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IRON SATURATION CONTROL IN RHIC DIPOLE MAGNETS*

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Abstract

The Relativistic Heavy Ion Collider[1] (RHIC) will require 360 dipoles of 80 mm bore. This paper discusses the field perturbations produced by the saturation of the yoke iron. Changes have been made to the yoke to reduce these perturbations, in particular, decapole < 10^{-4}. Measurements and calculations for 6 series of dipole magnets are presented.

Introduction

The proposed RHIC will include 360 "standard" superconducting dipoles(bore=80mm, design field=3.45 T). The iron return yoke is used as the mechanical restraint. The good field radius (25 mm) is a larger fraction of the iron inner radius (59.69 mm) than common. For dipoles in a circular iron yoke, the maximum field perpendicular to the iron surface occurs at the pole; the maximum return flux occurs at the midplane. The saturation near the poles produces positive changes in the harmonics- b2' and b4'. (Where $bn' = C_{n+1}(@25mm)/B_o$ X 10^4, with C_{n+1} the field coefficient for $\cos(n+1)\theta$). Midplane saturation effects have the opposite sign. The chromaticity correctors will be used to correct the saturation sextupole. Since saturation b6' is negligible, the goal is limiting the b4' variation with field.

First Series of Dipoles

The first series of RHIC dipoles were constructed with an iron inner radius of 54.61 mm. (See parameters in Table 1). Figure 1 shows a generic RHIC dipole. In this figure, portions of the yoke which have a significant effect upon saturation behavior are labeled.

1. **RFE** , iron inner radius.
2. **POLE NOTCH** , rectangular notch at the pole, used to locate the coil accurately with respect to the iron. It has a significant effect upon the saturation of the iron in the pole region.
3. **MIDPLANE NOTCH** , effects the width of the iron at the midplane.
4. **HE-HOLE** , this is a large (>25mm) circular hole.
5. **PIN** , This is a circular pin, which together with the key, holds the yoke compressed about the coil.

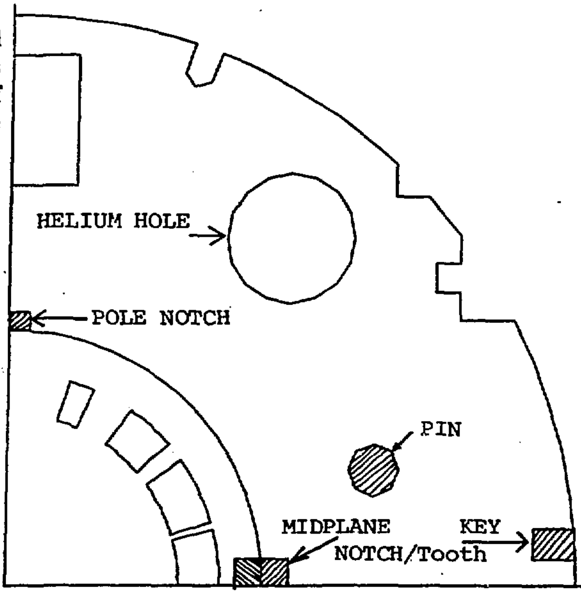

Figure 1: Generic RHIC Dipole Cross Section

6. **KEY** , This is a rectangular piece on the outer periphery of the magnet which completes the restraint system.

Figures 2,4, and 6 show the field shape of these magnets as a function of field. In these graphs, the measured values are plotted with dashed lines, and the calculated with solid. The curves have been offset for legibility. The calculations, done with the finite element program PE2D, (confirmed with POISSON), underestimate the saturation reduction of the transfer function. The calculated saturation dependence of b2' and b4' is slightly high for DRS001,DRA001, which were constructed by BNL; DRA001-3 were constructed by BBC with a different yoke assembly technology, the saturation effects were slightly underestimated for these magnets. The allowable b4' swing is 1 unit. Morgan[2] has developed a theory for controlling the saturation by changing the inner iron surface from a circle to a smoothly distorted surface. Reducing the saturation swing by putting additional holes in the iron was also investigated. The simplest method, increasing the iron inner radius to 59.69 mm was used in subsequent RHIC dipoles.

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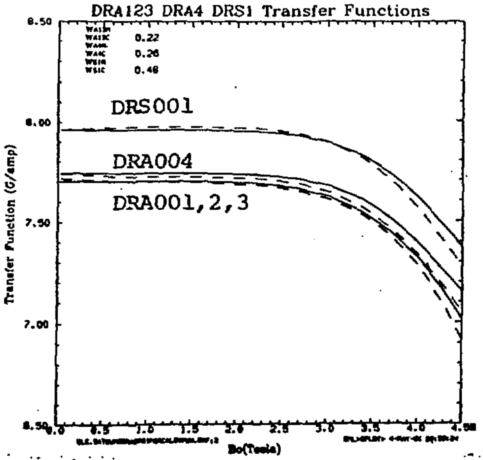

Figure 2: Transfer Function 55 mm Dipoles

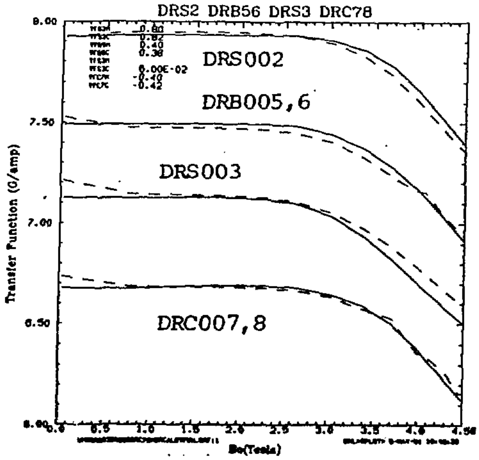

Figure 3: Transfer Function 60 mm Dipoles

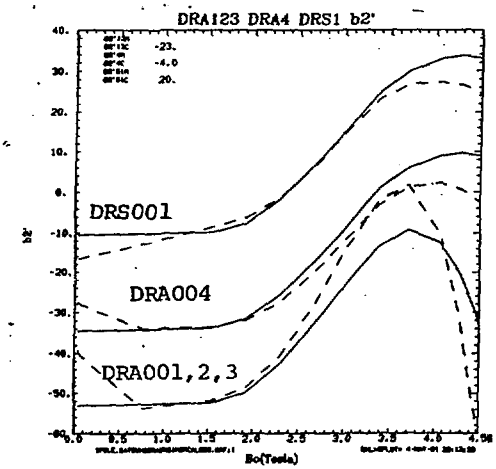

Figure 4: b2' 55 mm Dipoles

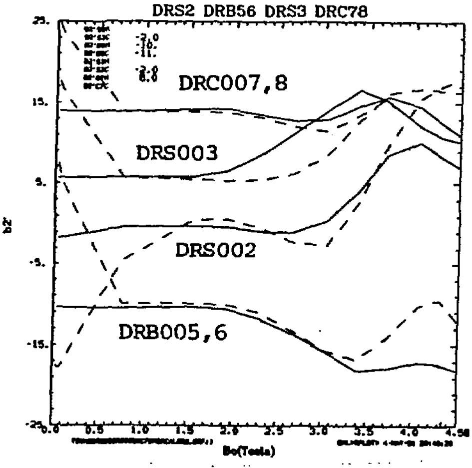

Figure 5: b2' 60 mm Dipoles

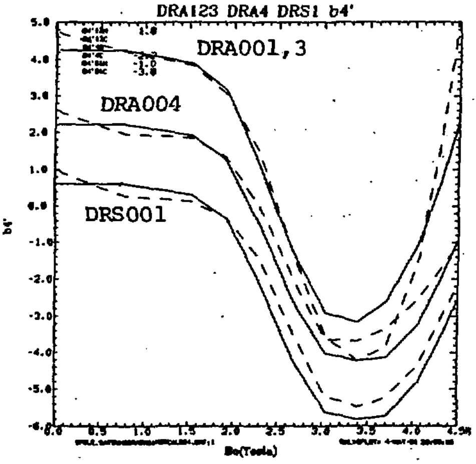

Figure 6: b4' 55 mm Dipoles

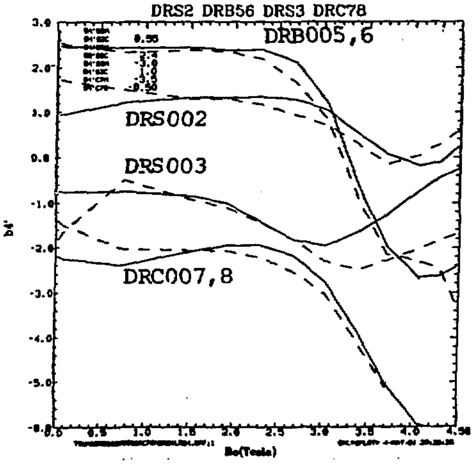

Figure 7: b4' 60 mm Dipoles

TABLE 1: Summary of RHIC Dipoles

Magnet	RFE (mm)	POLE NOTCH mmxmm	MIDPLANE NOTCH mmxmm	HOLE R(mm) theta	PIN R(mm) theta	KEY material	Saturation measured b2'	b4'
DRS001	54.6	5x5	...	110 69	95 SS 45	SS	+34	-5.4
DRA004							+33	-5.2
DRA1-3	54.6	5x5	...	105 90	120 SS 30	...	+53	-7.8
DRB5.6	59.7	..	5x5	110 69	95 SS 45	SS	-6	-4.8
DRS002	59.7	...	-5x5	110 69	95 SS 45	SS	+8	-1.1
DRC7,8	59.7	...	5x5	110 69	95 SS 45	SS	-4	-2.8
DRS003	59.7	2x5	...	105 51	90 FE 45	SS	+10	-1.2
DRE	59.7	2x5	...	105 51	90 SS 45	FE	+18	0.7 (DRE is calculated)

60 mm Iron Radius Dipoles -DRB Series

Two changes were made from the DRA series; the iron ID was increased, and the indexing notch was moved from the pole to the midplane. Figures 3,5, and 7 show the saturation effects. The b2' saturation swing has been strongly suppressed; however, the width of the midplane iron is reduced both by the key and the notch, resulting in in a large negative b4' swing of -4. Except for the failure to predict the secondary peak in b2', the agreement between calculation and measurement is excellent.

DRS002 and DRC007,DRC008

Replacing the midplane notch with a inward projecting "tooth" increases the width of iron at the midplane. A "tooth" at the midplane has little effect upon the low field harmonics; whereas the equivalent "tooth" at the pole has a very large effect (and saturates very rapidly). This tooth serves the mechanical indexing function. DRS002 was constructed to investigate this concept. As the figures show, the performance was excellent as is the agreement with calculation. This design differs from the "traditional" thinking that a circle is the best case, and any deviations from a circle should be smooth distortions. Previous attempts with an integral magnetic field program (GFUN) had produced meaningless results for such a "discontinuous" geometry. These two magnets were identical to DRS002 without the iron tooth. The saturation behavior is typical of strong midplane saturation. The agreement between calculation and measurement is good.

DRS003-Current Design

Since the large b4' swing was due to midplane saturation, studies were made of ways to reduce this. There are two ways to reduce this saturation: 1) increase the width of iron at the midplane (either by "teeth", iron keys, or distorting the inner surface inwards), or 2) reduce the flux returning through the midplane (which can be done by notches or holes at 30-40°). Calculations showed that both these methods work, and further by moving the existing Helium bypass hole, the saturation could be suppressed without changing the inside surface. DRS003 was constructed as a test of this design. The calculations and measured results are shown in figures 3,5 and 7. The marginally acceptable b4' swing is expected to be further reduced with the use of iron for the retaining key, which is the "final" DRE design, which has not yet been tested.

Conclusions

By careful design, it has proven possible to reduce the b4' saturation swing to less than 1 unit, while retaining the necessary mechanical features of the iron yoke. At the same time the b2' swing has also been reduced by a factor of two. Modern finite element magnetic field programs (PE2D,POISSON, et al) accurately predict relatively large saturation effects and handle discontinuities in the iron. (cf. DRS002 results)

References

1. "Conceptual Design of the Relativistic Heavy Ion Collider", Brookhaven National Laboratory, BNL 51932 (1986)
2. G .Morgan, "Use of an Elliptical Aperture to Control Saturation in closely-coupled, Cold Iron, Superconducting Magnets", IEEE Transactions on Nuclear Science, Vol. NS-32,No. 5,(1985)