COMPARISON OF COMPUTER PREDICTIONS AND MAGNETIC FIELD MEASUREMENTS FOR AN IRON SPECTROMETER MAGNET*

G.T. Danby, J.W. Jackson, W. Meng, C. Spataro
AGS Department, Brookhaven National Laboratory
Associated Universities, Inc.
Upton, New York 11973

Abstract

Three dimensional computer calculations using the Program TOSCA have been made for a complex-shaped iron magnet. Precision field measurements were made on this magnet in preparation for its installation in a new Low Energy Separated Beam for the post-Booster high proton intensity AGS at Brookhaven National Laboratory. Point-by-point direct comparisons for field values will be described encompassing the entire useful acceptance. The predictability of higher order multipoles will be described, including the region of the magnet ends. Computer predicted focal properties will be compared with results of experimental data analysis. The method of measurement and analysis, as well as comments on the computer calculations will be described. Conclusions will be drawn on the accuracy of calculations with respect to higher order moments and the impact on future beam optical design and execution of three dimensional computer codes.

I. DESCRIPTION OF MAGNET

The sector magnet for the LESBIII is shown in Fig. 1. Following the target two quadrupoles form the beam which then enters the sector magnet and is bent through 44.1 degrees. An electrostatic separator follows the sector magnet. The LESBIII, which operates up to 800 MeV/c in momentum, traverses the sector magnet as a parallel beam in the vertical plane and almost parallel in the horizontal plane. Protons which survive the target and two secondary beams are of much higher momentum, so are only deflected slightly by the straight away portion of the sector magnet. Thus the straight away portion has parallel pole edges for the upstream and downstream ends. (See Fig. 1.) The magnet gap is 6 inches and the length of the pole tips in the forward direction is 48 inches.

II. METHOD OF MAGNETIC MEASUREMENTS.

Point-like search coils were mounted on a moveable trolley. A straight track was used in the forward direction. A curved track which traversed 44.1 degrees with the same radius of curvature as the LESBIII central ray was used for the LESB portion of the field.

Both the straight track and the 44.1 degree track were displaced horizontally to map the entire acceptance of both beams. For the 44.1 degree beam, data was also taken with the straight track normal to the pole end faces and displaced sideways. With the combination of data the basic and dominant pole edge fringe field can be well described and small discrepancies between mechanical and magnetic lengths can be removed from the ray traces.

Beyond the pole tip ends, both tracks extended outward through the fringe fields in a direction normal to the pole edge face. Hall probe measurements were used to supplement the search coil measurements in the far fringing fields.

NMR was used at the center of the magnet to normalize the search coil signal to absolute Gauss. All data was taken on a down cycle, starting from a few percent above the highest nominal field to minimize magnetization effects.

The field was recorded at a very large number of linearly encoded longitudinal positions. The field was substantially known everywhere relevant in the magnet at a variety of central field values.

III. COMPUTER PREDICTIONS VERSUS MAGNETIC FIELD MEASUREMENTS.

The requirements for extensive field mapping provided an excellent opportunity to check the precision of computed fields. Calculations were made on TOSCA using mechanical data for the iron and coil geometry and a nominal 1006 permeability table. Figure 2 shows the measured field, passing entirely through the magnet, at the center of the 0 degree forward beam. Superimposed is the TOSCA generated field. At the level of visual inspection, i.e. about 1%, the results including the fringing fields are indistinguishable. Thus the horizontal deflection and vertical edge focusing will be very well predicted by TOSCA. Note that the central field normalization is done based on measurements, since the computations do not include magnetization. However beam optical properties do not depend on absolute magnitudes to high precision in most cases.

Figure 3 shows a point-by-point difference between the measured and computed fields, again for the zero degree central ray.

Figure 4 shows an azimuthal first difference between adjacent measured points. Note the near identity of the first difference on both ends: the peak amplitude and the width at half maximum. Also note the flatness over more than half of the magnetic length. Furthermore, the point-to-point jitter in the data due to either positional error or field measurement error is at the 1×10^{-4} level of field.

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Referring back to Fig. 3, we must conclude that the differences are mainly due to errors in the computed fields. The antisymmetric parts of the peaks at -50 cm and +50 cm could be simply due to a displacement of the Z=0 of the experiment compared to TOSCA. In other words, any Z=0 displacement will qualitatively look like Fig. 4.

Note in Fig. 3 that on either side of Z=0 there is a lack of flatness, at the few parts in 10^3 level, which must be in the TOSCA results. Also the peaks which approach greater than 1% difference, do not occur at the regions of the maximum slope of Fig. 2. This indicates slight errors in prediction, not Z displacement.

Figure 5 shows the experimental field measured along the central ray of the 44.1 degree LESBIII beam. Figure 6 shows the first difference in the direction of the beam of the measured field data. As was seen from Fig. 4, the smoothness of the data shows the measurements are of high accuracy. Note in Fig. 6, the differences are expressed per inch of displacement, whereas in Fig. 4 the differences were per .050 inches. Thus the amplitude of the first difference is 20 times bigger at the peaks in Fig. 6 compared to Fig. 4. The upstream peak is otherwise the same in both cases, since the upstream end is common to both the 0 degree and the 44.1 degree beams. Again, the downstream peak at 44.1 degrees is almost identical to the upstream peak, indicating the magnet has essentially the same fringing field shape entering and leaving both beams. This result strengthens the interpretation that errors in the measured field data are not responsible for the differences seen in Fig. 3.

Table I lists for the 0 degree beam central ray (x=0) and at several parallel displaced lines the measured and computed field integral. The calculated field at the magnet center was normalized to the experimental value, so the differences are due to differences in relative field shape along the length of the magnet, including ends.

The last column indicates TOSCA agrees with experiment to about 1/3 percent discrepancy. The last column is identical to an integration over Z of the point-by-point differences in Fig. 3. The first column shows the measured field is quite uniform inside the magnet.

IV. DISCUSSION

1. Figure 2 shows the agreement of field shape between TOSCA and experiment azimuthally through the magnet is good enough to very well predict horizontal deflection except for the most exacting precision requirements.
2. The vertical or wedge focusing should also be predicted quite well, since the field shape in the rapidly changing end region is quite close to experiment and the vertical focus end impulse is not very sensitive to exact details.
3. Transverse nonlinearities in the horizontal and vertical planes, based on these limited results, may not be adequately known for high precision beams from TOSCA alone.
4. The large body of measurement data that exists on this and other spectrometers will permit further studies of computer predictions of aberrations.
5. It is clear that even at the level demonstrated by these early comparisons, TOSCA does a very good job.

Acknowledgement

The magnet was built under the direction of W. Leonhardt of BNL. Members of the first experimental collaboration to use the beam were responsible for the design. (Private communication from A. Otter of TRIUMF.)

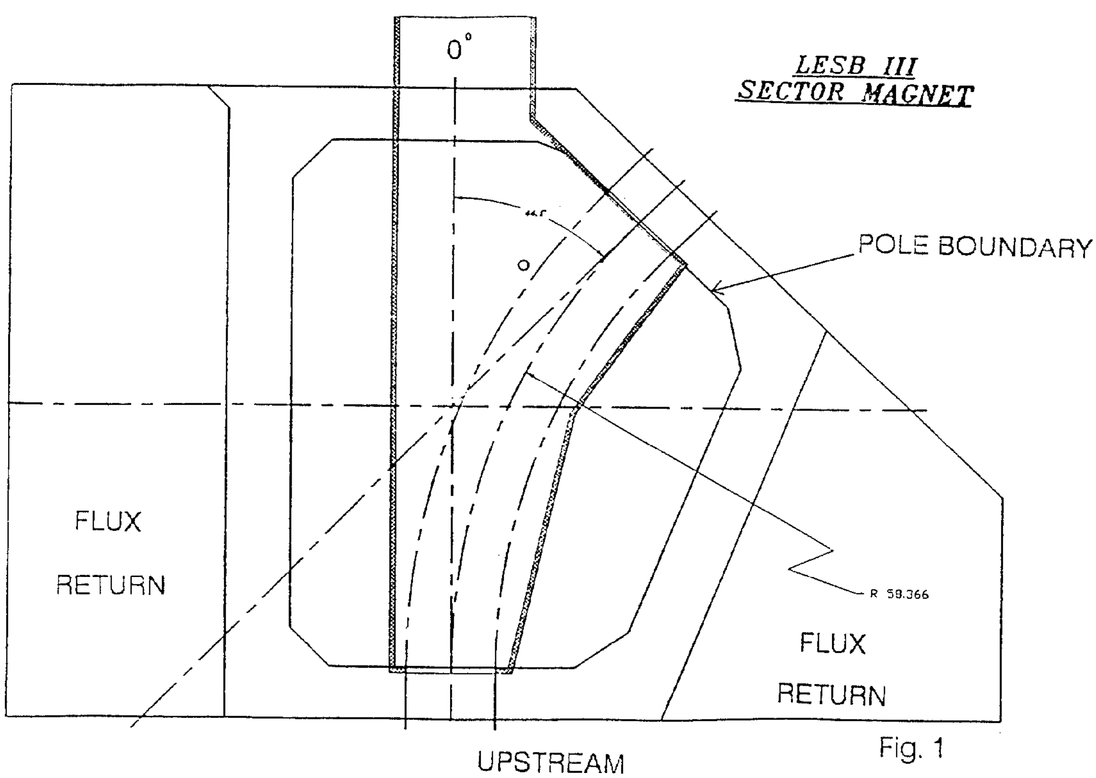

Fig. 1

D1 ZERO DEGREE CENTRAL RAY AZIMUTHAL FIELD
MEASURED FIELD AND TOSCA PREDICTED FIELD

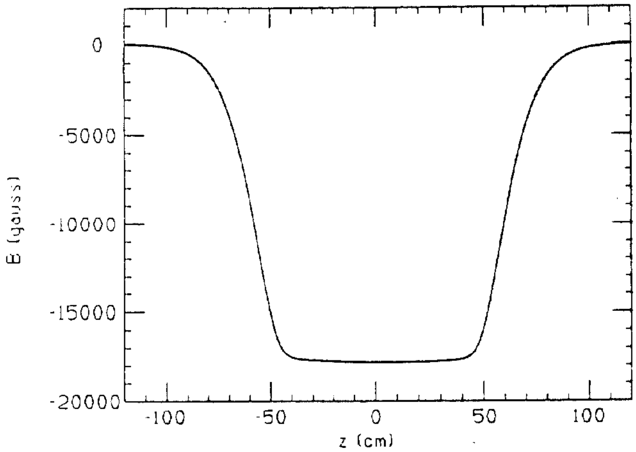

Fig. 2

D1 44.1 DEGREE CENTRAL RAY
EXPERIMENTAL DATA

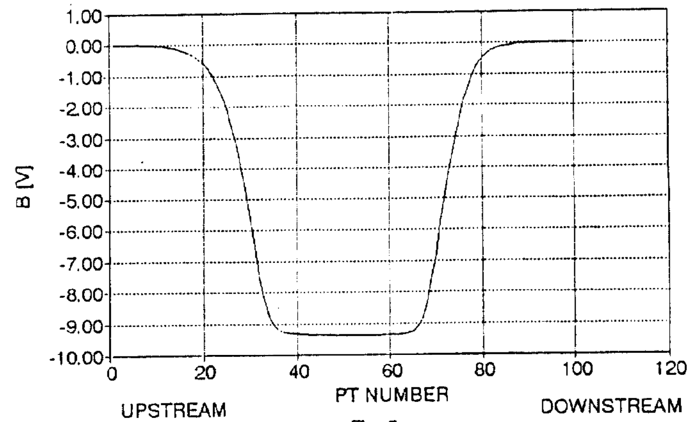

Fig. 5

D1 ZERO DEGREE CENTRAL RAY
TOSCA - EXPERIMENTAL B AS FUNCTION OF Z

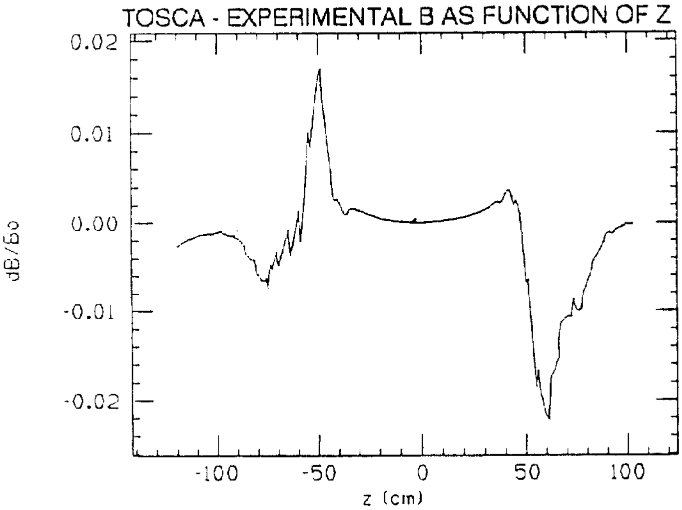

Fig. 3

D1 44.1 DEGREE CENTRAL RAY EXPERIMENTAL DATA
1ST DIFFERENCE PER Z=1.0"

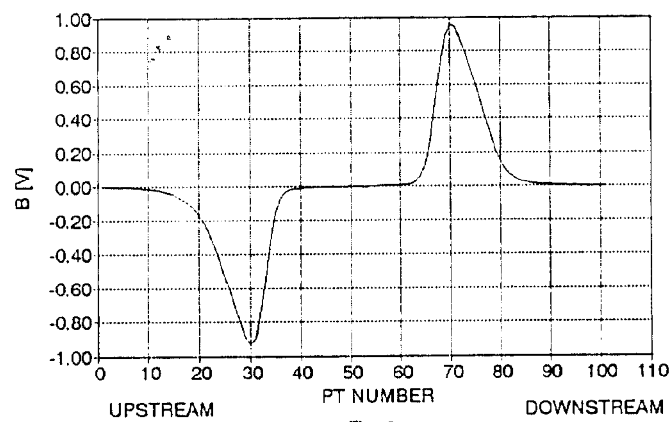

Fig. 6

D1 ZERO DEGREE EXPERIMENTAL DATA
[1ST DIFFERENCE PER Z=0.050"]

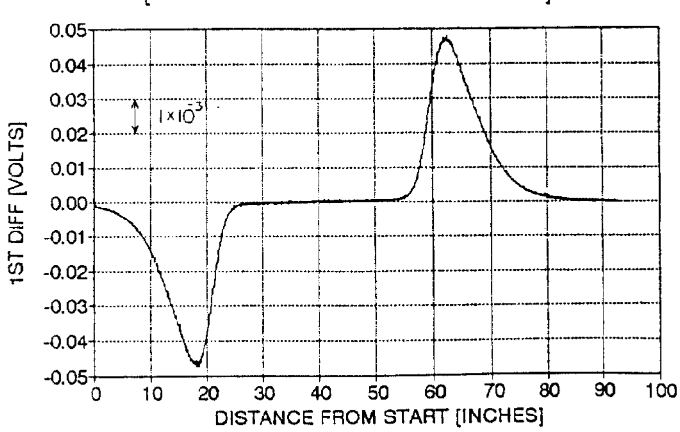

Fig. 4

TABLE I
TOSCA VS LESBIII EXPERIMENTAL DATA

$$\textit{Normalized} \int_{Z=-120\ cm}^{Z=+102\ cm} \textit{Comparison}$$

B_{point} vs x. [z=0]	Integral Path	Tosca Cal. (G-cm)	Measurements (G-cm)	Diff. $\Delta\int Bdz$ / $\int Bdz$
1.0000	x = 0	-2227288	-2221776	0.0025
1.0004	x= -5"	-2219944	-2211879	0.0036
	x=-5.5"	-2216182	-2208336	0.0035
1.0002	x=-6"	-2210865	-2204136	0.0030
0.9998	x=-7"	-2198551	-2191179	0.0033