DESIGN AND B-FIELD MEASUREMENTS OF A LAMBERTSON INJECTION MAGNET FOR THE RHIC MACHINE[*]

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Two Lambertson-type injection magnets have been designed, constructed and tested magnetically. One magnet is the mirror image of the other and each will serve as an injector in the rings of the Relativistic Heavy Ion Collider (RHIC) accelerators under construction at Brookhaven National Laboratory (BNL). To obtain the required field quality in the injected beam region and low stray fields in the circulating beam region of the magnet, an optimization study was performed using computer codes to provide solutions for a two and three dimensional model of the magnet. The calculations are compared to the magnetic field measurements taken in the injected and circulating beam regions mentioned above. Field inhomogeneities in the injected beam region were less than 6×10^{-4} for either measured or calculated B-fields. The magnetic-field strength in the circulating beam region was less than 0.1 Gauss (measured or calculated). A description of the mechanical design of the magnet as well as a detailed comparison of the measured magnetic fields to those calculated using the two and three dimensional computer codes is presented here.

I. INTRODUCTION

The Lambertson injection magnet which will be described in this paper is the last magnetic element of the beam transfer line between the Alternating Gradient Synchrotron (AGS) and RHIC accelerators at BNL. Two such magnets have been constructed, each of which will inject into the counter circulating beam-rings of the RHIC machine. Since each magnet is the mirror image of the other, we will only describe the magnet which injects into the counterclockwise circulating beam-ring of RHIC.

II. GEOMETRY and DESIGN PARAMETERS

The relative location of the magnet with respect to the straight section of the RHIC ring is shown in Fig. 1a (top view), 1b (side view), and 1c (view looking upstream).

Fig. 1a shows the injected beam at the entrance of the magnet which will bend by ~38 mrad and will then continue at the exit of the magnet on the same vertical plane as the RHIC circulating beam.
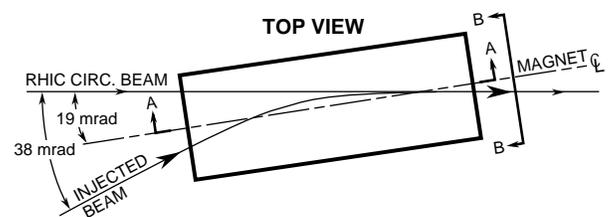
Figure 1a.
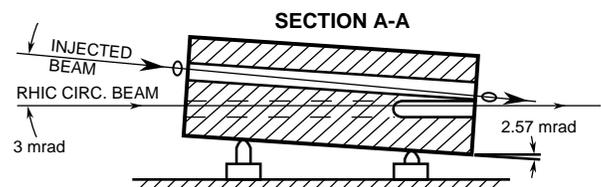
Figure 1b.
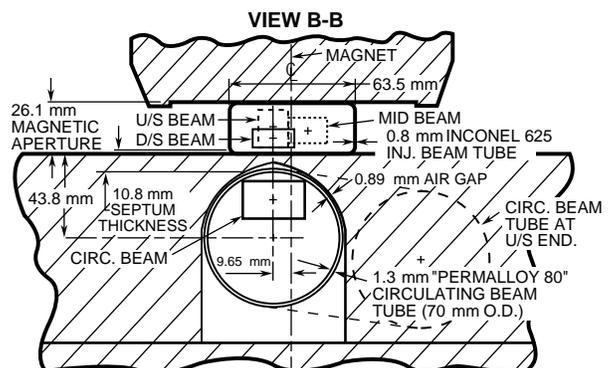
Figure 1c.

A cross section of the magnet by a vertical plane containing the symmetry axis (AA) of the magnet is shown in Fig. 1b. In this figure, the central ray of the injected beam makes an angle of ~3 mrad with the central ray of the RHIC circulating beam. Beam size considerations at the entrance and exit of the magnet for both the injected and circulating beams dictated that the surface of the bottom pole of the magnet make an angle of ~2.57 mrad with the central ray of the circulating beam, and ~2.24 mrad with the axis of the circulating beam pipe. This geometry helps minimize the septum thickness of the magnet, which is 10.8 mm as seen in Fig. 1c.

Fig. 1c, a view of the magnet looking upstream shows the injected and circulating tube sizes, wall thickness, and their relative locations. There is a ~0.89 mm air space between the circulating beam tube and the magnet iron. The locations of the beam at the upstream (U/S) and downstream (D/S) ends of the magnet is also shown.

The design parameters of the magnet, which appear below and in Figs. 1a through 1c were determined from optimization calculations, taking into account the geometry of the injection region the magnetic properties of the magnet steel and permalloy-80 pipe, and the maximum field at the beam injection gap, which in turn was determined by the field requirements in the injection and circulating beam regions.

Magnet design parameters
1. Length = 4 m
2. Bend angle = 38 mrad @ B.ρ=100 T.m
3. Magnet gap = 26.1 mm
4. Inner diam. of circulating beam tube = 67 mm
   Wall thickness = 1.3 mm

III. MECHANICAL DESIGN

Details of the mechanical design of the magnet as well as the magnetic properties of the steel and the high permeability of the circulating beam tube appear in Ref. 1.

IV. MAGNETIC FIELDS (CALCULATIONS and MEASUREMENTS)

The magnetic field calculations were performed using the computer code OPERA of VECTOR FIELDS Inc. (Ref. 2) and were separated into two parts: first in the calculations of the fields well inside the magnet where the 2-D version of the code was used, and second, the calculations of the fields at the entrance and exit of the magnet where the 3-D version of the code was used.

A) Two Dimensional Calculations.

The 2-D calculations were performed in order to determine the minimum septum thickness (minimum distance of the RHIC beam pipe from the lower magnetic pole of the magnet) and the maximum radius of the circulating beam pipe, which will keep stray fields in the circulated beam region at values of less than 1 Gauss, and field uniformity in the injected beam region of $\Delta B/B \leq 6 \times 10^{-4}$. One of the cross sections of the magnet where 2-D calculations were performed is shown in Fig. 2 and corresponds to the middle of the magnet.
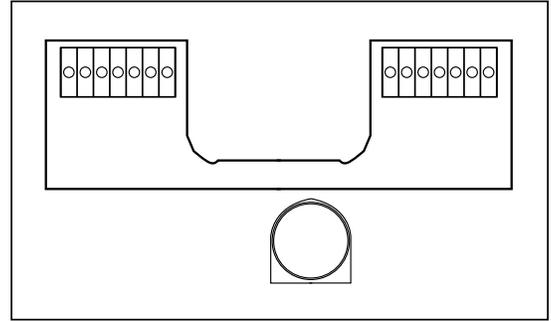
Figure 2.

Because of the ~3 mrad vertical slope of the magnet axis with respect to the horizontal plane (Fig. 1b), the septum thickness along the magnet varies and is at a minimum at the exit of the magnet. For this reason we performed the 2-D calculations on a cross-section at the exit of the magnet and subsequently verified that the optimum 2-D solution at the exit of the magnet also satisfies the B-field requirements mentioned above at any other cross-section of the magnet. The permeability of the magnet's iron and that of the permalloy-80 tube used in the calculations were equivalent to C1006 steel, and to μ-metal respectively.

The results of an optimized solution for a cross section at the middle of the magnet and at an excitation current corresponding to a 38 mrad bend of a 100 Tm rigid beam are as follows: In the injected beam region the calculated field uniformity is $\Delta B/B \leq 6 \times 10^{-4}$ and is computed over the area covered by 95% of the injected beam. The measured field uniformity is $\Delta B/B = (5.0 \pm 0.5) \times 10^{-4}$.

The measurements of the field uniformity in the injected beam region, were performed with a 30" long rotating coil of radius=1 cm. The axis of the measuring coil was parallel to the center axis (AA) (Fig. 1a) and at ~1.2 cm above the bottom surface of the magnet's gap and the coil was inserted well inside the magnet gap and away from the fringe field region. The measurements were performed at three locations inside the magnet with the axis of the coil placed (-1, 0 and +1 cm) away from the (AA) symmetry axis of the magnet.

The measurements of the B field (for the same excitation current as above) in the circulating beam region were made by placing the 30" long coil well inside the circulating beam tube with its axis parallel to, and 1.8 cm above, the circulating beam tube axis. The measured field value was (0.04 ± 0.01) Gauss. The corresponding calculated

value of the B-field was 0.055 Gauss.

In order to demonstrate the effect of the high permeability material of the circulating beam tube, the 2-D calculations above were repeated on the same cross section (at the middle of the magnet), except this time the circulating beam tube was made of the same material as the magnet and the air space between the tube and the magnet was filled with the same material as the magnet. The results of the calculated B field at the same location inside the circulating beam tube as above was 7.5 Gauss, which is two orders of magnitude higher as compared to the corresponding field of 0.055 Gauss when the permalloy-80 tube is in place.

B) Three Dimensional Calculations

The 3-D calculations were necessary to help us design the entrance and exit regions of the magnet in order to minimize the fringe fields in the circulating beam tube at the entrance and exit of the magnet. An isometric schematic plot of the entrance and exit regions of the magnet with the magnet coil and the field clamps is shown in Fig. 3.
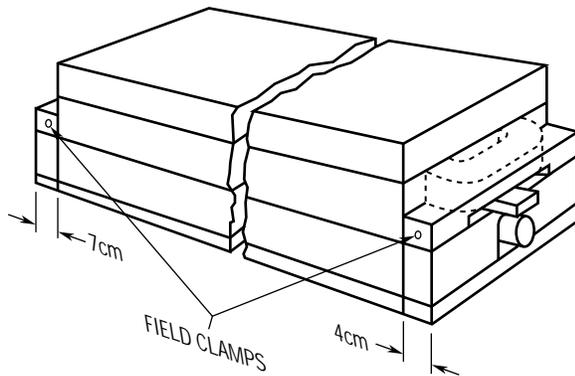
Figure 3.

The lower pole piece of the magnet was extended by 7 cm at the entrance and 4 cm at the exit beyond the edge of the top pole piece of the magnet (Fig. 3) to reduce the fringe field at the circulating beam region. The field clamps also shown in Fig. 3 were placed at the entrance and exit of the magnet to further reduce the fringe field inside the circulating beam pipe.

The calculated cumulative effect of the B_y (vertical) component of the fringe field inside the circulating beam region on a 100 Tm rigid beam is equivalent to 0.4 µrad bend when the extensions of the lower magnetic poles and the field clamps are in place. The experimental measurements of the corresponding field integral inside the circulating beam pipe were done with a 4.946 m long coil which was placed inside the circulating beam pipe with end of the coil extending well beyond the

fringe field region of the magnet. From these measurements a beam bend of (0.8 ± 0.1) µrad was calculated. This value is in good agreement with the calculated value of 0.4 µrad.

In order to demonstrate the effect of the extensions and field clamps mentioned above, we performed 3D calculations on the same magnet with the extensions and field clamps removed. The calculated fringe field integral of the B_y component of the field in the circulating beam pipe, with the extensions and the field clamps removed, yields a bending angle of 75 µrad on a 100 Tm rigid beam.

A plot of the calculated B_y component of the field inside the circulating beam pipe at the exit of the magnet from -10 cm inside the magnet to 40 cm outside, (with the extensions and field clamps removed), is shown in Fig. 4. The high fields (~ 1000 Gauss) and high field gradients shown in Fig. 4 were reduced by a factor greater than 1000 with the use of extensions and field clamps. This reduction of the fringe field is shown in Fig. 5 of Ref. 1. This figure is a view of a 3-D plot of the B_y component of the fringe field in the region of the circulating beam pipe of the magnet, with extensions and field clamps in place.
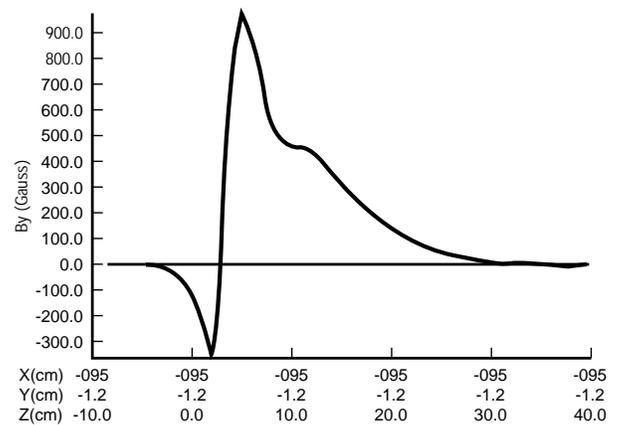
Figure 4

V. REFERENCES

[1] Design of a Lambertson injection magnet for the RHIC machine. E. Rodger, N. Tsoupas, J. Claus, H.W. Foelsche. BNL PAC Washington DC May 17-20 1993.

[2] Vector Fields Inc.