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CALCULATIONS AND MEASUREMENTS FOR THE SLAC SLC POSITRON RETURN QUADRUPOLE MAGNET*

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Abstract

The three-dimensional magnetostatic computer program TOSCA, running on the NMFECC CRAY X-MP computer, was used to compute the integral of gradient length for the SLC type QT4 positron return line quadrupole magnet. Since the bore diameter of the magnet is 12.7 centimeters, and the length is only 10.16 centimeters, three dimensional effects are important. POISSON calculations were done on a two-dimensional model to obtain magnetic shimming which assured enough positive twelve pole to offset end effects, while TOSCA was used to estimate the effective length of the quadrupole. No corrections were required on the magnet as built. Measurements showed that the required integrated gradient was achieved for the given current, and that integrated higher harmonics were generally less than 0.1 percent of the quadrupole component.

Introduction

The SLAC SLC QT4 positron return line quadrupole magnet has a length of 10.16 centimeters and a bore diameter of 12.7 centimeters. The required strength ($\int G\,dz$) is 1.5 Tesla at 19800 ampere turns per pole. Strength calculations were done using TOSCA, a three-dimensional magnetostatic code,[1] running on the NMFECC Cray X-MP computer. Because of inexperience with this code, it was used primarily to predict saturation effects. POISSON was used to shim the quadrupole to offset end effects. The original plan was to over-correct the integral 12-pole end effect and then reduce the shim as required after measurements. This later step proved unnecessary. Since then, the latest version of TOSCA (4.3) has been installed on the X-MP. This version allows more symmetry options for coils and a more accurate model of the quadrupole was made. This was done in order to gain a better understanding of how to use a three-dimensional computer code for quadrupole design. The results of these computer studies and the associated measurements are reported here.

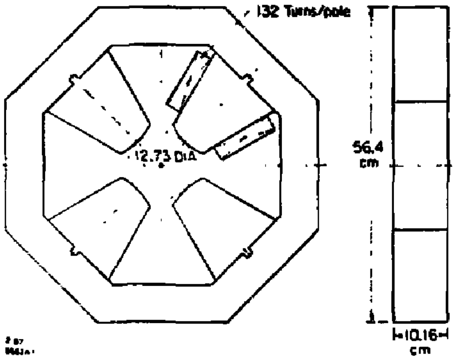

Fig. 1. The SLC QT4 Positron Return Line Quadrupole.

Computational Results

A drawing of the quadrupole is shown in Fig. 1. The short length was dictated by space requirements in the beam line. The TOSCA model was initially made two-dimensional by the use of periodic boundary conditions in order to compare the resulting field distributon with POISSON results. The POISSON runs were used to shim the magnet for a positive three percent twelve-pole component in two dimensions. These runs were also used to check that the mesh density in the two-dimensional TOSCA runs was sufficient, and finally, to check that approximating the quadrupole poleface by only two line segements did not cause significant error. This scheme worked because the shim was a line, tangent to the hyperbolic surface and occupied most of it.

One sixteenth of the problem was set up to take full advantage of symmetry. The element configuration for the base plane is shown in Fig. 2. This mesh was generated by XMESH, a pre-processor written by John Stewart of LLNL.[2] The three-dimensional mesh used is shown in Fig. 3. Iron elements only are shown in Fig. 4. Quadratic mesh elements were used everywhere. While this causes an increase in running time compared to a mesh of linear elements, quadratic elements approximate the potential distribution better. This follows the work of M. R. Harold et al.[3] The final runs utilized nearly ten thousand nodes and took between forty and forty-five minutes of CPU time on the Cray X-MP.

Because so much of the field in this magnet is in the fringe region, care had to be taken to position the boundary far enough away from the center of the problem. A value of 30 centimeters was chosen. The integrations were made over z to 27.5 centimeters. This corresponded to the length of the long coil used in the harmonic analysis and strength measurements.

Calculations on initial designs for this magnet showed that saturation at the root of the pole was occurring and the required strength was not being met. Two B–H tables were used in these calculations. (See Fig. 5.) Table 1 is the standard table to be found in POISSON and corresponds to annealed 1010 steel. Table 2 is a table which is often used at SLAC for magnet calculations and has been made more pessimistic as a safety factor in shim calculatons. For a given H, the induction,

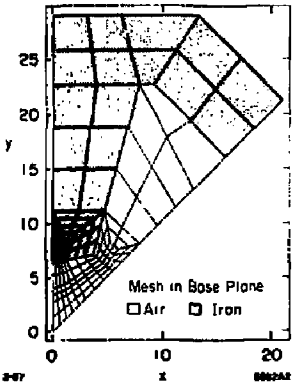

Fig. 2. Finite Element Configuration in the Base Plane.

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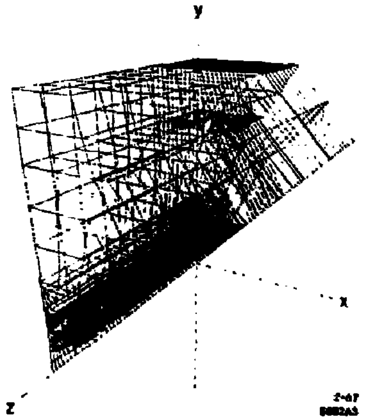

Fig. 3. Finite Element Mesh for one-sixteenth of the Quadrupole.

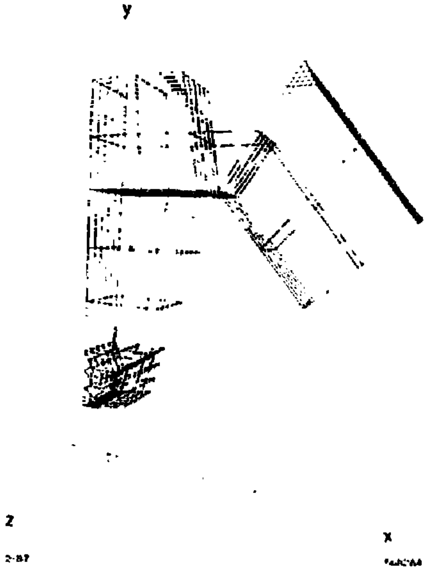

Fig. 4. Finite Element Mesh for Iron Elements Only.

B is about a kilogauss lower. The initial design was done with the more pessimistic table. Later, calculations were repeated with Table 1.

The results for values of the induction, B versus distance along the beamline from the center of the magnet, are shown in Fig. 6. The results for values of the integral of the gradient are shown in Fig. 7 and compared to measurements. The agreement is good when Table 2 is used, and results are more optimistic for Table 1, as one would expect. The magnet was specified to be built with 1010 steel. The agreement is better using Table 2. This has been found to be true also for results from POISSON for long magnets. The strength measurements were made with a long, rotating coil. The axial field distribution shown in Fig. 6 was made with a Hall probe through the magnet from -25.4 centimeters to +25.4 centimeters. The two sets of data reflect a slight error in locating the center of the quadrupole. Also, the points fall slightly below the calculations for Table 2, while the integrated quadrupole component of the calculations agrees closely with the long coil results. We believe that this discrepancy is due to small errors in the radial position of the probe.

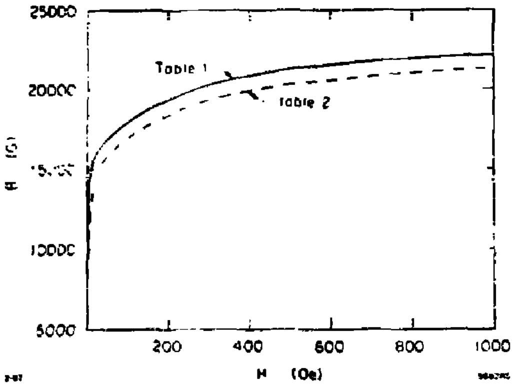

Fig. 5. B-H Tables Used in Calculations.

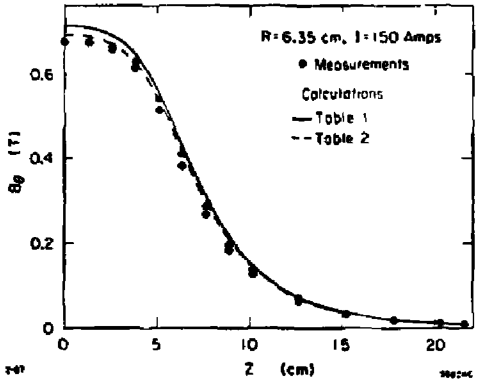

Fig. 6. Measurements and Calculations, B vs. Z

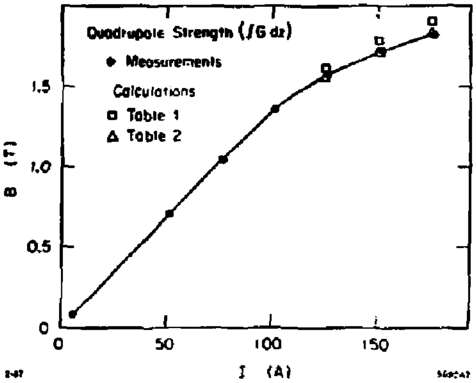

Fig. 7. Measurements and Calculations of Strength.

The results from harmonic analysis are shown in Fig 8. These are quite encouraging. Calculations can only be done for multipole numbers 2, 6, 10, *etc.*, because of the symmetry of the problem. Measurements show additional terms which are due to construction errors. Unfortunately, no axial survey of harmonic content was taken due to scheduling requirements for installing the quadrupole.

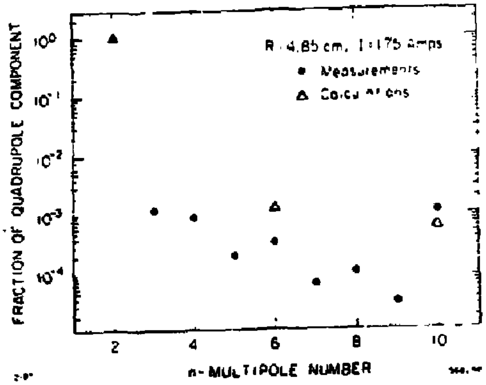

Fig. 8. Integrated Harmonics.

Acknowledgements

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