

Three Dimensional Field Analysis for the AGS Combined Function Magnets

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Abstract

In order to study the particle trajectories in the fringe field of the AGS ring during the single bunch multiple extraction (or fast extraction) from the the AGS to the muon g-2 experiment and to the RHIC, the magnetic field of the AGS combined function magnets were calculated by using the TOSCA program. The results are compared with the field maps of the previous measurements. The particle tracking is achieved by using the TOSCA program post-processor.

I. INTRODUCTION

The design of the AGS new fast extraction beam (NewFEB) system for the g-2 experiment and RHIC injection[1] requires detailed magnetic field knowledge about the AGS main magnets, so that one may predict the trajectories of 29 GeV/c protons in the fringe field region during the extraction (Fig.1). 2d and 3d magnetic field computations have been done by using POISSON and TOSCA programs. Partial results are described in this note. The comparisons between calculated field values and measured field maps show that if one properly handles the TOSCA program, high accuracy can be achieved. Further studies will show that particle tracking by using the post process of the TOSCA program is feasible[2].

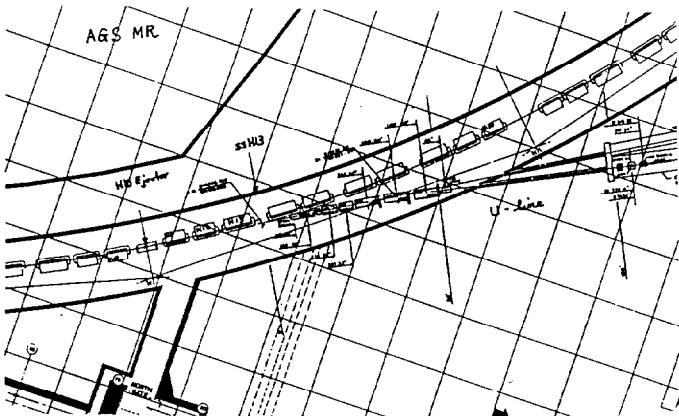


Figure 1: New FEB in AGS

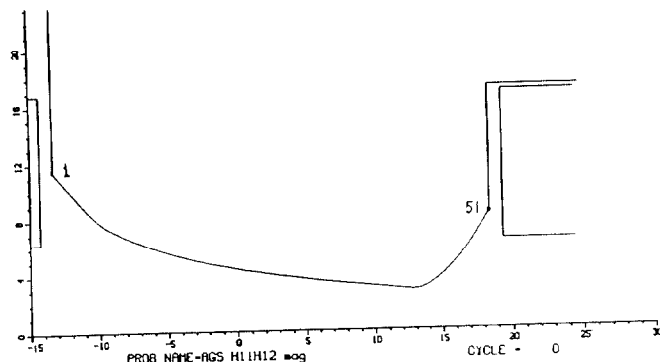


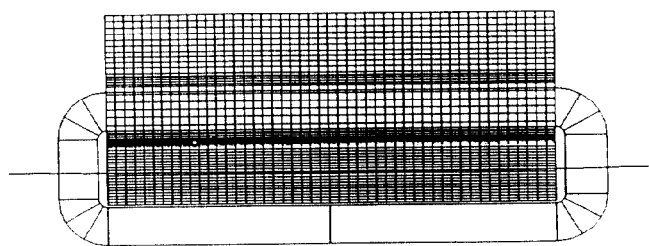
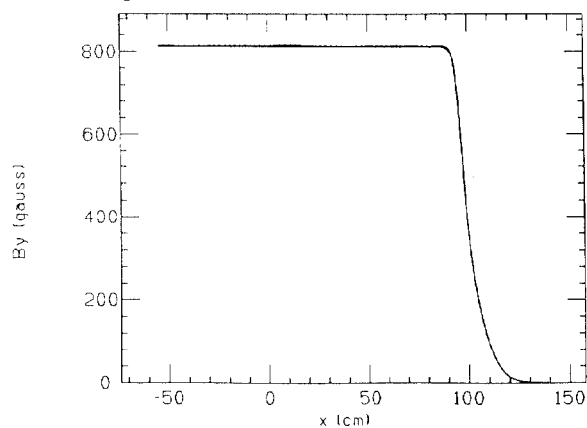
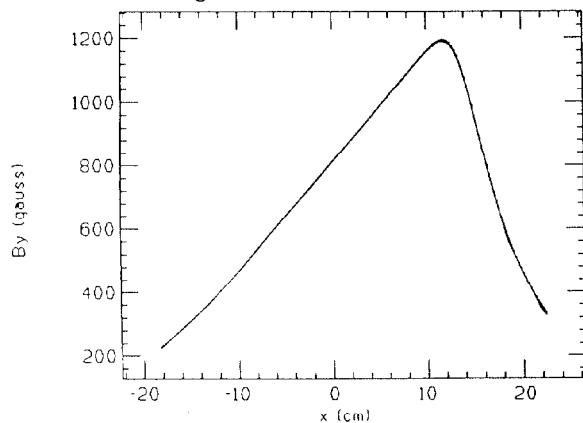
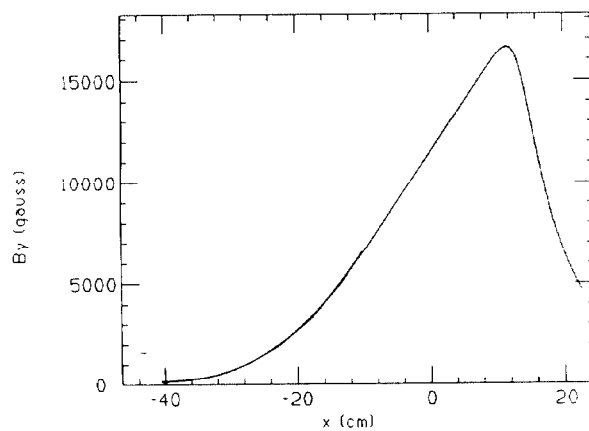
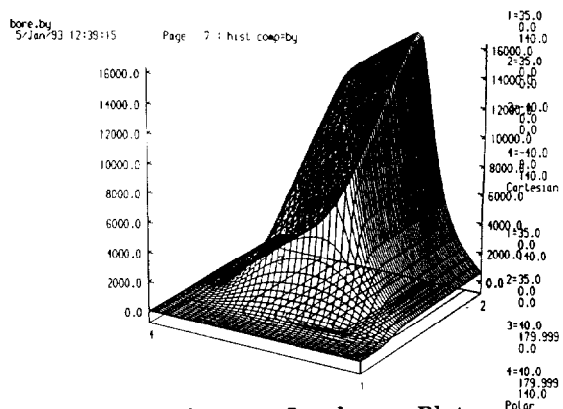
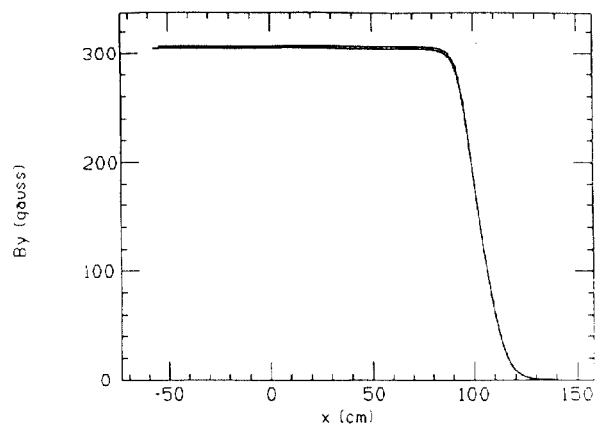
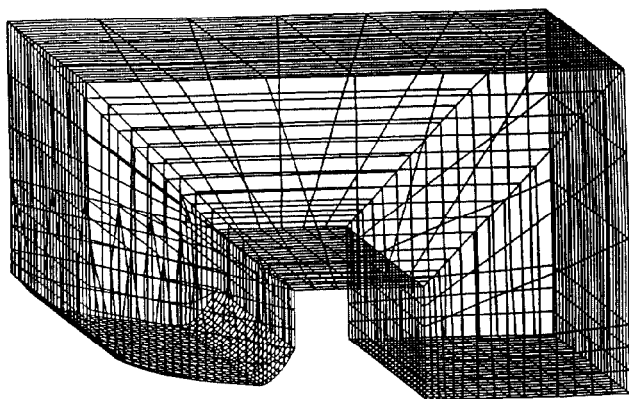
Figure 2: Pole Shape (open type)

II. AGS MAGNETS

The AGS combined function main magnets perform two functions: a) guiding the proton beam into the circle and b) focusing the beam. Each of the 240 magnets around the AGS ring deflects the protons by 1.5 deg, or 360 deg in all, to complete a nearly circular path. The reference circle is 128.46 meter in diameter. The physical length path of the magnets occupies about two thirds or the circumference, the rest being available as straight sections between magnets for other equipment. According to the principle of alternating gradient strong focus, two types of magnets are utilized - "open" type and "closed" type. Figure 2 shows the pole shape of a "open" type[4]. The pole surface of the AGS magnets was well designed many years ago, based on constant magnetic scalar potential surface. The material of the magnets is the Electrical Grade M-36 Steel Laminations, which contains 1.80% silicon and 0.03% carbon. The laminations are insulated from one another by a coating of varnish to inhibit eddy currents. The stacking factor of the laminations is about 0.98[3]. The B-H data used in calculations was based on a measured magnetization curve. It was interpolated in order to ensure the smoothness of its first derivatives and the continuity of its second derivatives.

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III. TOSCA CALCULATIONS



The advent of relatively inexpensive and powerful computers has inspired the development of the large scale three dimensional codes. TOSCA is one of the most well known commercial codes which is widely used in the industry and accelerator field.

Based on the reference [4], a finite element model of one-quarter of the "open" type AGS magnet was constructed. Figure 3 only shows the steel part. The origin of the coordinate system of the TOSCA calculations is in the middle of the magnet and also at the beam center which is 2 inch away from the geometrical center of the pole. The positive x direction is pointing the ring center.

Figure 4 shows the landscape plot of the vertical components of B-field on the median plane, around the edge of the magnet. The base area 1-2-3-4 stands for the part of the median plane. The cartesian and polar coordinates of these four corners are listed on the right side of the figure. The vertical height of the surface stands for the magnitude of the component B_y at particular position on the median plane. On the base area, there is a family of curves which represents the equal-height contours (or constant B_y lines).

Followings are part of the comparisons between the TOSCA results and the measured data.

(a) Compare with the low field measurements:

Measured data file A[5] is the field map with the applied current 2880 ampere per coil. The center field is about 815 gauss, corresponding to 2 GeV/c protons. Figure 5 shows the comparison between the measured data and the calculation, on the median plane, near the center of the magnet. The difference is about 0.6%. Figure 6 shows the comparison along the central beam line; the difference is about 0.7%. Figure 7 shows the comparison in the fringe field region (6 inch away from the center); the difference is about 0.3%.

(b) Compare with the high field measurements:

Measured data file B[5] is the field map of a open type AGS magnet; the applied current is 41000 ampere per coil (5150 ampere per pair), corresponding to 29 GeV/c protons.

Measured data file BF[5] is again the field map of a open type AGS magnet, except it measured only in the fringe field region along the open side of the magnet.

Figure 8 shows the comparison between the above two measured field maps and the TOSCA calculated results. The measured data B covers from $x = 0$ cm to $x = 18$ cm. The difference between this measured data and the calculation is about 0.5%.

The measured data BF covers the region x from -40 cm to 0, along the z axis. It is noticed that near the point $x = -9.14$ cm, the second order derivative shows some discontinuity. Accordingly one may estimate that the measurements error could be about 1.1 %. These possibly arose from relocating the equipment and remaining magnetization in the steel core during the measurements.

IV. DISCUSSIONS

Authors like to comment the TOSCA program and computations on the following points.

(a) Time Consumption. The time cost for constructing the finite element model depends on the problem size, complexity and the experience of the user. The computer CPU time has reduced tremendously since softwares are available on the UNIX machine (IBM RISC System). Generally speaking, to obtain a field map with a reasonable accuracy, it takes less man power by using TOSCA program than by carrying out a measurement. Nevertheless measurements are always indispensable, since it is the most important way to examine the computed results, as long as the magnet is existing and accessible.

(b) The Accuracy of the TOSCA program. The local error at a field point is determined by (1) the size of the elements surrounding the point; (2) the types of these elements (linear or quadratic); (3) the method required to calculate the field value from the potential array (differentiation of shape function, interpolation of nodal averaged values, or integration of magnetization and currents); (4) the far boundary conditions and the potential types. From first glance, one could say that the accuracy is strongly linked to the size of the elements which is limited by the capacity of the program, but this is not the only factor. By making correct choices from factors (2), (3) and (4), reasonably high accuracy is achievable. According to the results presented in this note, the error of the TOSCA computation is within the error of the measurements.

The TOSCA output file contains the complete information of the magnetic field, and its post-processor is capable of performing particle trackings. Figure 9 shows an example of 29 GeV proton trajectory in an AGS open type magnet. Further studies about the beam tracking in the fringe field region will be carried out.

V. ACKNOWLEDGMENT

Authors appreciate the AGS initiator G. Danby for his instructive guidance and discussion.

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VI. REFERENCES

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- [2] W. Meng and M. Tanaka, to be published.
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File A=AGBU01.MPA; File B=B5150A.MPA; File C=A5150A.MPA.