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STATISTICAL ANALYSIS OF MULTIPOLE COMPONENTS IN THE MAGNETIC FIELD OF THE RHIC ARC REGIONS*

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Abstract

The existence of multipolar components in the dipole and quadrupole magnets is one of the factors limiting the beam stability in the RHIC operations. Therefore, the statistical properties of the non-linear fields are crucial for understanding the beam behavior and for achieving the superior performance in RHIC. In an earlier work [1], the field quality analysis of the RHIC interaction regions (IR) was presented. Furthermore, a procedure for developing non-linear IR models constructed from measured multipolar data of RHIC IR magnets was described. However, the field quality in the regions outside of the RHIC IR had not yet been addressed. In this paper, we present the statistical analysis of multipolar components in the magnetic fields of the RHIC arc regions. The emphasis is on the lower order components, especially the sextupole in the arc dipole and the 12-pole in the quadrupole magnets, since they are shown to have the strongest effects on the beam stability. Finally, the inclusion of the measured multipolar components data of RHIC arc regions and their statistical properties into tracking models is discussed.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two rings, Blue and Yellow. The two beams, traveling in opposite directions in the two rings, are maneuvered to collide head on at the interaction regions (IRs). The magnet system of the collider consists primarily of the superconducting dipole and quadrupole magnets for guiding and focusing the counter-circulating ion beams into well-defined orbits in the regular arcs of the machine lattice, as well as a large complement of special magnets required for steering the beams into collisions in the IRs.

The field quality in the magnets influences the ultimate luminosity performance of RHIC. In order to study the performance of the machine, it is desirable to build a non-linear model using the field quality measured in the individual magnets. There are large number of dipole and quadrupole magnets in the RHIC arc regions. About 80% of these magnets don't have cold measurement under superconducting condition which makes the non-linaer model difficult.

In this paper, we describe the available measurements in the arc magnets, and the estimate of the field quality under operating conditions by extrapolating from low field measurements at room temperature. We then present the field quality analysis in the RHIC arc regions. Finally, the implementation of the measured multipolar components data of RHIC arc regions and their statistical properties into tracking models are discussed.

MAGNETIC FIELD MEASUREMENTS

The RHIC magnet lattice is divided into 6 arcs and 6 insertions for each of the two rings. In the arcs, the rings are separated radially by 90 cm. In the arc of the two rings there are 264 dipoles, 276 quadrupoles, 276 sextupoles, and 276 correctors. The details about the design and performance of these magnets can be found in [2]. The field quality of all magnets in RHIC was measured at room temperature at low fields, as part of the magnet quality control and acceptance. However, due to cost and schedule constraints, only 22% of the arc main dipoles and 24% of the arc quadrupoles were bench measured in the superconducting state before their installation into the RHIC tunnel. The integrated magnetic field harmonics were mainly measured at currents of 660A, 1450A and 5000A for the arc dipoles; some were also measured at 570A and 2400A. Table 1 lists the total number and the availability rates of RHIC arc dipoles that have integrated measurement data at the currents stated above. Out of 380 magnets of are quadrupole type 92 magnets were measured cold at 36 different currents from 50A to 6000A. They are also included in Table 1 at the limited currents listed above for comparison with arc dipoles. The field harmonics were also measured in 18% of arc dipoles at a central 1m-long section at about 35 different currents between 50A and 7000A.

Table 1: Available warm and cold measurement of integrated data. The measurements with 30A are made at room temperature. The measurements with other magnet currents are performed cold. The total numbers of magnets (including spares) of type DRG, DR8 and QRG are 264, 34 and 380, respectively.

Curr.	Available Magnets			Availability Rate (%)		
(A)	DRG	DR8	QRG	DRG	DR8	QRG
30	262	34	380	99	100	100
570	17	2	18	6	6	5
660	56	2	92	21	6	24
1450	57	2	91	22	6	24
2400	8	0	92	3	0	24
5000	58	2	92	22	6	24

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In order to create a realistic model of the arc region, one needs to estimate the field quality under operating conditions for the magnets that do not have the cold measurements. Since all the magnets were measured at room temperature, we have used these data to estimate the needed corrections to the cold data.

FIELD QUALITY ANALYSIS IN RHIC ARC DIPOLES

All of the 264 arc dipoles are of magnet type of DRG. The 10 spare magnets are made in the type of DR8 which were designed for D8s in RHIC. The magnet type DR8 is similar to DRG and it is interchangeable with DRG (but not vice versa). Since DR8 magnets contribute to the field quality in the arc when they are installed in the region, they are also included in this statistical analysis.

With the available integrated measurement data as listed in Table 1, the normal and skew multipole components of DRG and DR8 dipole magnets are analyzed. Fig. 1 shows the statistics of normal and skew multipole components as function of the magnet operation current. It can be clearly seen that the normal sextupole (b2) gives the major contributions to the field errors. So, it is important to have a good estimate of the arc normal sextupole (b2) of the entire set of the arc dipole magnets. Fig. 2 shows the average, RMS, maximum and minimum values of integrated sextupole (b2) components in DRG and DR8. In these figures we display and compare the statistics of data of measured and estimated from the warm-cold conversion.

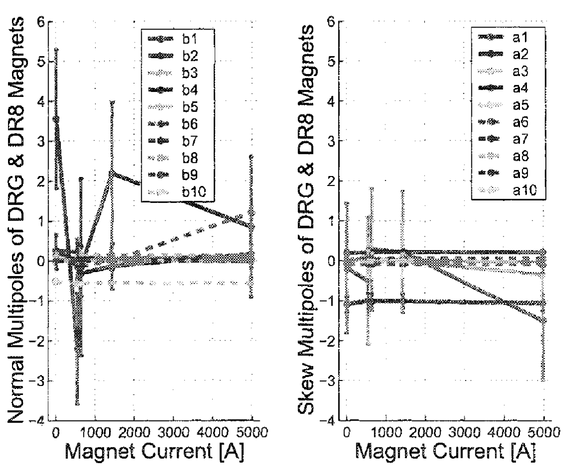

Figure 1: Normal and skew multipole components in RHIC arc dipole magnets as function of the magnet operation current

FIELD QUALITY ANALYSIS IN RHIC ARC QUADRUPOLES

All the 276 arc quadrupoles and their 6 spares are of the magnet type QRG. In addition to the arc, there are also 96 QRG type of quadrupoles installed in insertion region,

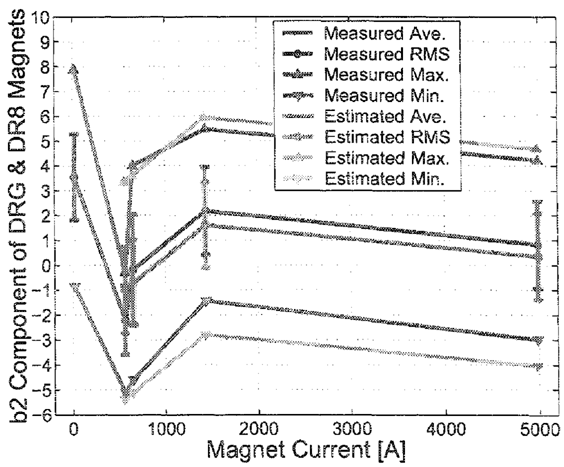

Figure 2: Integrated sextupole (b2) components in RHIC arc dipole magnets as function of the magnet operation current.

plus their 2 spares, serving as Q5, Q6, Q8 and Q9 magnets. Since we are interested in the statistical properties of this magnet type and bigger sample group is beneficial, in this field quality analysis we include all 380 QRG type magnets regardless where they are installed.

Fig. 3 show the statistics of normal and skew multipole components from the available integrated measurement data, as listed in Table 1 as function of the magnet operation current of QRG magnets. It can be observed from the figure that the normal 12-pole (b5) contributes most to the field errors, especially at the higher operation current. So, it is important to have a good estimate of the arc 12-pole (b5) of the entire set of the QRG magnets. Fig. 4 show the average, RMS, maximum and minimum values of integrated sextupole (b2) components in QRG magnets. In this figure we display and compare the statistics of data of measured and estimated from the warm-cold conversion.

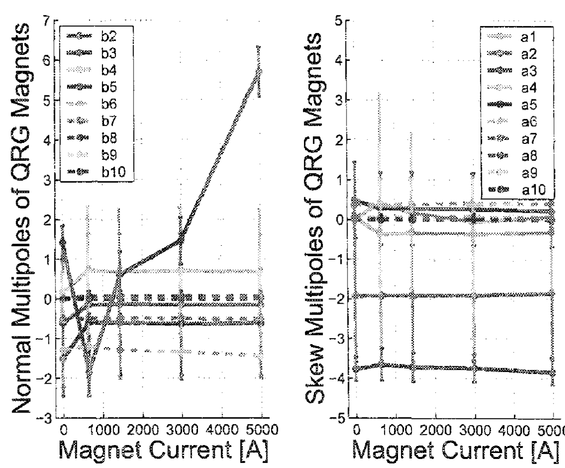

Figure 3: Normal and skew multipole components in RHIC arc quadrupole magnets as function of magnet current

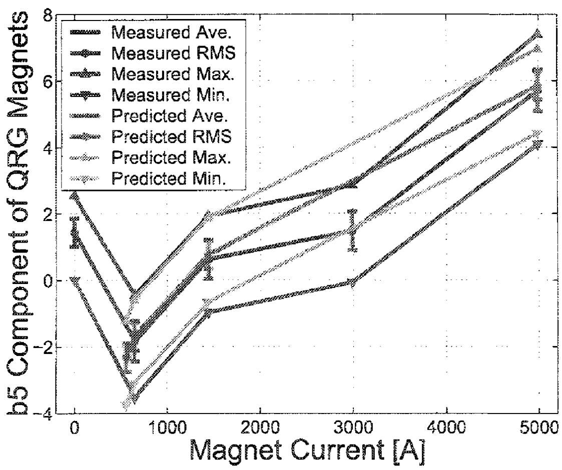

Figure 4: Integral b5 components in RHIC arc QRG Quadrupole magnets

BUILDING NON-LINEAR TRACK MODEL

The realistic nonlinear tracking models where built for both Blue and Yellow ring at RHIC [1] including measured or estimated magnet errors in the IR. However, so far, these models do not include the complete multipolar expansion of the arc magnetic fields. There are two options to include the arc magnetic errors into the realistic non-linear tracking models. One is treating each arc magnets individually as in the earlier work where the IR nonlinear models were built. The other is treating the arc magnets globally and include the statistical properties of the multipole fields into the arc magnets.

Ideally, the non-linear models could be built in the following way. All the normal and skew multipolar expansion of the magnetic field up to the 22-pole ($n = 10$) are estimated at the RHIC operation currents for all arc magnets that have no cold measurements. All the arc magnets are subdivided into N_s slices and the multipoles are placed as N_s-1 thin lenses between the slices. In addition, two thin lenses are placed at the ends of each magnet to account for the multipoles from the end fields. This method was used in the earlier work of the non-linear model building that includes IR magnets errors [1]. However, this method requires much effort on data compilation and model rebuilding.

Alternatively, an error distribution generated with statistical properties, as presented in this paper, can be included in the arc magnets. In an earlier work of linear chromaticity measurements and modeling [3] all the arc dipoles were artificially divided into two halves and one sextupole multipole was inserted in between. All the inserted sextupole multipoles have the same strength. Considering there are 132 arc dipoles in each ring, it is perhaps sufficient to use the average of integrated sextupole multipoles. The similar method can be used to include all order of the normal and skew multipole component into all arc dipole and quadrupole magnets.

REFERENCES

[1] J. Beebe-Wang and A. Jain, "Realistic Non-linear Model and Field Quality Analysis in RHIC Interaction Regions", Proc. PAC 200 7, pp 4309-4311 (2007).

[2] M. Anerella et al., "The RHIC Magnet System," Nucl. Instrum. Meth. in Physics Research, A499, pp. 280-315 (2003).

[3] Y. Luo et al., "Modeling RHIC Linear Chromaticity with Sextupole Components in the Arc Main Dipoles", BNL, C-A/AP#276 (2007).