magnetic Field B_z of the TESLA Quadrupole along z for $0 < r < 1.5a$

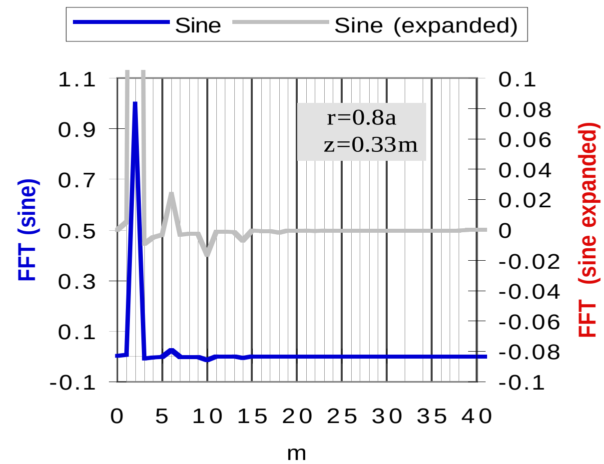

Figure 6: Relative strength of the higher order multipoles at $r = 0.8a$ and $z = 0.33$.

4 WINDING ERRORS

Magnetic field deviation due to misalignment of wires can be easily calculated. An example of the field errors of a magnet with the center of one loop shifted by 1° is shown in Figure 7. $\Delta B_i \; i = (r, \theta, z)$ is the difference between the ideally symmetric magnet to the one with the shifted loop in Tesla. The error $\frac{\Delta B_r}{B_r}$ in this example is 1.8%.

Shifting the coils of one loop as in the above example will cause a localized error in the azimuthal direction over the length of the whole magnet. Because the error is localized in θ, its total effect on the integrated multipoles will be relatively small [4].

5 QUADRUPOLES AND DIPOLE COMBINED

An option which will save space and cryogenic cooling is to wind the dipole magnet, needed for misalignment com-

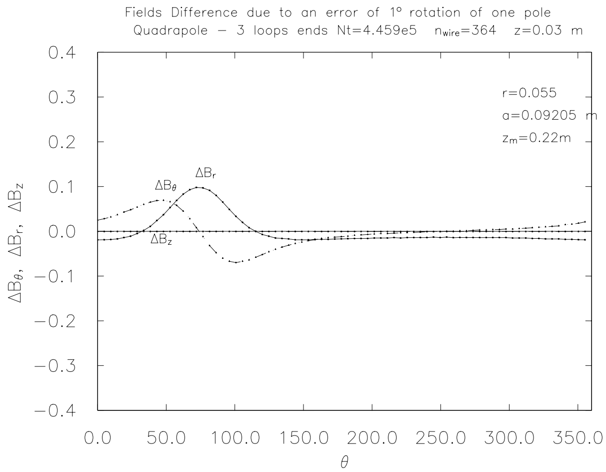

Figure 7: Field errors due to 1° shift in the center of one loop

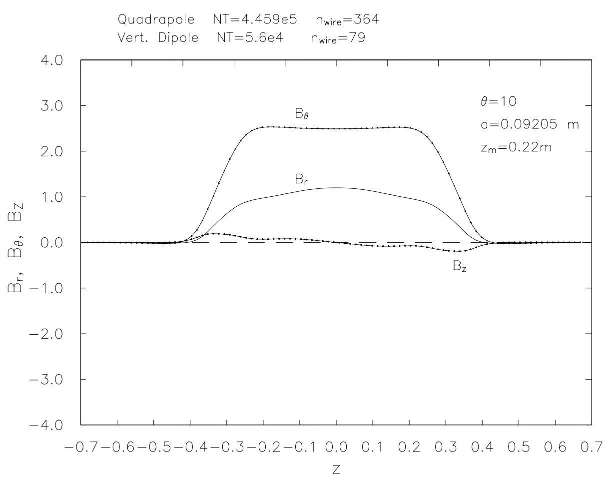

Figure 8: Combined Field of the above Quadrupole and Dipole at $r = 0.055\,m$.

pensation, on top of the quadrupole. The basic dimensions of the dipole are determined by the outside diameter of the quadrupole and its length. These constraints make the dipole loops ellipse-like, almost without straight sections. The combined field of the quadrupole and (without subdivisions of the dipole loops) dipole can be seen in Figure 8. The total field obtained is distorted by the dipole. A more complex dipole winding is being designed. For additional field calculation see CBN 96-09 [3].

6 THE SUPERCONDUCTIVE QUADRUPOLE TRANSFER MATRIX

The particle trajectory through the whole magnetic field including the fringe fields at the edges, total length of 83 cm, was calculated by solving the equation of motion numerically. The magnetic fields were recalculated at each step by the 3-D numerical code BST.c. Using these results the transfer matrix ,T, of the horizontal quadrupole magnet was calculated.

$$T = \begin{pmatrix} 0.3082 & .6854 & 0.0 & 0.0 \\ -1.4932 & -0.0799 & 0.0 & 0.0 \\ 0.0 & 0.0 & 1.885 & 1.650 \\ 0.0 & 0.0 & 2.237 & 2.460 \end{pmatrix}$$

From the transfer matrix it can be seen that there is no coupling between the horizontal and vertical motion. The main reason that there is no coupling is that the magnetic field B_z has opposite polarities at the ends of the magnet, as seen in Figures 2,4. Also the particle's azimuthal angle changes very little through the whole magnet. Therefore the effect of the B_z field on the particle motion is canceled out. The exact transfer matrix can be used in simulation of the whole storage ring instead of the thin lens approximation.

7 SUMMARY

The strength of the higher order multipoles characterizes the quality of a superconducting magnet. The sources for these multipoles can be the rounded ends of the wire loops and manufacture winding errors. In order to calculate the multipoles, especially those generated by manufacture errors, a 3-D code like the BST.c is needed. This code has no restrictions on the wire layout. Also, in designing combined magnets where the layout of the wires is complex, the flexibility of the code is essential. A study of the expected coupling between horizontal and vertical motion due to B_z component at the magnet ends was done by calculating the transfer matrix.

8 ACKNOWLEDGMENT

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9 REFERENCES

[1] Z. Greenwald, "3-D Numerical Code for Field Calculation of Super Conducting Magnets." CBN 97-10. (Available on the web at http://www.lns.cornell.edu)

[2] J. J. Welch, G. F. Dugan, E. Nordberg, D. H. Rice, "The Superconducting Interaction Region Magnet System for the CESR Phase III Upgrade." This conference.s

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