SUPERCONDUCTING SEXTUPOLES AND TRIM QUADRUPOLES FOR RHIC *

P. Thompson, M. Anerella, G. Ganetis, A. Ghosh, A. Greene, R. Gupta, A. Jain, E. Kelly, M. Lindner, G. Morgan, J. Muratore, W. Sampson, P. Wanderer, E. Willen

RHIC Project, Brookhaven National Laboratory, Upton, NY 11973

Abstract

RHIC requires 288 sextupole and 72 trim quadrupole magnets. These iron poletip superconducting magnets have been constructed by Everson Electric Co. Room temperature field measurements have been completed for 75% of these magnets with acceptable results. Approximately 15% of them have been tested at 4.6 K for maximum (quench) current. The quench performance for the early magnets was good and improved to excellent during the production run. These magnets have more than 100% margin at quench.

I. INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) will be a colliding beam facility with design energy of 100 X 100 GeV/u for heavy ions. The two accelerator/storage rings are divided into "regular arcs" and intersection regions. A set of 288 sextupole elements are necessary to reduce the natural chromaticity ($\chi \sim$ -42) and correct sextupole field imperfections in the dipole magnets.

These are positioned at every quadrupole in the regular arcs, and have a design strength of 588 Tesla/meter with an inner bore of 80 mm and length of 750 mm. The detailed design of these "superferric" magnets has been published previously [1] . In addition, to vary the β^* in the interaction regions 72 trim quadrupoles are required. These are assembled with quadrupoles Q4,Q5, and Q6 . Their overall dimensions are identical to the sextupoles and their detailed construction is very similar. This paper will emphasize the test results and design differences of the quadrupoles.

II. DESIGN

Table I lists the basic parameters of these magnets. They consist of racetrack layer wound coils mounted on iron poletips. The method used in the sextupoles for securing the coils proved somewhat cumbersome. For the quadrupoles, a projection was added to the iron yoke so that the coil fits in a slot between this projection and the poletip(see Figure 1). A thin non-ferrous spring is inserted between the poletip and the coil to hold it against the support projection. There is no real "prestress" in this design. A small tab is placed over the ends of the coils so that they can not move radially but the ends are unsupported against the Lorentz forces.

A. Magnetic Design

Since these magnets operate with a pole tip field of $\sim$ 1.1 Tesla, iron poletips were used. At low field, the poletip dominates the field, reducing the sensitivity to coil location errors.

Table I

Parameters of RHIC Sextupoles and Trim Quadrupoles

Parameter	Value	
	Sextupole	Quadrupole
Wire Diameter	0.508mm	0.508mm
Copper/SuperConductor	3:1	3:1
Ic(2.0 T,4.22 K)	230 A	230 A
Turns per pole	200	200
Clear Bore	80 mm	80 mm
Length	750 mm	750 mm
Design Current	100 A	100 A
Design Strength	588 Tesla/meter	22 Tesla
Quench Current	220 A	205 A
Quench Strength	780 Tesla/meter	37 Tesla
Inductance at 100 A	530 mH	590 mH
Number for RHIC	288	72

For the sextupole, because of mechanical limitations, the actual poletip is narrower than optimum. This results in very noticeable saturation. For the trim quadrupole the poletip was widened to reduce this saturation. The poletip was also shaped and a hole was put in it to further reduce the saturation. The coil support projection of the yoke does not affect the field. For ease in coil manufacture, the ends are semi-circular and generate acceptably small error fields.

III. QUENCH RESULTS

The results of quench testing are summarized in Figure 2. Note that only the last and the worst(usually the first) quenches are plotted. For the initial sextupoles the worst quench was at least 80% of the conductor limit. As production progressed, a problem developed with the coil support hardware. This subset typically displayed a first quench in the range 55 to 75% of I_{ss} and very rapid training to short sample. At about magnet SRE260, a problem developed in the epoxy potting of the coils. This group of magnets trained slowly, and many of them were not trained to short sample. At magnet SRE280 all known problems were fixed and the quench plot looks much better.

For the trim quadrupoles, the support mechanism was much more robust and the problems of quality control in production were understood. Twelve quadrupoles have been tested with only one quench below (92%) the conductor limit. Except for the epoxy problem sextupoles(which are being 100% tested), only 10% of these units are subjected to quench testing.

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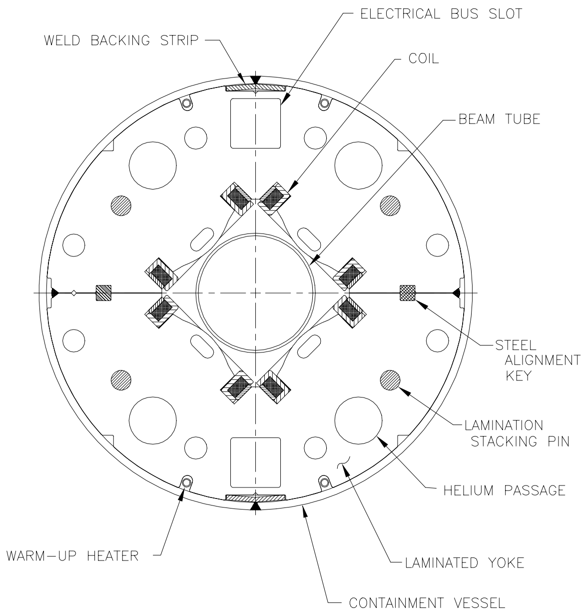

Figure 1. Cross Section of RHIC Trim Quadrupole.

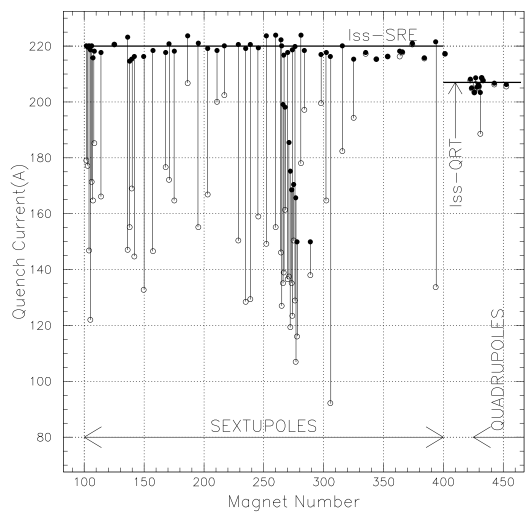

Figure 2. Quench Histories

IV. FIELD QUALITY -SEXTUPOLE

All of these magnets are measured at room temperature at 0.25 A. A small sample is also measured at 4.5 K with currents ranging up to 150 A. There is good agreement between the two measurement techniques. Table II shows the low current integral field measurements. The non-negligible b0 and b4 terms are probably due to the dipole symmetry of the yoke assembly. Figure 4 shows a trend plot of the transfer function. There appear to be steps associated with the fixes in the assembly technique. The allowed harmonics measured in 49 magnets at 4.6 K are presented in Figure 5. The strong saturation arises from the "neck" of the poletip which is narrower than optimum. The reproducibility is apparent.

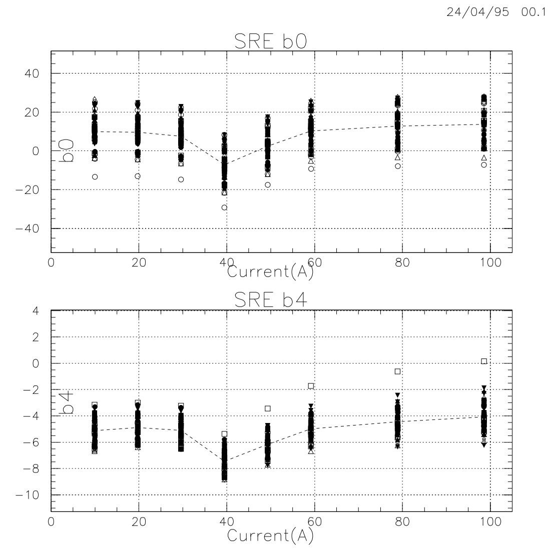

Figure 3. Sextupole Notch Harmonics

Table II
Sextupole Integral Field Harmonics measured at 0.25 A - 300 magnets

Harmonic	Calculated	Measured	
	bn only[a]	bn	an
B2/A(T/m*A)	8.66	8.69(0.013)	...
b3	0	-0.27(1.14)	-0.06(2.82)
b4	0	-4.58(1.37)	-0.14(1.17)
b5	0	0.24(0.21)	0.15(1.01)
b6	0	-2.67(0.55)	-0.12(0.54)
b8	-93.15	-90.3(0.19)	-0.31(0.12)

[a]...All skew(an) harmonics are calculated to be 0
bn is 10^{-4} of the Sextupole field at R= 25mm
The measured values are the mean of 300 magnets.
The rms spread is given in ( )

A. Anomalous Behavior

The b0 and b4 data in Figure 3 show a distinct "notch" at 45 A, this may be a manifestation of the dipole symmetry of the assembly. This has persisted through 300 magnets and appears in both up and down ramps. For mechanical compatibility with the rest of the magnets, the sextupole yoke is assembled in two pieces with an overall dipole symmetry. These harmonics are dipole symmetric, but why they should have this reproducible variation with excitation is unknown.

V. FIELD QUALITY -QUADRUPOLE

The low current measurements for the trim quadrupole are presented in Table III. The b3 term is probably a manifestation of the dipole assembly symmetry. The difference between calculation and measurement for b5 is unexpectedly large, however this harmonic is well within the accelerator requirements.

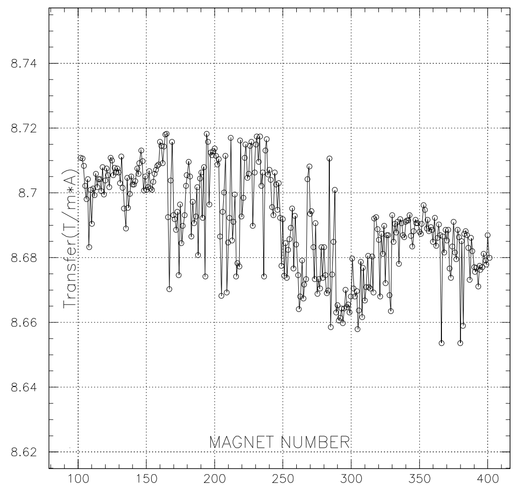

Figure 4. Sextupole Transfer Function History

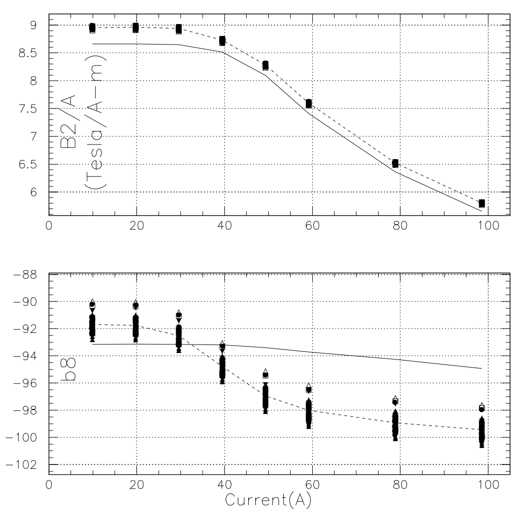

Figure 5. Sextupole Allowed Harmonics.
Total 49 Magnets Measured.
average=dashed curve. calculation=solid curve.

VI. CONCLUSIONS

Almost 400 of these two types of magnets have been built. The racetrack coil mounted on an iron poletip design has proven straightforward for commercial construction. The field quality of all the magnets tested has been acceptable without any iteration. With the final design used for the trim quadrupoles the quench performance is essentially perfect.

Table III
Integral Field Harmonics for Trim Quadrupoles. Total 53 Magnets. 0.25 A measurements.

Harmonic	Calculated	Measured	
	bn only[a]	bn	an
B1/A(Tesla/A)	0.2437	.2357(0.0002)	...
b2	0	0.692(0.684)	-0.837(1.510)
b3	0	-3.98(0.581)	-0.038(0.197)
b4	0	-0.031(0.168)	0.063(0.197)
b5	+2.5	-10.22(0.247)	-0.157(0.114)
b9	-0.73	-0.816(0.028)	-0.001(0.06)

[a]...All skew(an) harmonics are calculated to be 0
bn is 10^{-4} of the Sextupole field at R= 25mm
The measured values are the mean of 53 magnets.
The rms spread is given in ( )

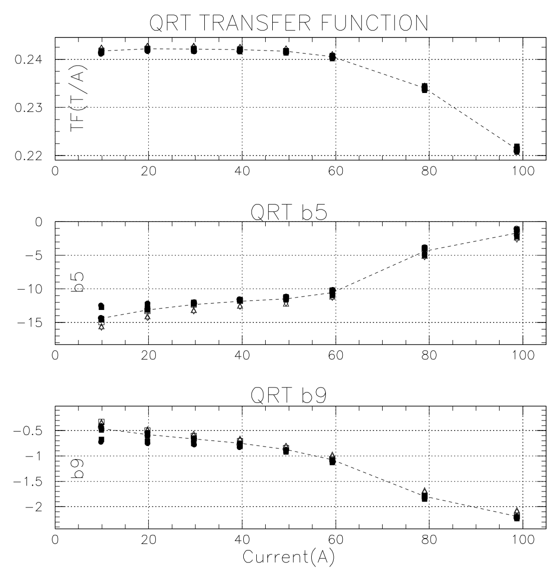

Figure 6. Trim Quadrupole Allowed Harmonics Saturation Behavior. Total 11 magnets measured.

References

[1] M. Lindner et al., *Construction Details and Test Results from RHIC Sextupoles*, IEEE Trans. on Magnetics, Vol. 30, No. 4, pp. 1730-3 (1994).