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:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil ID</td>
<td>100 mm</td>
</tr>
<tr>
<td>Coil OD</td>
<td>120 mm</td>
</tr>
<tr>
<td>Number of turns per pole</td>
<td>40</td>
</tr>
<tr>
<td>Magnetic length</td>
<td>3.6 m</td>
</tr>
<tr>
<td>Iron inner diameter</td>
<td>139.4 mm</td>
</tr>
<tr>
<td>Iron outer diameter</td>
<td>310 mm</td>
</tr>
<tr>
<td>Shell thickness</td>
<td>6.35 mm</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>4.6 K</td>
</tr>
<tr>
<td>Design current</td>
<td>5.0 kA</td>
</tr>
<tr>
<td>Design field</td>
<td>3.5 T</td>
</tr>
<tr>
<td>Quench current</td>
<td>7.4 kA</td>
</tr>
</tbody>
</table>

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.

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 to 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
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 dB/Bo on the x-axis based on these measurements.
The errors are <10^-4 within 60% of the coil radius and <4 x
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.

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.

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 b2 saturation. A small integral b2
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.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Midplane Cap Thickness (inches)</td>
<td>.008</td>
<td>.013</td>
<td>.014</td>
<td>.016</td>
</tr>
<tr>
<td>Pole Shim Thickness (inches)</td>
<td>.033</td>
<td>.033</td>
<td>.034</td>
<td>.034</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Harmonic $(n)$</th>
<th>Mean $b_n$ $(\text{units})$</th>
<th>Std. Dev. in $b_n$</th>
<th>Mean $a_n$ $(\text{units})$</th>
<th>Std. Dev. in $a_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.03</td>
<td>0.58</td>
<td>0.53</td>
<td>1.88</td>
</tr>
<tr>
<td>2</td>
<td>2.90</td>
<td>2.73</td>
<td>-2.98</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>0.05</td>
<td>0.12</td>
<td>0.02</td>
<td>0.37</td>
</tr>
<tr>
<td>4</td>
<td>-0.01</td>
<td>0.68</td>
<td>0.51</td>
<td>0.06</td>
</tr>
<tr>
<td>5</td>
<td>0.01</td>
<td>0.04</td>
<td>0.01</td>
<td>0.08</td>
</tr>
<tr>
<td>6</td>
<td>0.96</td>
<td>0.13</td>
<td>-0.23</td>
<td>0.01</td>
</tr>
<tr>
<td>7</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>8</td>
<td>-0.15</td>
<td>0.01</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>10</td>
<td>-0.15</td>
<td>0.01</td>
<td>-0.02</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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


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