RHIC D0 INSERTION DIPOLE DESIGN ITERATIONS DURING PRODUCTION*

J. Schmalzle, M. Anerella, G. Ganetis, A. Ghosh, R. Gupta, A. Jain, S. Kahn, G. Morgan, J. Muratore, W. Sampson, P. Wanderer and E. Willen,
Brookhaven National Laboratory, Upton, New York 11973, USA

Abstract

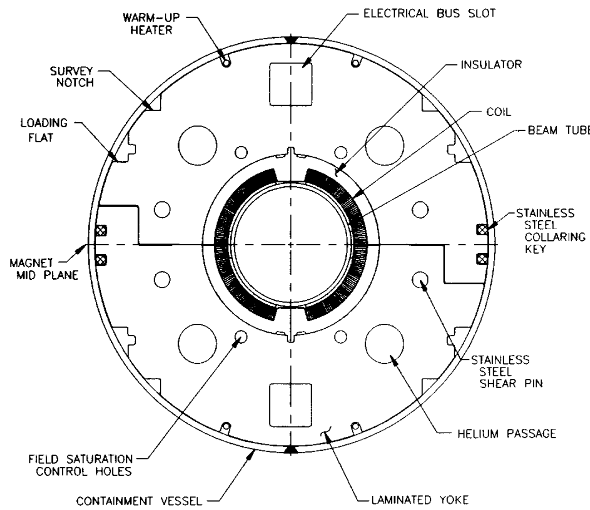
Iterations to the cross section of the Relativistic Heavy Ion Collider (RHIC) D0 Insertion Dipole magnets were made during the production. This was included as part of the production plan because no R&D or pre-production magnets were built prior to the start of production. The first magnet produced had the desired coil pre-stress and low field harmonics in the body of the magnet and is therefore being used in the RHIC Machine. On the first eight magnets, iterations were carried out to minimize the iron saturation and to compensate for the end harmonics. This paper will discuss the details of the iterations made, the obstacles encountered, and the results obtained. Also included will be a brief summary of the magnet design and performance.

I INTRODUCTION

There are twenty-four D0 insertion dipole magnets required in the RHIC machine. These magnets are being built at BNL, with the production broken into two stages. The first stage consisted of six magnets (four plus two spares) required for the first sextant and the second stage consists of the remaining magnets. The coil design uses 40 turns of 30 strand superconducting cable and 4 wedges. The cold mass design is very closely based on the 8cm arc dipole cold mass [1] adjusted for the increase in aperture. A cross section of the cold mass is shown in Fig.1 and the basic design parameters are as follows:

Coil ID	100 mm
Coil OD	120 mm
Number of turns per pole	40
Magnetic length	3.6 m
Iron inner diameter	139.4 mm
Iron outer diameter	310 mm
Shell thickness	6.35 mm
Operating temperature	4.6 K
Design current	5.0 kA
Design field	3.5 T
Quench current	7.4 kA

The D0 production plan called for cold mass production to begin without the benefit of any R&D or pre-production magnets. Several features were therefore incorporated into the design of these magnets that would allow iterations to the cross section to be made during the course of production in order to improve the field quality. Machined G-10 shims were used at the pole and filled Kapton [2] caps were used as spacers between the coil midplanes. Having various sizes of these two parts in stock would allow changes to be made without significantly interrupting production.



The field harmonics are defined in the following relation:

$$B_y + iB_x = 10^{-4} B_0 \sum_{n=0}^{\infty} [b_n + ia_n] \left(\frac{x+iy}{R_0}\right)^n ,$$

where B_x and B_y are the components of the field at (x,y) and B_0 is the central field. a_n are the skew harmonics and b_n are the normal. R_0 is the normalization radius which is chosen to be 31mm in these magnets.

II TEST ASSEMBLY

Past magnet building experience has shown that the first magnet does not usually have the desired pre-stress and/or the desired low field harmonics (b_2 and b_4). First article inspection sample yoke lamination were used to collar a portion of the straight section of two test coils in order verify the coil pre-stress and check the field harmonics in the body of the magnet prior to commencing production. The coils were collared with the design pole shim and midplane caps. This section was then measured at room temperature using a rotating coil to check the field harmonics. The measurements indicated that the pre-stress was low by 2000 psi and that b_2 and b_4 were unacceptable. Based on these results, the sample was disassembled and

* Work supported by the U.S. Department of Energy under Contract No. DE-AC02-76CH00016.

the thickness of the midplane caps was increased by 0.005”. The reassembled section was re-measured to determine if the desired shift in harmonics was achieved.

III PRODUCTION CROSS SECTION ITERATIONS

Based on the results of the test collaring and warm measurements some changes were made to the baseline cross section design. The thickness of the smallest wedge was increased by 0.004” by adding an additional layer of Kapton [2] wrap, the midplane cap thickness was increased by an additional 0.001”, and the pole shim thickness was increased by 0.001”. At this point coil production started, thereby limiting any future changes to small variations in pole shim and midplane cap thickness. Cold mass production of the first magnet was accelerated so that test data could be analyzed before the second magnet was assembled. The results of the first magnet confirmed this iteration. The desired pre-stress was obtained and the body harmonics at 2000 Amps were within one standard deviation of ideal values. Fig. 2 shows the relative field error dBy/B on the x-axis based on these measurements. The errors are $<10^{-4}$ within 60% of the coil radius and $<4 \times 10^{-4}$ at 80% of the coil radius. This is the best one can expect given the general manufacturing tolerances. Since the first magnet had the desired coil pre-stress and low field harmonics in the body of the magnet it has been installed in the RHIC ring.

The test assembly helped to get the desired geometric harmonics. However the saturation induced harmonics and the end harmonics were measured for the first time when the first magnet tested. The end harmonics could only be measured at room temperature because the meas. coil for 4.2K tests was not yet available. The saturation induced harmonics were an order of magnitude smaller than in the first arc dipole magnet, but they were still larger than desired. To reduce them in the following magnets, steel rods were inserted into the saturation suppression holes in the yoke. To compensate for the end harmonics observed, the thickness of the midplane caps was increased by 0.002” for the remaining magnets.

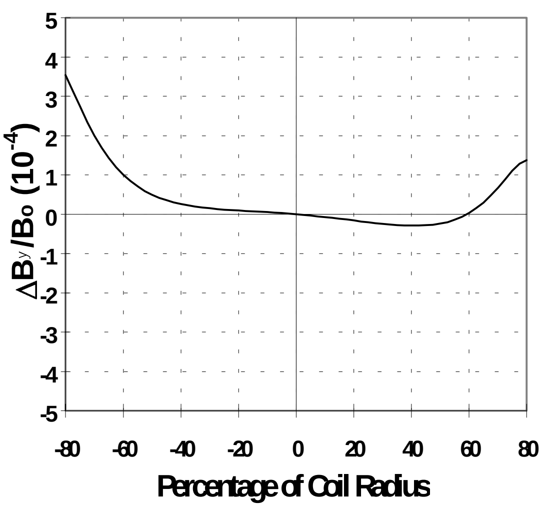


Figure 2. Geometric Field Errors on x-axis of DRZ101 body.

The test results from the next magnet showed that the desired changes had been obtained both in geometric and saturation induced harmonics (see Fig. 3). However, the saturation in the end harmonics, which was being measured for the first time, was found to be large. This prompted a decrease in pole shim thickness of 0.004” which was incorporated into the fifth and sixth cold masses. This geometric change in cross section was made to give the desired field quality at the design field.

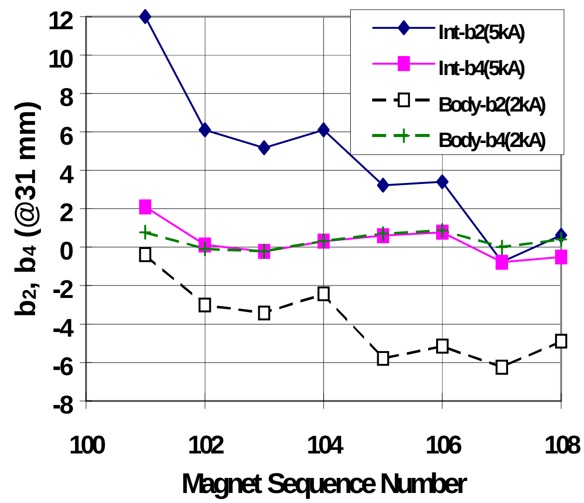


Figure 3. Plot showing b_2 and b_4 by magnet.

During the planned break in the production after the sixth cold mass, a change to the stamping die was made to remove the saturation suppression holes and thereby eliminate the need to fill the void with steel rods at cold mass assembly. The computer calculations indicated that this would reduce the b_2 saturation. A small integral b_2 which was seen in the fifth and sixth magnets was eliminated in the following magnets. No further changes are expected for the remainder of the production run.

Listed below in Table 1 are the thicknesses of the midplane caps and pole shims for the various assemblies.

Table 1. Midplane cap and pole shim data.

	Test Assy. 1	Test Assy. 2	Prod. Assy. 1	Prod. Assy. 2-4	Prod. Assy. 5-6	Prod. Assy. 7-24
Midplane Cap Thickness (inches)	.008	.013	.014	.016	.016	.016
Pole Shim Thickness (inches)	.033	.033	.034	.034	.030	.030

The measured integral harmonics at the design field in magnets DRZ103-DRZ108 are summarized in Table 2. Mean b_2 is expected to be reduced in the rest of the production as per the iterations described earlier. "Quench data will be reported in a later paper."

Table 2. Integral Harmonics at 5kA (up ramp) in D0 Dipoles.

Harmonic (n)	Mean b_n (units)	Std. Dev. in b_n	Mean a_n (units)	Std. Dev. in a_n
1	0.03	0.58	0.53	1.88
2	2.90	2.73	-2.98	0.25
3	0.05	0.12	0.02	0.37
4	-0.01	0.68	0.51	0.06
5	0.01	0.04	0.01	0.08
6	0.96	0.13	-0.23	0.01
7	0.00	0.01	0.01	0.02
8	-0.15	0.01	0.06	0.00
9	0.00	0.01	0.00	0.01
10	-0.15	0.01	-0.02	0.00

IV CONCLUSION

The production of the D0 magnets has demonstrated that with the help of a test assembly, the first magnet can be built with the desired pre-stress and field harmonics in the body of the magnets. It has also been shown that a number of design adjustments can be made during production without changing the coil geometry or significantly interrupting magnet production.

REFERENCES

[1] P. Wanderer et al., "Construction and testing of arc dipoles for RHIC" 1995 International Particle Accelerator Conference (PAC'95), Dallas.

[2] Kapton is a registered trademark of the DuPont Corporation.