MAGNETIC DESIGN OF DIPOLES FOR LHC INSERTION REGIONS*

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Abstract

A number of dipole magnets for the insertion regions of the Large Hadron Collider (LHC) will be built at BNL. All these magnets will have the 80 mm aperture coil design used for the RHIC arc dipoles. An oblate shaped yoke with a vertical height of 550 mm is developed for the twin aperture D4A and D4B dipoles. This design allows the cold mass to fit inside the LHC cryostat while providing adequate iron on the midplane to control iron saturation. Due to a large beam separation, the D3A/D3B dipoles are designed as single aperture magnets with the same yoke design as the RHIC arc dipoles. The expected field quality in these dipoles is presented.

1 INTRODUCTION

As part of the US-CERN collaboration for the Large Hadron Collider (LHC), Brookhaven National Laboratory (BNL) will build a number of superconducting insertion magnets. There are six different styles of dipoles, all of which will use the same 8 cm aperture coil design that was used for the RHIC arc dipoles. Also, the magnetic length of all the dipole types is 9.45 m, the same as the RHIC dipoles. The operating field for these magnets is 3.55 T. The salient features of the various magnet types are given in Table 1. The dipole fields in both the apertures point in the same direction in all these magnets. The D1 magnets will be similar to the RHIC dipoles, except that the cold mass will not be curved. The D2, D4A and D4B magnets must be built as twin aperture magnets due to small beam separations. The D3A and D3B magnets are designed as single aperture magnets with essentially the same yoke design as the RHIC dipoles. The magnetic design and expected field quality in these dipoles are presented in this paper.

2 TWIN APERTURE MAGNETS

An earlier magnetic design of D2, D3A, D3B, D4A and D4B magnets was carried out using a twin aperture style for all the magnets [1]. These designs used an oblate yoke with a vertical dimension of 550 mm and a horizontal dimension of 659.2 mm. This design allowed the cold mass to fit inside the LHC cryostat with standard support posts, while at the same time providing adequate iron on the midplane to avoid strong saturation effects. The beam separations specified at that time were different from those given in Table 1. Changes in beam separations necessitated a redesign of the yoke. It was estimated that if the D3A and D3B magnets were built as single aperture magnets, then the horizontal size of D4A and D4B (now the same as D2) could be reduced. Also, there were potential cost savings in using the existing RHIC design for the D3A/D3B cold masses.

Table 1: Dipoles to be built by BNL for the LHC.

Name	Type	Cold Masses in One Cryostat	Aperture Separation, Cold (mm)	Number (Spares)
D1	1-in-1	1	—	4(1)
D2*	2-in-1	1	194	8(0)
D3A	1-in-1	2	400	2(1)
D3B	1-in-1	2	382	2(1)
D4A	2-in-1	1	234	2(1)
D4B	2-in-1	1	194	2(1)

* D2's are magnetically similar to D4B's, but have copper plating on the beam tubes and do not have a beam screen.

In view of the above, a redesign of the twin aperture D4A and D4B yokes was carried out with the same vertical dimension of 550 mm, but a reduced horizontal size. A horizontal size of 624.9 mm was found to be adequate for controlling saturation effects.

A schematic cross section of the D4A cold mass inside a LHC cryostat is shown in Fig. 1. The 80 mm aperture coils are held in place by 20 mm wide (141.6 mm outer diameter) stainless steel collars, which are not shown in this figure. Each half of the yoke is obtained by removing a 40 mm wide strip of material from the midplane of a semi-circular piece of 315 mm radius, giving a horizontal size of 624.9 mm. The control of saturation induced harmonics is achieved by a pair of $40\ \text{mm} \times 10\ \text{mm}$ rectangular slots located at 45 mm above and below the center of the yoke, as shown in Fig.1. It should be noted that the positions and sizes of helium bypass holes and bus slots shown in Fig. 1 are still tentative.

The iron cross section for the D4B/D2 magnets with 194 mm beam separation is identical to the D4A magnets, except that the rectangular saturation control slots are located at a distance of 38 mm from the center of the yoke, instead of 45 mm.

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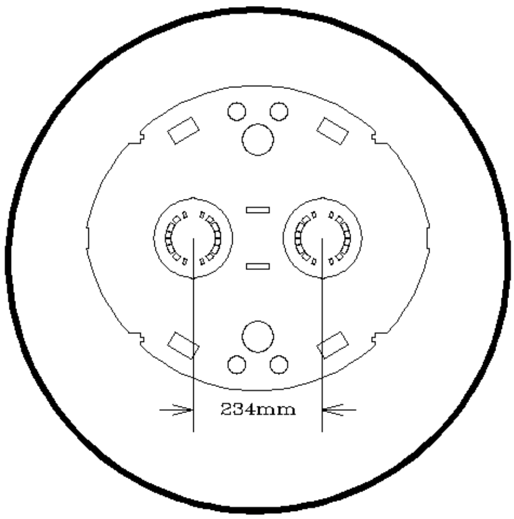

Figure 1: D4A cold mass inside the LHC cryostat.

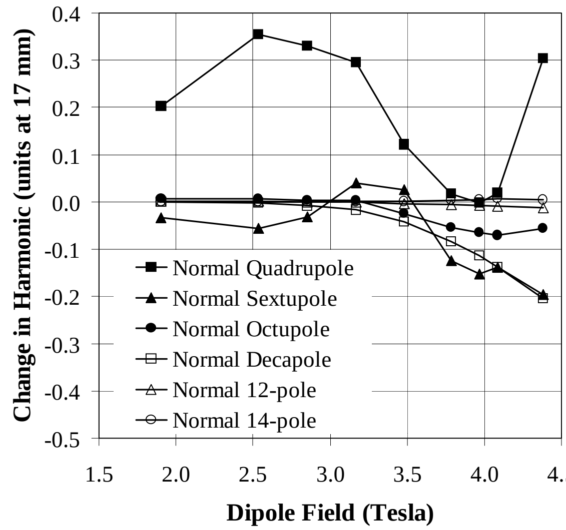

Figure 3: Satuation behaviour of various harmonics in D4B magnets, calculated using POISSON.

2.1 Field quality in D4A and D4B(D2) magnets

The dipole field in both the apertures points in the same direction in these magnets. Thus, the flux in one aperture does not have a return path through the other aperture, leading to a stronger saturation of the iron yoke at high fields. Such saturation effects have been minimized by providing adequate iron at the midplane in the oblate yoke design. The presence of a second aperture also introduces a left-right asymmetry, giving unallowed harmonics, such as the normal quadrupole, octupole, etc., at high fields. The field dependence of all the harmonics is brought within acceptable levels by two 40 mm × 10 mm rectangular saturation control slots. The field dependence of various harmonics in the D4A and the D4B magnets was calculated using a POISSON model. The results of these calculations are shown in Figs. 2 and 3. The changes in harmonics from a low field value are plotted for a reference radius of 17 mm. The saturation up to 4 T central field is about –0.15 unit for the sextupole/decapole terms. The saturation in the normal quadrupole term is somewhat more pronounced in the D4B magnet with a smaller beam separation. The up-down asymmetric placement of the cold mass in the cryostat (see Fig. 1) introduces only ~0.1 unit of skew quadrupole at dipole fields up to 4 T. A detailed discussion of the expected field quality in these magnets at various dipole fields, including the superconductor magnetization, iron saturation and other high field effects, can be found in [2]. Table 2 summarizes the expected integral harmonics at 3.8 T in the D4A magnets. The harmonics for D4B magnets are similar within the uncertainties , $\Delta(b_n)$ or $\Delta(a_n)$. The random errors, $\sigma(b_n)$ or $\sigma(a_n)$ are estimated from the RHIC production data. The unallowed skew terms are mostly from the ends.

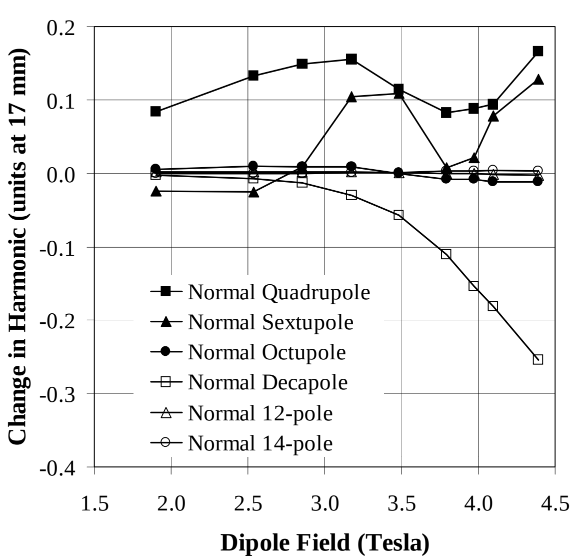

Figure 2: Satuation behaviour of various harmonics in D4A magnets, calculated using POISSON.

3 SINGLE APERTURE MAGNETS

The magnets D1, D3A and D3B are designed to be single aperture magnets. All these magnets employ the same cold mass design that was used for the RHIC arc dipoles. The D1 magnet is similar to a RHIC dipole, except that the cold mass is not curved. A single cold

Table 2: Expected integral harmonics in D4A at 3.8 T

n*	$\langle b_n \rangle$	$\Delta(b_n)$	$\sigma(b_n)$	$\langle a_n \rangle$	$\Delta(a_n)$	$\sigma(a_n)$
2	0.03	0.54	0.19	0.36	2.52	1.03
3	1.06	1.65	0.79	–0.49	0.25	0.08
4	–0.02	0.07	0.03	0.02	0.34	0.13
5	–0.02	0.17	0.08	0.04	0.04	0.01
6	0.00	0.01	0.01	0.00	0.08	0.02
7	0.00	0.02	0.01	–0.01	0.01	0.00
9	0.00	0.01	0.00	0.00	0.00	0.00
11	–0.01	0.00	0.00	0.00	0.00	0.00

* n=2 denotes quadrupole.

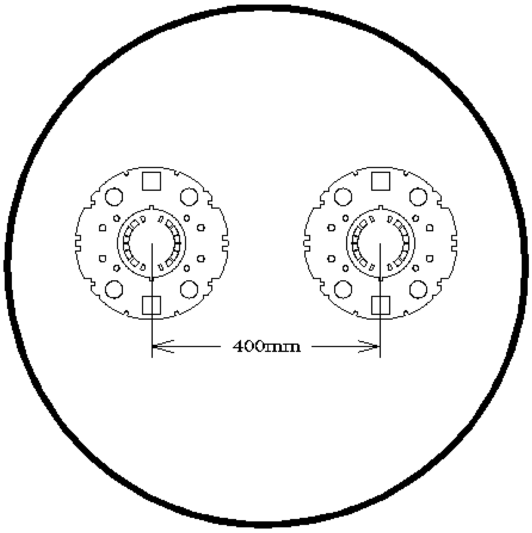

Figure 4: Two RHIC-type cold masses inside a LHC cryostat to give a D3A magnet. The D3B magnets are similar, except that the separation between the two beams is 382 mm.

mass is placed inside a cryostat, which is also the same as the RHIC cryostat (610 mm outer diameter). In the case of the D3A and the D3B magnets, two such cold masses are placed side by side in a LHC cryostat (914 mm outer diameter), as shown in Fig. 4.

3.1 Field Quality in D1 Magnets

Extensive data are available on the field quality in the RHIC arc dipoles, which would also apply to the D1 magnets. The measured current dependence of various harmonics in the straight section of a typical RHIC dipole, DRG107, is shown in Fig. 5. For each harmonic, the values measured in the up ramp of the current are shown. For the sextupole term, the current dependence during the down ramp is also given, showing the effect of superconductor magnetization. About –2.5 units of sextupole (at 17 mm radius) is generated at 4 T. Since the D1 magnets will not have any left-right asymmetry, no saturation in the normal unallowed terms is expected. Tables of expected harmonics in D1 magnets can be found in [2,3].

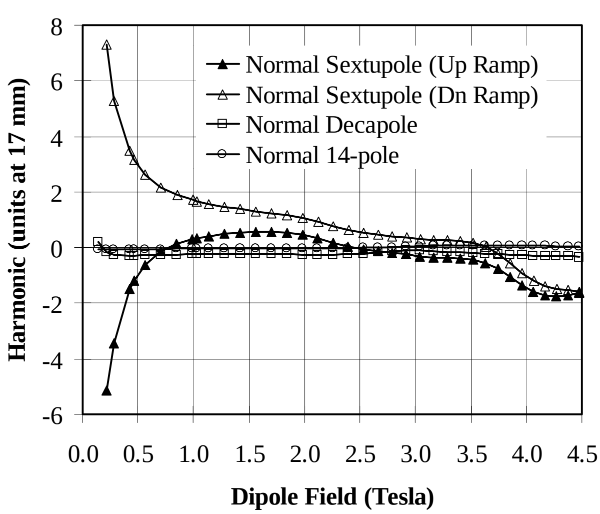

Figure 5: The measured current dependence of harmonics in a typical RHIC arc dipole, DRG107.

3.2 Field Quality in D3A and D3B magnets

In the case of the D3A and D3B magnets, there are two cold masses in a common cryostat (see Fig. 4). Calculations using a POISSON model suggested that the sextupole saturation in these magnets employing the RHIC cross-section will be –5.5 units for D3A and –5.8 units for D3B magnets at a reference radius of 17 mm. In order to correct this problem, a fresh optimization of the yoke may be necessary. However, simple solutions, such as changing the material of the yoke keys from stainless steel to iron can be quite effective. Preliminary calculations using POISSON show considerably improved saturation behaviour with just this simple change. The calculated saturation behaviour for D3A magnets using the RHIC dipole cross-section, but iron keys instead of stainless steel, is shown in Fig. 6. The results for D3B are very similar to D3A. Further optimization of the yoke for the D3A and D3B magnets is in progress.

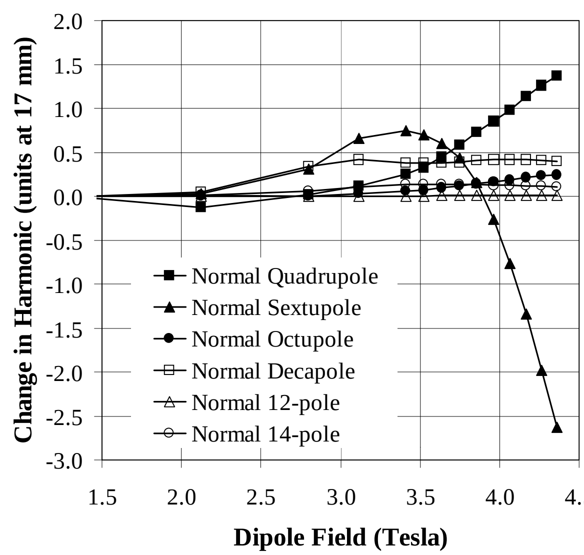

Figure 6: Calculated saturation behaviour of various harmonics in D3A magnets using an iron key.

REFERENCES

[1] R. Gupta, et al., "Coldmass for LHC Dipole Insertion Magnets", MT-15, Beijing, China, Oct. 20-24, 1997.

[2] A. Jain, "Expected Harmonics (Version 1.0) in BNL-built LHC Dipoles", BNL Note RHIC-AP-147, March, 1998

[3] J. Wei, et al., "US-LHC IR Magnet Error Analysis and Compensation", these proceedings.

* This work is supported by the U.S. Department of Energy under contract No. DE-AC02-98CH10886.