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TOSCA CALCULATIONS AND MEASUREMENTS FOR THE SLAC SLC DAMPING RING DIPOLE MAGNET*

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1. INTRODUCTION

The SLAC damping ring dipole magnet was originally designed with removable nose pieces at the ends. Recently, a set of magnetic measurements was taken of the vertical component of induction along the center of the magnet for four different pole-end configurations and several current settings. The three dimensional computer code TOSCA[1], which is currently installed on the National Magnetic Fusion Energy Computer Center's Cray X-MP, was used to compute field values for the four configurations at current settings near saturation. Comparisons were made for magnetic induction as well as effective magnetic lengths for the different configurations.

2. MAGNET DESCRIPTION

The magnet is a standard H-magnet with two symmetric bedstead-shaped coils of 48 turns each, as shown in Fig. 1. The pole-end configurations are shown in Fig. 2. They consist of a 90 degree blunt end, and a 70 degree end (actually 69.33 degrees) with a 1 centimeter radius at the edge. The 70 degree end-piece was machined to three different lengths.

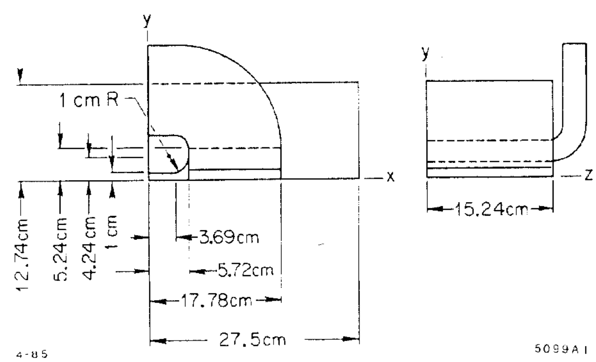

Fig. 1. Octant of the Damping Ring Dipole

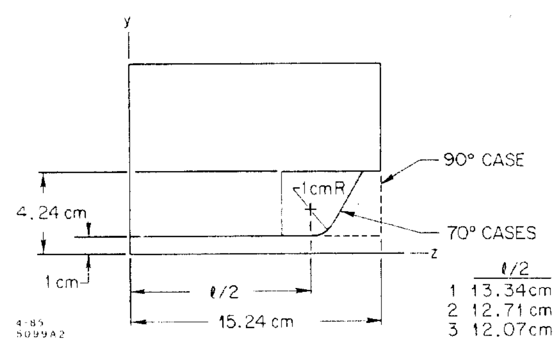

Fig. 2. Pole end Configurations

3. MEASUREMENTS

All of the magnetic measurements were made using a commercially available Hall probe digital gaussmeter, set up on a precision lead-screw drive so that the probe could be moved along the longitudinal axis from −33 centimeters to +33 centimeters, with the center of the magnet as the origin. This lead-screw was driven by a Slo-syn stepping motor which was controlled by the data acquisition system computer to move the probe in one centimeter steps, then read the gaussmeter. The measurement accuracy was approximately ±0.1% for the gaussmeter readings. The excitation current for the measurements was extremely stable during the measurements, varying no more than ±0.01% during a data run. The various configurations were measured at four different excitation values each, but here we are only comparing the runs at an excitation of approximately 450 amperes.

4. TOSCA CALCULATIONS

The object of the TOSCA calculations was to determine whether the code could be used to predict the effective length of a dipole magnet using a reasonable number of nodes and within a reasonable running time. There were further questions such as whether it could predict the effects of small changes in geometry. The limit on the NMFECC Cray X-MP was 15,000 nodes. We achieved sufficient accuracy for our purposes with about 10,000 nodes, using smaller elements in the regions where the field was changing most rapidly. The elements used in the pole-end regions were 0.5 centimeter cubes, which is one quarter of the gap. Elongated hexahedrons were used in regions greater than five half-gaps from the pole-ends. Running times for the TOSCA step of the program were in the range of 30 to 40 minutes on the Cray X-MP, but the code had not been optimized.

The finite-element mesh extended from 0 to 40 centimeters in the horizontal direction, 0 to 30 centimeters in the vertical direction (in order to accommodate the bedstead coil), and 0 to 35 centimeters in the axial direction. Figure 3 shows the finite-element mesh for one-eigth of the problem. Figure 4 shows only iron elements. These plots were generated by the pre-processor SCARPIA, which was designed to run interactively, but on this

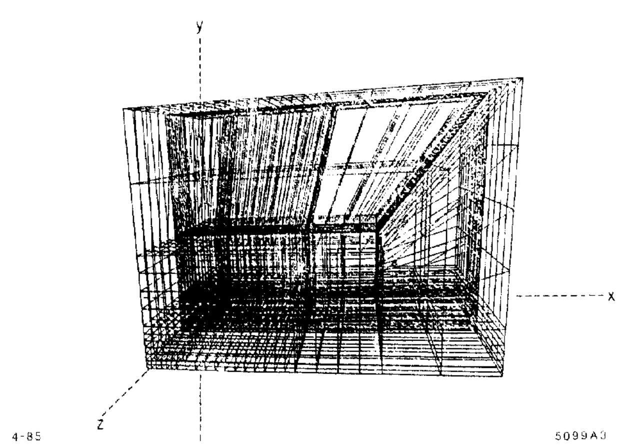

Fig. 3. Finite-element Mesh for One Octant.

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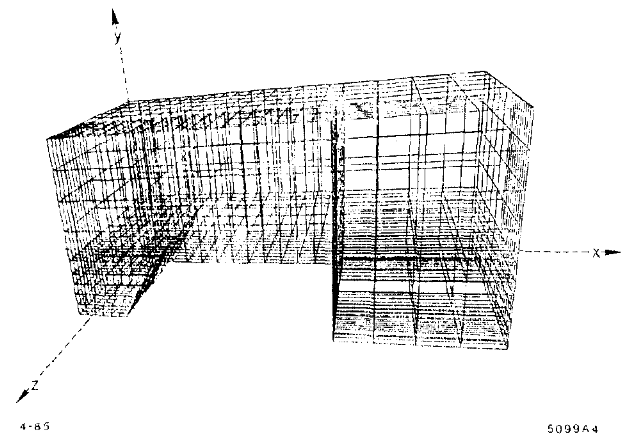

Fig. 4. Finite-element Mesh Showing Only Iron Elements.

system ran too slowly to be of practical use. We used a non-interactive version of SCARPIA devised by Susarla Murty of NMFECC, which accessed a pre-composed input file. This version generated the finite-element mesh in less than two minutes of running time for the 10,000 node problem.

The B-H curve used is shown in Fig. 5. This curve has been used in the SLAC POISSON program for most accelerator magnet designs and gives good agreement for the middle of the magnet in this case. The excitation current used in all cases was 21,539 ampere-turns per pole, which corresponds to 448.731 amperes (48 turns). While this current does not exactly match the excitation currents at which all of the measurements were made, it is at most 0.15% in disagreement, and is completely factored out in the effective-length comparisons. In modeling the pole-ends for the 70 degree cases for TOSCA, the one centimeter edge radius was approximated by a single bevel.

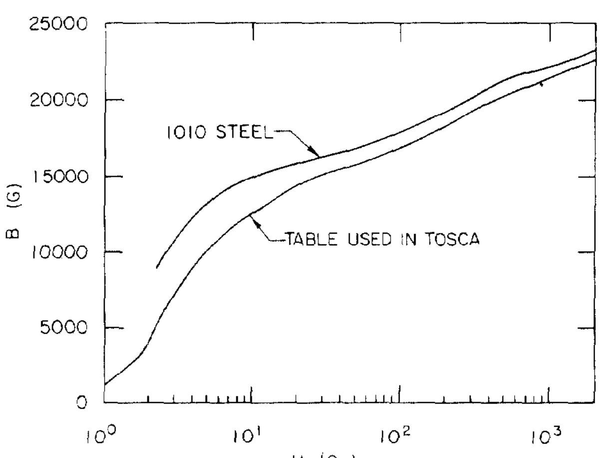

Fig. 5. B vs. H Graph Showing Comparison Between Values Used in the Calculations and that for 1010 Steel.

5. COMPARISONS AND RESULTS

Figures 6 through 10 show comparisons of magnetic induction from measurements and calculations for each of the four cases. These show quite good agreement, especially for the 90 degree pole-end case and the longest of the 70 degree cases. The differences between calculations of TOSCA and measurements are shown in Figs. 11 and 12 for the best and worst cases. From these figures it appears that the TOSCA calculations predict too much induction in the extreme fringe. Test cases have shown that this effect is a function of the distance to the z boundary. Increasing this distance, however, leads to longer running times.

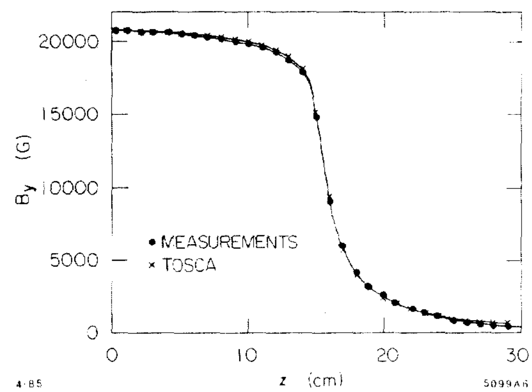

Fig. 6. By (gauss) vs. z(cm) for 90 Degree Case for z Values Between 0 and 30 cm.

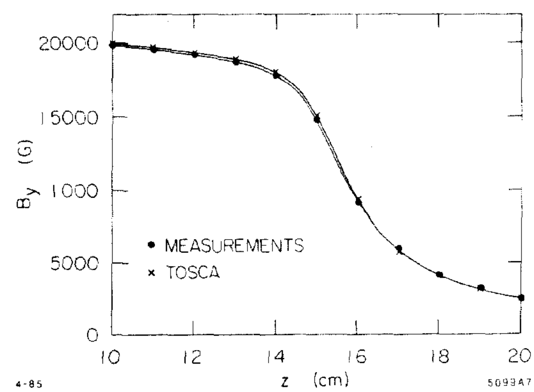

Fig. 7. By (gauss) vs. z(cm) for 90 Degree Case for z Values Between 10 and 20 cm.

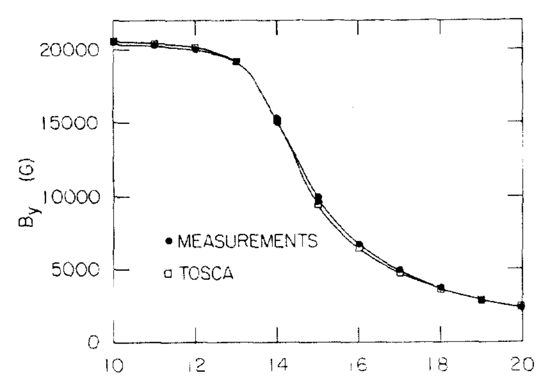

Fig. 8. By (gauss) vs. z(cm) for 70 Degree Case for a Half-length of 13.34 cm and for z Values Between 10 and 20 cm.

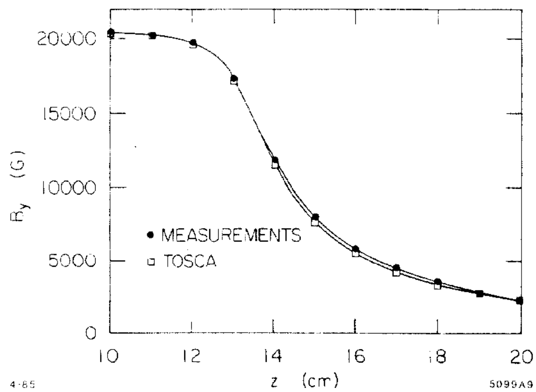

Fig. 9. By (gauss) vs. z(cm) for 70 Degree Case for a Half-length of 12.71 cm and for z Values Between 10 and 20 cm.

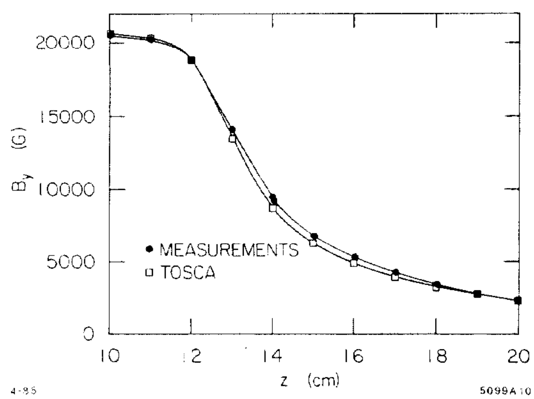

Fig. 10. By (gauss) vs. z(cm) for 70 Degree Case for a Half-length of 12.07 cm and for z Values Between 10 and 20 cm.

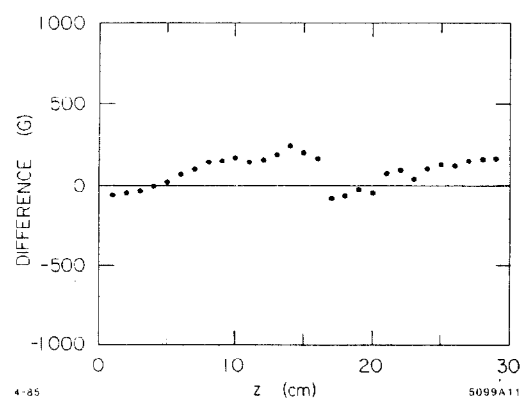

Fig. 11. By(calculated) - By(measured) vs. z for the 90 Degree Case. The Steel Half-length was 15.24 cm.

The results for effective half-length calculations are shown in Tables I and II. The integrations were carried out from the center of the magnet to a distance of 29 centimeters from the center. The measured data was integrated from −29 centimeters to +29 centimeters by a trapezoidal summation, then divided by two for these half-length comparisons. Table I contains comparisons of the magnetic induction lengths, defined as the integral of induction from 0 to 29 centimeters divided by the induction at the magnet center. Since this is a magnet for a damping ring, a quantity of more interest than the magnetic induction length is the length of the magnetic induction squared. Thus, Table II contains comparisons of the squared magnetic induction lengths defined as the integral of

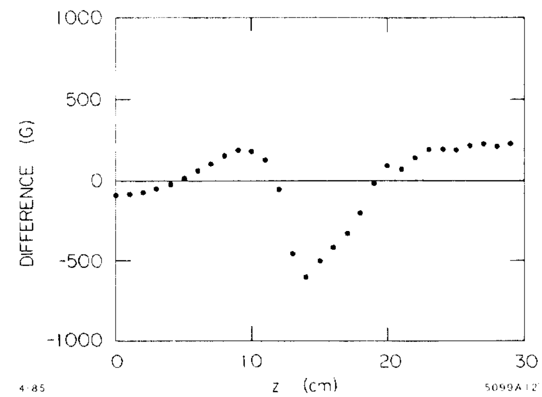

Fig. 12. By(calculated) - By(measured) vs. z for the 70 Degree Case. The Steel Half-length was 12.07 cm.

the squared induction divided by the induction at the magnet center squared.

Table I - Effective B Lengths

Configuration	Half-length from Measurements	Half-length from TOSCA	Difference (Percent)
90 Degree end Steel Half-length = 15.24 cm	16.312 cm	16.469 cm	0.96
70 Degree end Steel Half-length = 13.34 cm	15.838 cm	15.945 cm	0.68
70 Degree end Steel Half-length = 12.71 cm	15.353 cm	15.410 cm	0.37
70 Degree end Steel Half-length = 12.07 cm	14.892 cm	14.932 cm	0.27

Table II - Effective B^2 Lengths

Configuration	Half-length from Measurements	Half-length from TOSCA	Difference (Percent)
90 Degree end Steel Half-length = 15.24 cm	14.370 cm	14.580 cm	1.46
70 Degree end Steel Half-length = 13.34 cm	13.999 cm	14.127 cm	0.92
70 Degree end Steel Half length = 12.71 cm	13.446 cm	13.518 cm	0.54
70 Degree end Steel Half-length = 12.07 cm	12.892 cm	12.965 cm	0.57

REFERENCE

1. A.G.A.M. Armstrong, C. J. Collie, J. Simkin, and C. W. Trowbridge, The Solution of 3D Magnetostatic Problems Using Scalar Potentials, Proceedings of COMPUMAG Conference, Grenoble, 1978.