BNL-94134-2011-CP

The dipole corrector magnets for the RHIC fast global orbit feedback system

P. Thieberger, L. Arnold, C. Folz, R. Hulsart, A. Jain, R. Karl, G. Mahler, W. Meng, K. Mernick, R. Michnoff, M. Minty, C. Montag, V. Ptitsyn, J. Tuozzolo, J. Ritter, L. Smart, J. White

Presented at the 2011 Particle Accelerator Conference (PAC'11)
New York, N.Y.
March 28 – April 1, 2011

Collider-Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy
Office of Science

DISCLAIMER

The dipole corrector magnets for the RHIC fast global orbit feedback system[*]

P. Thieberger[†], L. Arnold, C. Folz, R. Hulsart, A. Jain, R. Karl, G. Mahler, W. Meng, K. Mernick, R. Michnoff, M. Minty, C. Montag, V. Ptitsyn, J. Tuozzolo, J. Ritter, L. Smart and J. White
Brookhaven National Laboratory, Upton, New York, U.S.A.

Abstract

The recently completed RHIC fast global orbit feedback system uses 24 small "window-frame" horizontal dipole correctors. Space limitations dictated a very compact design. The magnetic design and modelling of these laminated yoke magnets is described as well as the mechanical implementation, coil winding, vacuum impregnation, etc. Test procedures to determine the field quality and frequency response are described. The results of these measurements are presented and discussed. A small fringe field from each magnet, overlapping the opposite RHIC ring, is compensated by a correction winding placed on the opposite ring's magnet and connected in series with the main winding of the first one. Results from measurements of this compensation scheme are shown and discussed.

INTRODUCTION

Shortly after RHIC started operating in 2001, it was noticed that the beam position as measured with beam position monitors at various locations around both rings showed small horizontal fluctuations with frequencies close to 10 Hz. It was later determined [1] that these oscillations could be attributed to mechanical vibrations of the large superconducting quadrupole magnets that are part of the quadrupole triplets present at either side of each of the six interaction regions, integrating the respective low-beta insertions. These magnets are mounted on vertical insulating pedestals made of ULTEM plastic, the flexibility of which allows the large masses of the magnets to act somewhat like inverted pendulums. It was further determined [1] that the excitation of these oscillations is probably due to unavoidable fluctuations in the helium flow.

While at the beginning the luminosity was mostly unaffected, that situation has been gradually changing as the beam size at the interaction points is being reduced [2]. Recently luminosity fluctuations correlated with these oscillations have been observed and this effect, if not mitigated, could become the dominant luminosity-limiting factor.

Over the past years, several potential solutions were investigated. Stiffening of the Quadrupole support structures had been extensively studied and found to be difficult and expensive to implement, mainly due to cryogenic heat load limitations. Mechanical sensing of magnet motion and active mechanical damping was implemented on one of the RHIC quadrupoles and found to be effective [3], but too expensive to implement at the 36 locations around each ring. Local orbit feedback, designed to suppress the relative offset between the beams at the interaction points, was developed however with no discernible improvement in the luminosity lifetime observed with the feedback [4]

Finally it was decided to adopt a global orbit feedback system [5] based on using one small dipole corrector magnet per Quadrupole triplet (24 in total; 2 in each of the 6 interaction regions of each RHIC accelerator), a subset of the existing beam position monitors equipped new daughter cards to allow for high temporal resolution of the measured beam positions, and a dedicated Gigabit Ethernet network topology [6]. Fig. 1 shows the locations of four of these dipole correctors corresponding to one of the six RHIC interaction regions.

This feedback scheme, the design and implementation of the computer hardware and software as well as performance results are described elsewhere in these Proceedings [5, 6]. Here we describe the magnet design, fabrication and testing.

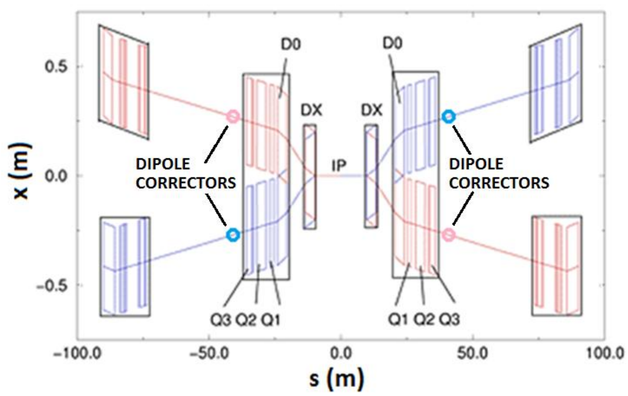

Figure 1: Schematic view of the RHIC "6 o'clock" interaction region. The circles indicate the approximate locations of the corrector magnets close to the cryostats.

MAGNET SPECIFICATIONS AND DESIGN

Based on the measured beam oscillation amplitudes and on the proposed feedback scheme, accelerator model calculations were performed to establish the required maximum dipole strength of 1.6E-3 Tm corresponding to a maximum deflection of ~1.9 μ radians for 250 GeV protons. The optimum location of these magnets as shown in Fig. 1 is in close proximity of the quadrupole triplet cryostats. A severe design constraint was

[*] Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy
[†] PT@BNL.GOV

imposed by the scarcity of available space at some of these locations. For two locations (4 magnets) it was necessary to deviate from this configuration by placing the magnets ~9 m away from the cryostat instead of the standard ~1 m elsewhere.

A very short "window frame" dipole was designed that could be mounted on vacuum tees, available at most of these locations. Figure 2 shows the dimensions of this laminated yoke dipole magnet. Extensive model calculations were performed to establish integrated field quality as well as frequency response.

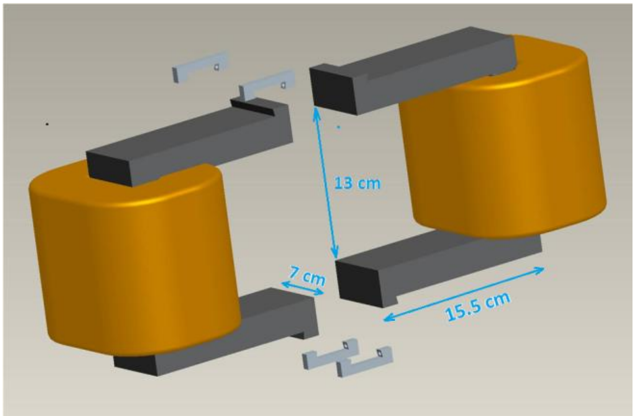

Figure 2: Drawing of the two halves of one of the corrector dipoles and the clamps used in their assembly designed so as to avoid vacuum system disruptions during installation.

FIELD QUALITY AND FREQUENCY RESPONSE TESTING

Extensive measurements were performed on a prototype magnet before proceeding with the fabrication. A long flat coil was used to obtain values of dB/dt integrated along the beam direction, as the power supply was delivering sinusoidally varying currents of selectable amplitude and frequency. Figures 3 and 4 show some of the results of these tests. Both field uniformity as well as frequency response was found to be adequate.

FABRICATION AND INSTALLATION

Upon order and receipt of the 48 halve yokes (plus a few spares), coils consisting of 225 turns of #6 gauge magnet wire were wound on each, using a motor driven rotating table arrangement (see Fig. 5). Vacuum epoxy resin impregnation was performed using specially designed molds (see Fig.6). As shown in Fig. 7 the magnets were installed in the RHIC tunnel on vertical supports anchored to the floor.

FIELD OVERLAP COMPENSATION

The proximity of the two RHIC rings at the corrector locations as well as the geometry of the magnet yokes causes the fringe field from each magnet to be measurable at the opposite ring location. The measured overlap strength of about 3% is small considering the very small bending strength of these magnets, but possible undesirable cross-talk effects are further minimized by cross-connected compensation coils as shown in Fig.8. The number of turns on the compensating windings was determined experimentally. As can be seen in Fig. 9, better compensation is obtained by using a single winding rather than symmetric windings on both sides of the magnet. This compensating field is not shorted out by the iron on the opposite side since both main coils are connected in parallel effectively coupling both sides of the magnet. We see from Fig. 9 that this compensation scheme provides almost perfect fringe field cancellation at the center of the magnet and a factor ~5 improvement at 4 cm from the center. This compensation will be adequate in view of the weak overlap field.

Fringe field interference with convection enhanced Pirani gauge vacuum readings was resolved by eliminating the unnecessary temperature compensation. The temperature sensing windings were replaced by fixed resistors.

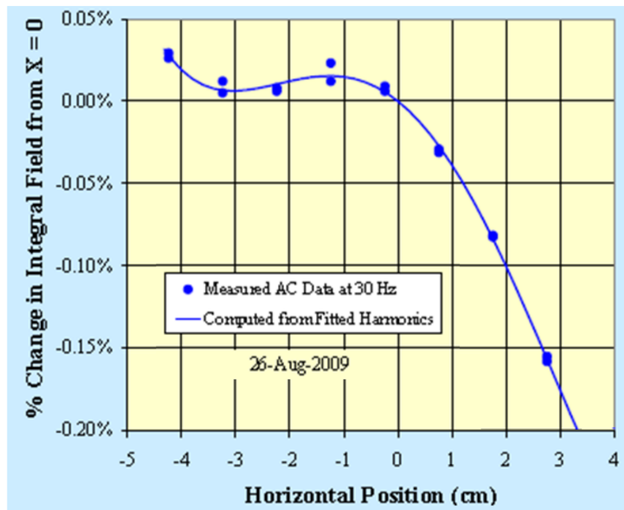

Figure 3: Example of measured integrated field variations as function of distance from the nominal beam axis, obtained with a 0.61 m long flat coil and 30 Hz field excitation in this case.

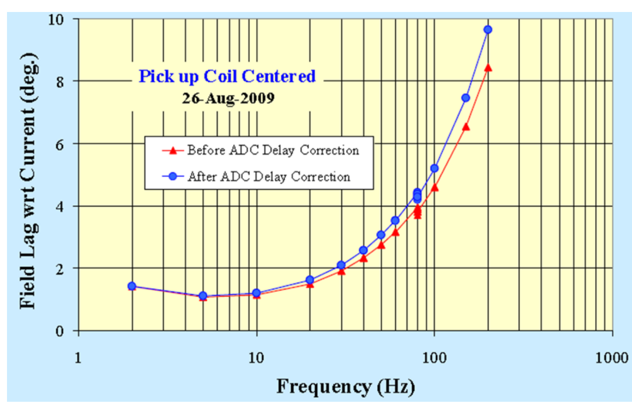

Figure 4: Measured frequency response of the prototype laminated yoke corrector magnet.

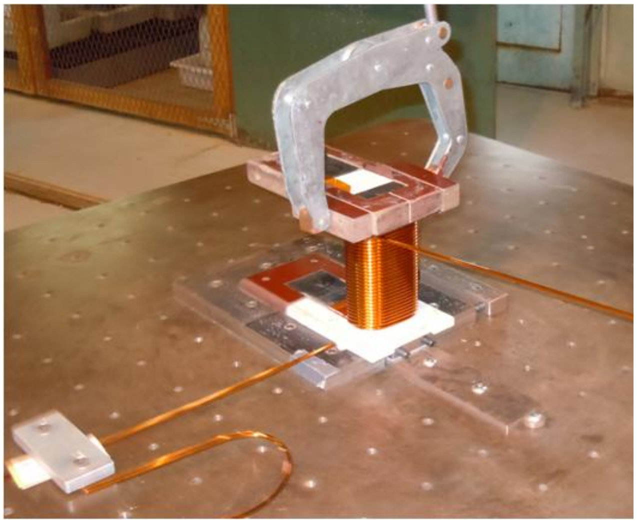

Figure 5: Rotating table arrangement for coil winding.

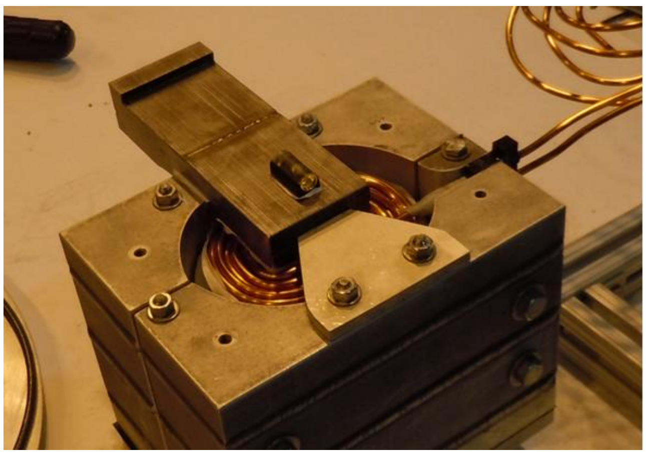

Figure 6: Coil in potting mold ready for vacuum impregnation.

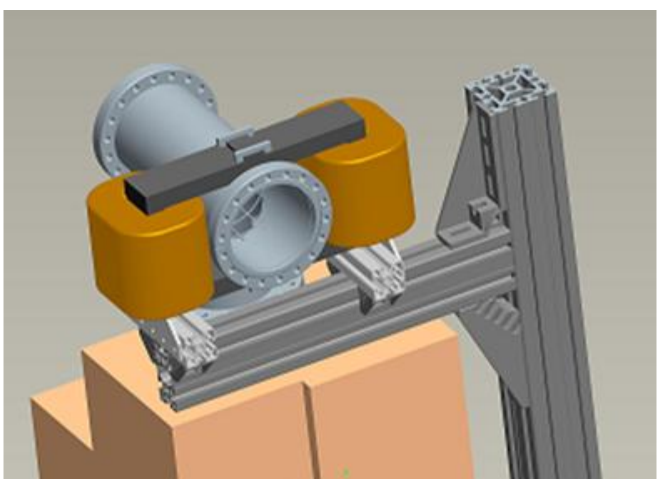

Figure 7: Dipole corrector mounted on its stand. Also shown is the vacuum-T where the magnet is located.

.

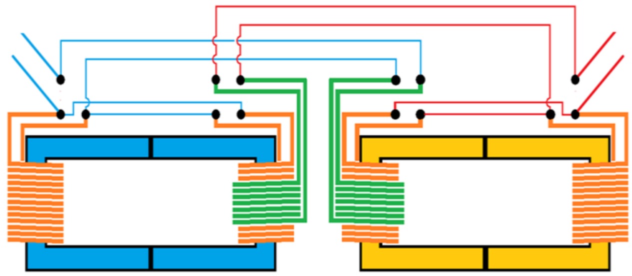

Figure 8: Schematic diagram of the connections for a pair of corrector dipoles mounted close to each other on the "blue" and "yellow" rings. The green windings are the compensation coils connected in series with the main coils of the opposite magnet.

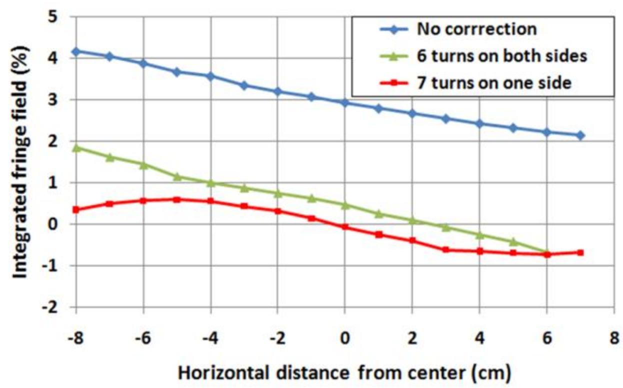

Figure 9: Results of tests performed to determine the best configuration of the coils used to compensate the cross-over field affecting the opposite ring.

CONCLUSIONS

The successful design, fabrication, testing and installation of small laminated yoke dipole magnets, now located at twelve locations around each of the RHIC rings, provides the corrector capabilities required for the implementation of a fast global orbit feedback system [5] designed to effectively eliminate the horizontal beam oscillations at frequencies close to 10 Hz. that have plagued these accelerators for years.

REFERENCES

1) C. Montag *et al*, Nucl. Instr. Meth. A 564, 26-31 (2006).
2) M. Minty, proc. of IPAC10, p. 528 (2010).
3) R. Bonati *et.al.* , proc. of IPAC10, p. 516 (2010).
4) C. Montag *et.al.*, proc. of PAC05, p. 3298 (2005).
5) R. Michnoff *et. al.*, these proceedings
6) R. Hulsart *et.al.*, these proceedings