

DESIGN OF A LAMBERTSON INJECTION MAGNET FOR THE RHIC MACHINE*

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Abstract

A Lambertson magnet has been designed to serve as an injector into the Relativistic Heavy Ion Collider (RHIC) under construction at Brookhaven National Laboratory. The design is predicted to achieve field uniformity of $DB/B < 6 \times 10^{-4}$ at $B_0 = 9.5$ KG transverse to the beam direction over the width of the beam path and stray fields in RHIC's circulating beam pipe of less than 0.2 Gauss. In addition, the magnet is ultra-high vacuum compatible in that only the insides of the beam tubes are exposed to the vacuum and the entire assembly is bakeable in situ to 300°C.

I. INTRODUCTION

The injection Lambertson magnets described herein will be the last elements in the beam transfer line between the Alternating Gradient Synchrotron (AGS) and the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. They are designed to deflect the injected beam onto a path horizontally parallel to the circulating beam. Two such magnets will be used, each one injecting into one of the counter circulating beams of the RHIC machine. The two magnets will be identical magnetically, but will be physical mirror images of each other.

II. DESIGN PARAMETERS

Extensive parametric studies arrived at the following design parameters.

1. Bend angle = 38 mrad @ $B\rho = 100$ T·M/rad
2. Length = 4 M ($B_0 = 9.5$ kG)
3. Field non-uniformity < 6 parts in 10^4 over beam path
4. Stray fields < 0.2 Gauss
5. Vacuum level $< 1 \times 10^{-10}$ Torr
6. 26.1 mm vertical aperture
7. 67 mm i.d. circulating beam tube

III. MECHANICAL DESIGN

a. Slab Construction

A major consideration from the start was to operate the injection magnet in series (d.c.) with the transfer line dipole

*Work performed under the auspices of the U.S. Department of Energy.

magnets, thus saving the cost of a separate large power supply. This and the fact, as mentioned in the preceding section, that the geometry changes along the magnet, made laminated construction unnecessary and impractical.

b. Steel Characteristics

Two and three-dimensional computer modeling showed that the design parameters could be met and exceeded by fabricating the magnet body out of an ultra-low carbon ($< 0.005\%$) steel in the unannealed condition. The material (called "INTRAK" [1]) is available in large slabs and can be machined without significantly altering the magnetic properties.

c. Beam Tube Materials

The material for the circulating beam is critical as it serves a number of functions. First, it must be ultra-high vacuum compatible, which means prefiring at a temperature of at least 950°C in a vacuum of at least 1×10^{-5} Torr and should be corrosion-free like stainless steel. In addition, it serves a vital magnetic shielding function. The tube is spaced from the surrounding ultra-low carbon steel by a 1 mm air gap and intercepts leakage fields. For this function, it must have high permeability at low field levels. It must also have sufficient physical strength to resist the vacuum loads with a relatively thin wall. Finally, it helps if the thermal coefficient of expansion is close to that of the magnet body. These conditions are all met by a material called "Permalloy 80" [2]. To reach the required annealed condition, it must be heated to 1150°C after fabrication. This also serves as the vacuum firing.

The injection tube material selected is Inconel 625. It is completely non-magnetic, has good vacuum and thermal expansion properties, and has high stiffness and yield strength to resist vacuum loading. Both the beam tubes can be welded into the common stainless steel downstream chamber (see Figure 1).

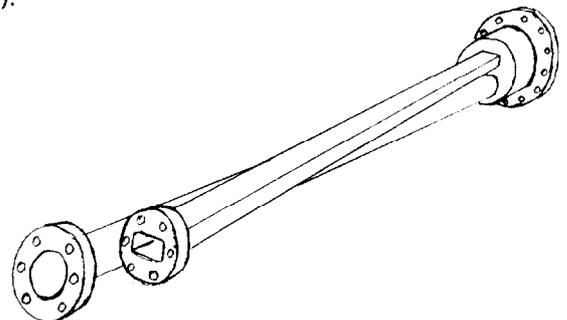


Figure 1.

d. *Bakeout*

Because of the difficulty of trying to heat the injection tube (which is in intimate contact with the poles) independently of the magnet, it was decided to heat the entire magnet. The coil was thermally insulated from the core and is water cooled during bakeout. A covering heater blanket of 20 kW will heat the assembly to 250°C in 12 hours.

e. *Vertical Motion*

During injection, the magnet must be positioned so that the circulating beam almost touches the upper inside surface of the circulating beam tube. This condition represents an aperture restriction for the RHIC machine during the subsequent operating cycle. To solve this problem, provision has been made to raise the entire magnet, after injection, so that the center lines of the circulating beam tube and the circulating beam coincide. This is to be accomplished to an accuracy of ± 0.1 mm by coupling the three support jacks to a common motor with suitable position feedback and limit switches.

IV. MAGNETIC DESIGN AND PERFORMANCE

The magnetic calculations were separated into two parts. First, the aperture field uniformity and stray fields well within the magnet were modeled in two dimensions using the PE2D code [3]. Next, the field behavior and stray field level within the circulating beam tube near the exit and entrance of the magnet were modeled using the TOSKA [3] three-dimensional code. The two-dimensional study had two purposes. The first was to verify a magnetic field uniformity of $DB/B < 6 \times 10^{-4}$ transverse to beam direction over the entire beam path, and second, to show that the stray fields inside the circulating beam tube could be held below 2 Gauss. The predicted performance meets or exceeds the goals. This was accomplished by the following means.

1. The ultra-low carbon steel selected for the magnet body saturates at a relatively high field level, thus creating relatively low stray fields in the air. Table I shows the experimental B vs. H curve for this material.

| TABLE I | |
|------------|------------|
| $H_{(Oe)}$ | $B_{(kG)}$ |
| 1 | 2.5 |
| 2 | 8.0 |
| 4 | 13.5 |
| 10 | 15.5 |
| 100 | 18.2 |

2. The magnet length of 4 meters was chosen in part to limit the magnet's gap field to 0.95 Tesla. This choice is compatible with the chosen steel because the steel does not run into saturation in the critical septum region.
3. The pole tip edges were shaped to maximize the good field region. This shaping took into account the aperture geometry, the steel characteristics, and the field levels in the steel.
4. As mentioned in Section III. c., the circulating beam tube material (Permalloy 80") was chosen in part because of its high permeability at relatively low field levels. This enables the circulating beam tube to shield the interior of the tube from the fields leaking from the septum area. These leakage fields are on the order of several Gauss. The 50 mil. thick Permalloy 80 tube is predicted to reduce these down to 0.1 Gauss within the tube.
5. The septum region has been shaped (see Figure 2) to minimize stray fields and make the gap field as uniform as possible. The results of this optimization appear in Figure 3, which shows a cross section of the magnet with zone areas depicting variations of the B_y gap field. Each zone boundary corresponds to a 5 Gauss field change. The rectangle inside the magnet's aperture represents 2 sigma (standard deviation) of the beam size.

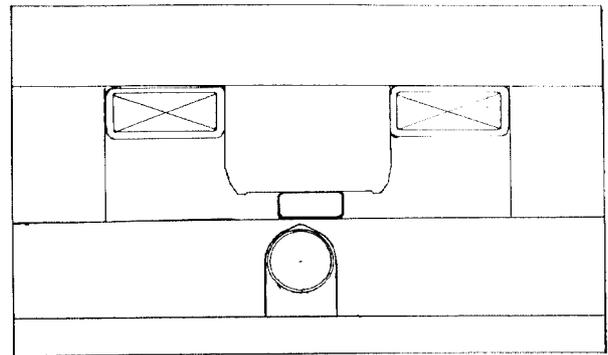


Figure 2.

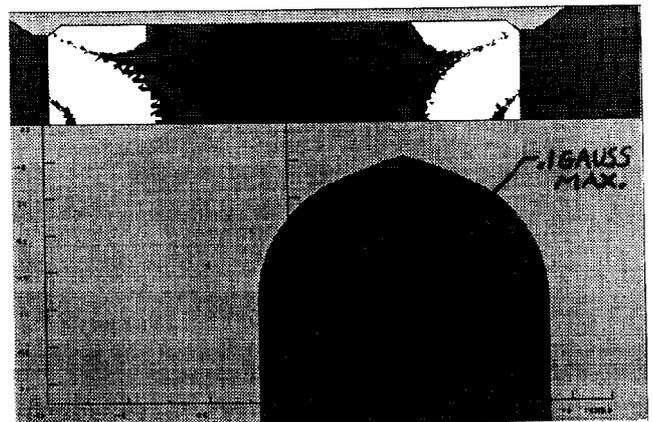


Figure 3.

A three-dimensional study was undertaken to minimize the stray fields in the circulating beam tube where it enters and exits the magnet. These entrance and exit areas required special attention as they are subject to the stray fields of both the gap and the coil. In addition, the highly permeable (and easily saturated) circulating beam tube must pass through these areas. This study showed that if special protective measures were not taken, the field levels inside the circulating beam tube could reach 1500 Gauss at these areas. Consequently, the following design features were added to the ends of the magnet.

1. The bottom pole piece (septum) was extended 7 cm and 4 cm beyond the top pole piece at the entrance and exit of the magnet, respectively. This shielded the circulating beam tube from the fringe gap field (see Figure 4).
2. "Field clamps" were designed to shield coil end fields (see Figure 4).

The results of the shielding can be seen in Figure 5, which shows the magnitude of the field inside the circulating beam tube on a rectangular surface that is parallel to the top part of the beam starting 30 cm inside the magnet and ending 30 cm outside. The field levels below this rectangular surface, where the beam is, are lower.

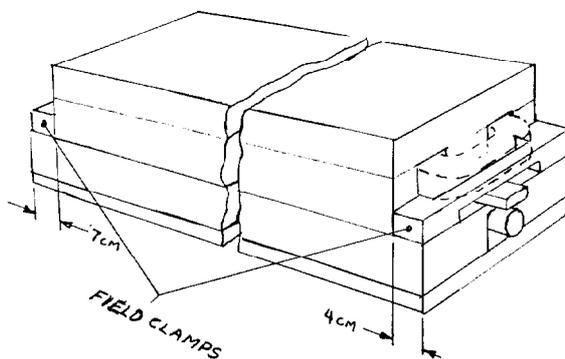


Figure 4.

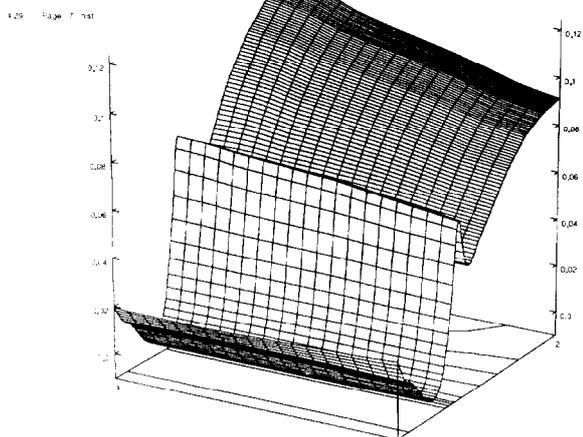


Figure 5.

V. CONCLUSION

As designed, the RHIC Lambertson magnet has met or exceeded the design goals and represents a state-of-the-art injector in terms of vacuum compatibility, field uniformity, and stray field levels.

VI. REFERENCES

- [1] Trademark of Inland Steel.
- [2] Trademark of Sprang Specialty Metals.
- [3] Trademark of Vector Fields, Inc.