IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

SUPERCONDUCTING MAGNET SYSTEM FOR RHIC*

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Abstract

The proposed Relativistic Heavy Ion Collider[1] (RHIC) will operate at ion energies of 7 to 100+ GeV/Amu for ions as heavy as Au^{197}. This paper discusses the superconducting magnet system for this machine. It will consist of 372 dipoles typically 9.7 meters long with an operating field of 3.4 Tesla, 492 quadrupoles with typical length 1.4 meters, gradient 76 T/m, and approximately 1000 sextupole and corrector magnets. A detailed design has been developed for the dipoles which will have a clear bore of 76 mm; less detailed designs are presented for the other components. A proof-of-concept magnet has been constructed and successfully tested.

Introduction

The RHIC is designed as a two ring, six interaction region machine with a heavy ion energy range from 7 to 100+ GeV/Amu for ions as heavy as Au^{197}. The magnetic rigidity of 100 GeV ions is approximately that of 250 GeV protons-significantly less than that of existing proton machines (e.g. FNAL 1000 GeV). Because of the much higher charge, the emittance of heavy ion beams is greatly increased by intra-beam scattering.[2] This requires a larger aperture than an equivalent proton machine. Important physics can be done by running with protons in one ring and heavy ions in the other. To do this the magnetic fields in the two rings must differ by a factor of 2.5. This specific proposal is designed to take optimum advantage of the existing facilities at BNL including a completed accelerator tunnel of 4 km circumference. To minimize R&D the design is based as much as possible on existing technology, particularly that developed at FNAL and BNL.[3]

These constraints, together with the usual ones of cost and technology produce specifications which differ in several ways from proton machines: large bore - 76 mm, modest dipole field - 3.4 Tesla, short cell structure - 1 dipole/half cell, independence of the two rings.

The six regular arcs of the two rings will contain a total of 288 dipoles and 276 quadrupoles. In addition, the 6 intersection regions will contain 84 dipoles and 216 quadrupoles. Because of the need to run the two rings at drastically different magnetic rigidities, the rings will be magnetically, cryogenically and mechanically separate. Exceptions occur for the 18 magnets closest to each crossing point.

Regular Arc Half Cell

Figure 1 shows the layout of a half cell; the regular arcs are composed of 288 such units. Controlling the beam growth produced by intra-beam scattering favors this short structure with only one dipole. The modest operating field of the dipoles together with the small natural chromaticity (70) of the rings makes it possible to localize the sextupole next to the quadrupoles. Likewise, the expected small random errors of the magnets make it practical to use lumped correctors.

Dipoles

The largest component of the magnet system is the dipole. The design chosen uses a 4.5 K iron yoke for mechanical support as well as a magnetic return path. The entire assembly of length 9.7 meters is bent to a radius of 250 meters to minimize the aperture requirement. The stainless steel bore tube is also at helium temperature. A cross section of the design is shown in Fig. 2.

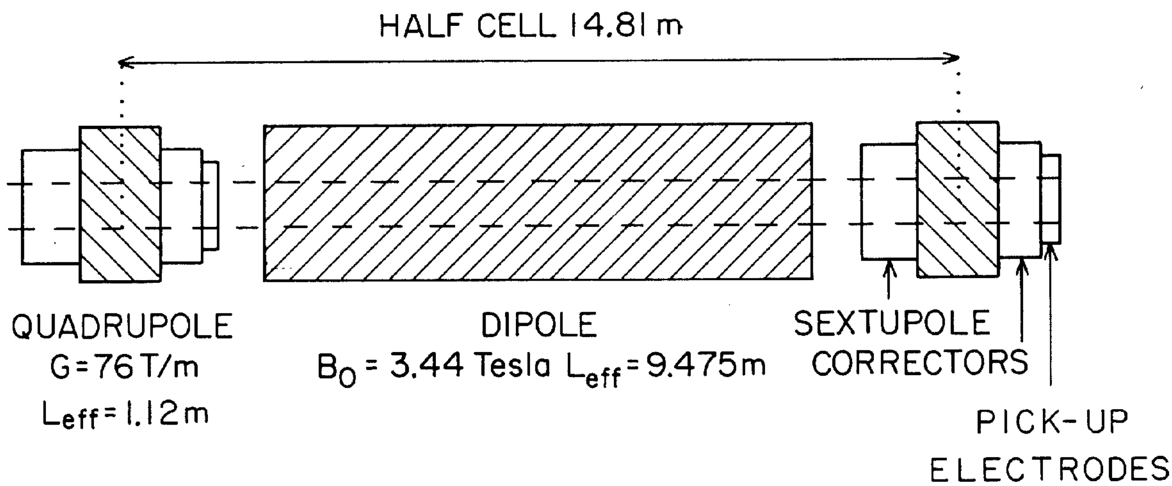

Figure 1. Schematic Diagram of Half Cell. The cross hatching shows the physical extent of the quadrupoles and dipole. The transverse scale is 10 times the longitudinal scale. Not shown are the components of the other ring which are displaced by 600 mm.

*Work supported by the U.S. Department of Energy

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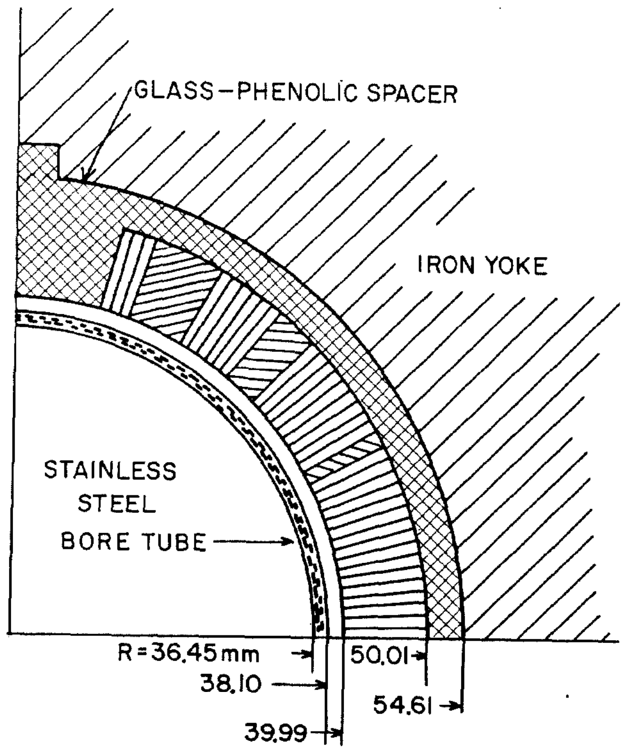

Figure 2. Cross Section of Dipole Magnet. The coil winding is subdivided into four blocks:

Block	Number of Turns	Included Angles
1	16	0.14-26.99 degrees
2	9	29.27-44.37 degrees
3	6	50.19-60.26 degrees
4	3	70.26-75.29 degrees

The coil is a single layer of Rutherford style cable, 9.73 mm by 1.16 mm, composed of 30 0.65 mm strands of Cu(63%)-NbTi(37%) conductor. The filament size is less than 9 μm to limit the harmonics generated by persistent currents. The expected short sample current is 6.2 kA @ 4.22 K and 5 Tesla. The cable will be insulated with Kapton and further protected with fiberglass impregnated with B-stage epoxy. The coils are wound on the outside of a cylindrical mandrel and precision molded at high pressure (>10 kpsi). These coils are located inside the iron yoke with precision glass phenolic insulators. After the assembly is compressed in a press, keys are inserted in the yoke halves to retain the compression. A stainless steel helium vessel is welded around the assembled yoke. When the unit is cooled the differential contraction of this vessel compresses the yoke, relieving the stress on the keys. The welding of this vessel also locks in the curvature of the magnet. Design prestress is 10 kpsi at 300 K, and (with allowance for creep) 6 kpsi at 4.5 K. Magnetic parameters of this device are:

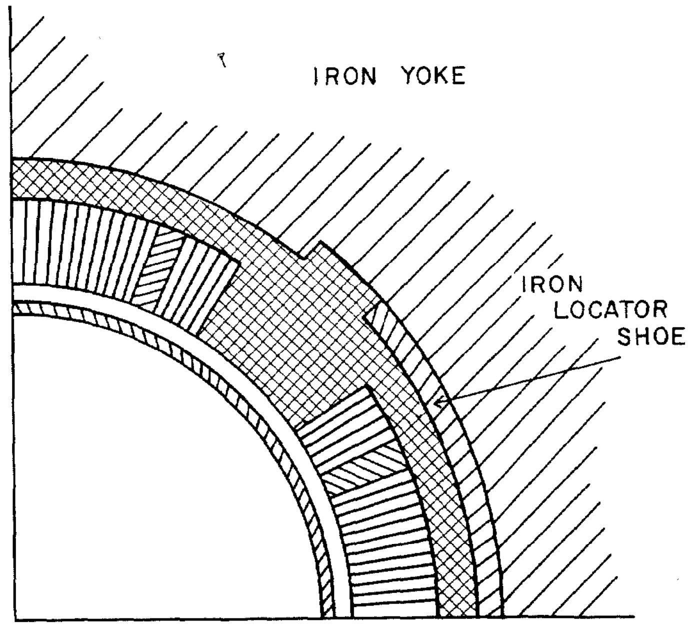

Figure 4. Cross Section of Quadrupole Magnet. Indicated is the moveable iron sector which locates the pole.

	100 GeV	Quench
Current	4.78 kA	6.46 kA
Field	3.44 Tesla	4.65 Tesla
Effective Length	9.475 meter	

Higher Multipoles

Figure 3 shows the combined assembly for the higher multipoles. A cross section for the quadrupole, the largest of the components, is presented in Fig. 4. The construction technique is

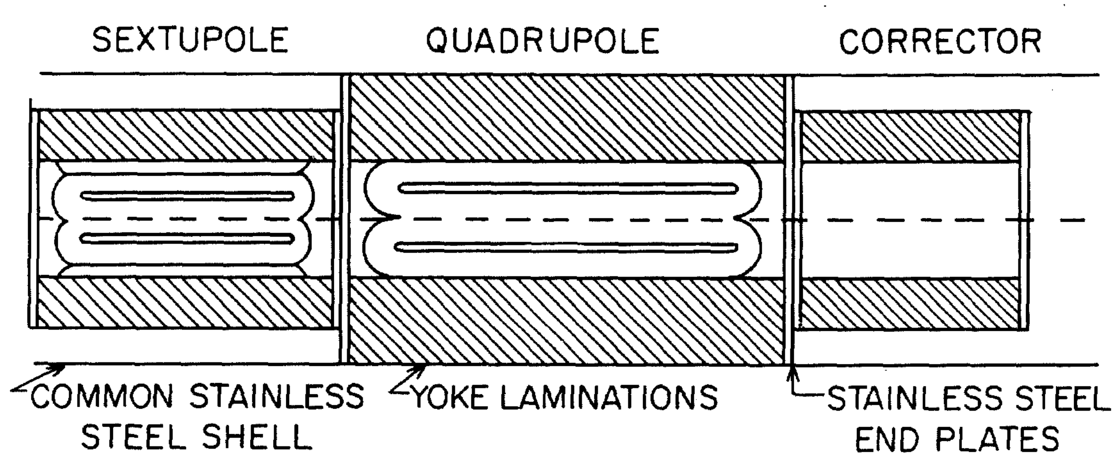

Figure 3. Schematic Multipole Magnet Assembly. The components are contained in a common stainless steel cylinder which serves as the helium confinement vessel.

similar to that for the dipoles with the addition of the sliding iron sector which accurately aligns the poles of the coils when the assembly is closed up. Magnetic parameters are:

	100 GeV	Quench
Current	4.78 kA	7.1 kA
Gradient	76 T/m	113 T/m
Effective Length	1.12 meter	

The next element is the sextupole magnet. For optimum correction of the natural chromaticity of the RHIC, several families of sextupole are required; for this reason a design with a large number (96) of turns of small (∼1 mm) wire was chosen. This minimizes the size of the connecting wiring and feedthrus. Magnetic parameters are:

	100 GeV	Quench
Current	180 A	400 A
Gradient	650 $T\text{-}m^{-2}$	1400 $T\text{-}m^{-2}$
Effective Length	0.75 meter	

The final magnetic element is the corrector package. This will contain wire windings capable of generating the following: 0.2 T-m of dipole, 1.5 T-m/m of quadrupole and small amounts of higher multipoles.

Insertions

One third of the total number of magnets will be in the insertion regions. Most of these will be similar to the regular arc magnets. The exceptions are:

BC1: which is common to both rings and is designed with the following parameters-- coil aperture 200 mm, effective length 3.3 meters, operating field 5.5 Tesla;

BC2: coil aperture 100 mm, effective length 4.4 meters, operating field 4.1 Tesla;

Q1-Q3: coil aperture 130 mm, effective lengths 0.5-1.5 meters, gradients ∼56 T/m.

BC2 is a modification of the design for the regular arc dipoles; the others are modifications of magnets developed for the CBA project.

Proof-of-Concept Dipole

Although the basic design of the RHIC magnets is conservative and based on demonstrated technology it is prudent to test the details of the design before proceeding. For this reason preliminary dipoles have been constructed by BNL and Brown Boveri Corp. to confirm the concepts - particularly the curvature and the use of a single layer coil.

The BNL model dipole has been tested. The coils for this magnet were wound and molded by FNAL, and except for the length (4.5 m) were identical to the Tevatron dipole inner coils (35 turns, inner radius 37.90 mm). These coils were placed in a 4.5 meter iron yoke assembly which had been bent to the 250 meter radius of curvature and had additional iron laminations inserted to reduce its inner radius to 51.2 mm. For this test vehicle, the yoke halves were held together with bolts rather than a stainless steel outer shell. The performance of this magnet is plotted in Fig. 5, where the curve is the expected quench current calculated from the short sample measurements of the cable. At the design operating temperature (4.5 K) the agreement is excellent; at lower

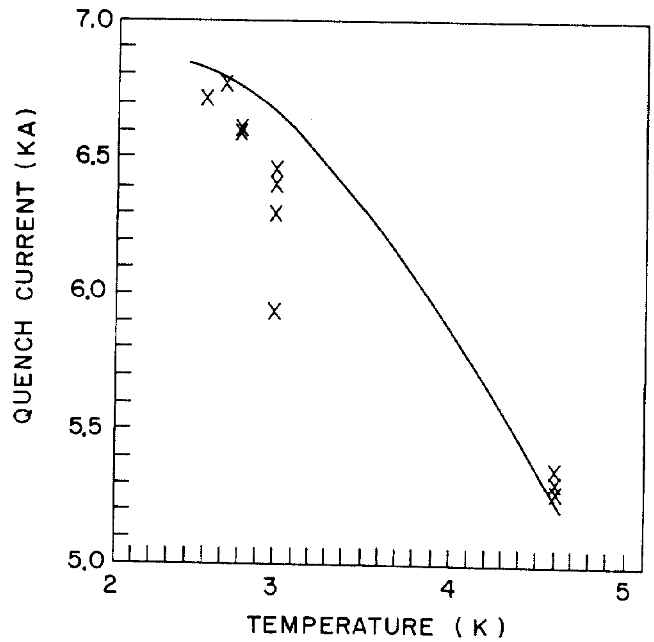

Figure 5. Quench Performance of RHIC-BNL-X1 Dipole Magnet. The measured quench currents are indicated with x. The predicted values are indicated with a solid line.

temperatures modest amounts of training appear and the magnet does not always reach the short sample limit. In the assembly the initial prestress was 10 kpsi. Due to creep and contraction this was approximately 6 kpsi under operating conditions. This is adequate to contain the motion up to currents of 5.8 kA.

Tests were made of the temperature rise in the conductor following quenches induced by small heaters. For normal operating conditions these gave a peak temperature of 150 K with a time integrated current-squared (I^2dt) of 4.2 x 10^6 A^2-sec. A conservative extrapolation of these results to production magnets gives an I^2dt of 8.4 x 10^6 A^2-sec and a peak temperature of 700 K. This is comfortably below the measured temperature at which damage occurs (1050 K). Thus the passive diode quench protection system developed for the CBA magnets can be used.

This test demonstrated that this design: 1) is straightforward to construct, and 2) reaches short sample current at operating temperature with no training.

References

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