THE RHIC PROJECT*

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Abstract

The design and construction status of the Relativistic Heavy Ion Collider, RHIC, is discussed. Those novel features of a heavy ion Collider that are distinct from hadron Colliders in general are noted. These features are derived from the experimental requirements of operation with a variety of ion species over a wide energy range including collisions between ions of unequal energies. The project is in the fourth year of a seven year construction cycle. A review of the superconducting magnet program is given together with progress to date on the machine construction.

1 INTRODUCTION

The overriding motivation for colliding heavy ions at ultra-relativistic energies is the belief that it is possible to create macroscopic volumes of nuclear matter at such extreme conditions of temperature and energy density that a phase transition will occur from hadronic matter to a confined plasma of quarks and gluons]. The main goal of RHIC is to provide head-on collisions at energies up to 100 GeV/u per beam for very heavy ions, which is defined to be gold ($^{197}Au^{79}$), but the program also calls for lighter ions all the way down to protons. Luminosity requirements for the heaviest ions were specified to be in the $10^{26\text{-}27}$ cm^{-2} s^{-1} range. The higher Au-Au total cross-section results in interaction rates comparable to p-p Colliders although this luminosity is several orders of magnitude lower than those machines. A short interaction point length (< 20 cm rms) is desirable for optimum detector design. The final, though most influential, experiment requirement was the need for collisions of different ion species (most notably p-Au) at the same center of mass energies per nucleon. This necessitates accommodating charge to mass ratios (A/Z) in the range of 1 (p) to ~2.6 (Au). Stabilizing the collision point involves equalizing the rotation frequencies of the two beams in turns requires the two rings to operate at different magnetic fields. The complications in the interaction region where the beams must pass through common magnets dictate a lattice design different from conventional hadron Colliders.

Based on these general requirements the detailed RHIC machine parameters were derived and are outlined in Table 1. Operation of the RHIC Collider at relatively low energies together with the enhanced intrabeam scattering, which scales as Z^4/A^2, result in beam of large transverse and longitudinal dimensions. This in turn has ramifications for the lattice (short cells, strong focusing), and magnet aperture. The rf system requirements are also determined by this consideration and the short interaction point. Colliders, unlike fixed target machines, are designed to operate for extended periods at high energies. The economics of power consumption argue strongly for superconducting magnets and RHIC is a superconducting machine.

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Table 1
Major Parameters for the Collider

Kinetic Ener., Inj.-Top (each beam), Au	10.8-100	GeV/u
protons	28.3-250	GeV
No. of bunches/ring	57	
Circumference	3833.845	m
Number of crossing points	6	
Beta @ crossing, horizontal/vertical	10	m
low-beta insertion	1	m
Betatron tune, horizontal/vertical	28.18, 29.18	
Transition Energy, γ_T	23.60	
Magnetic Rigidity, $B\rho$: @ injection	97.5	T·m
@ top energy	839.5	T·m
Bending radius, arc dipole	242.781	m
No. of dipoles (192/ring+12 common)	396	
No. quadrupoles (276arc+216insertion)	492	
Dipole field @ 100 GeV/u, Au	3.45	T
Arc dipole length, effective	9.45	m
Arc quadrupole gradient	71.2	T/m
Arc quadrupole length, effective	1.11	m
Coil i.d. arc magnets	8	cm

2 MACHINE LAYOUT AND LATTICE

The complete RHIC facility will be a complex set of accelerators interconnected by beam transfer lines. The RHIC rings are shown schematically in figure 1. The Collider is located in the existing ~3.8 km tunnel north of the AGS. It is comprised of two identical, quasi circular rings separated horizontally by 90 cm, and oriented to intersect with one another at six locations. Having 3-fold symmetry each ring consists of three inner and three outer arcs and six insertion regions joining the inner and outer arcs. Each arc consists of 11 FODO cells with each half cell consisting of a single dipole together with a spool piece assembly containing a quadrupole, sextupole and concentric correction elements. The nominal design magnetic rigidity of the dipoles is 840 T·m which corresponds to a design field of 3.45 T at 100 GeV/u. Injection takes place at 97.5 T·m. The half-cells are 15m long and have beta-functions in the range 10.5 -> 50 m with a dispersion maximum of 1.8 m. These relatively small values are dictated by the need to minimize the physical size of a beam (i.e. maximize dynamic aperture and thus intensity lifetime) with relatively large normalized emittances (40π mm-mrad 95%, 1.2 eV-s/u). The dipole coil i.d. of 8 cm is determined by the beam size at injection and also the projected emittance growth which occurs during a store at the lowest collision energy of 30 GeV/u. The quadrupoles run at a maximum gradient of 72 T/m and also have a coil i.d. of 8 cm. A cross-section of a dipole is shown in figure 2. The magnets are conceptually similar to the HERA dipoles with a 'cold-iron' design and cryogenic transfer lines located in the cryostat. Each dipole is 10.45 m long.

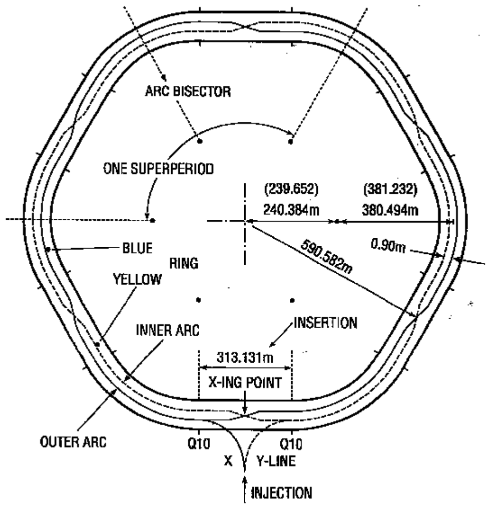

Figure 1. Layout of the Collider and (in parenthesis) of the tunnel.

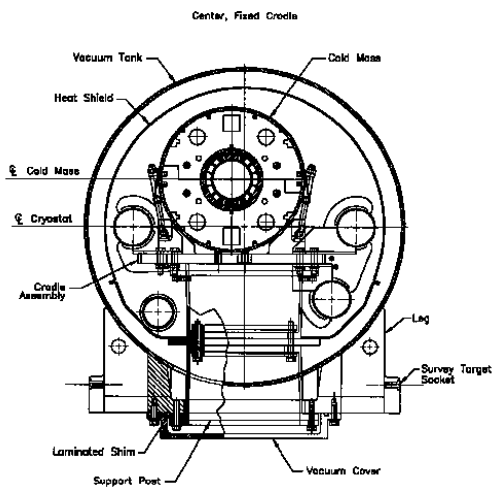

Figure 2. Arc dipole with cryostat cross section.

Collisions of the beams take place at the crossing point of the insertions. These regions contain the optics necessary for producing a small betatron amplitude function β^*, zero dispersion at the crossing point, and the bending magnets to bring the beams into head-on collisions. The 'non-arc' regions also contain the only warm regions of the machine where the machine utilities reside such as injection, beam abort, rf, collimators and specialized instrumentation. Locations available for these other devices are the 35m between Q3 and Q4, the missing dipole between Q7 and Q8, and the region adjacent to the short D9 dipole. The magnetic elements in the Q10 -> Q4 region are identical in cross-section to the standard cell but with various lengths. The final focus triplet (Q1, Q2, & Q3), and bending magnets (D0 & DX) are non standard magnets with apertures of 13cm, 10cm and 18cm respectively. The focusing is relaxed at injection with a β^*value of 10 m. During collisions at top energy a β^* of 1 m can be attained resulting a betamax of ~1400m in the triplet quadrupoles. The maximum focusing is determined by both the physical beam size in the triplet and the strength of the trim quadrupoles at Q4, Q5 and Q6. The lattice functions in the IR's are shown in figure 3.

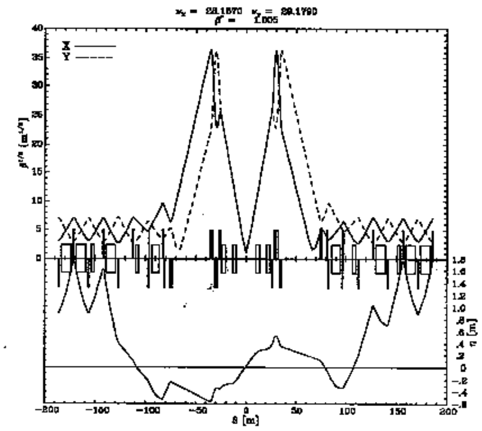

Figure 3. Betatron and dispersion functions in the insertion region.

Each insertion is independently adjustable and can be matched over a machine tune range of ± 1 unit. The phase advance across the insertion is almost constant during the squeeze, as is the triplet excitation.

3 MAGNET PROGRAM

A major goal of the Project to date has been the superconducting magnet construction program. The magnets naturally fall into two type; the 8cm elements which are used throughout the arc regions and constitute the bulk of the magnets, and a smaller number of variable aperture magnets used in the immediate vicinity of the interaction regions. A list of the various magnet type is given in Table 2.

Table 2
RHIC Magnet Inventory

8 cm dipoles	360
8 cm quadrupoles	426
sextupoles	288
8 cm multilayer correctors	426
13 cm IR quadrupoles	72
13 cm IR correctors	72
10 cm IR dipoles	24
18 cm IR dipoles	12

The 8 cm dipoles, quadrupoles and sextupoles were all produced industrially. The low current correctors, the final focus triplet quadrupoles and beam splitting dipoles were produced internally by BNL. BNL also performed the integration of the quadrupole, sextupoles and correctors into a single cryogenic module. The dipole magnets, produced by the Northop-Grumman Corporation in a build to print contract, were complete cryogenic elements suitable for immediate installation. The industrially produced magnets were completed during a two year period of 1994-96. The BNL production program will continue through 1998.

The crucial aspects of superconducting accelerator magnets involve field quality and quench threshold. Since it was decided that cold testing of each magnet was not realistic it became important to establish that there was a good correlation between warm and cold magnetic field measurements. An example of the results obtained by comparing warm and cold field measurements is shown in figure 4 which compares normal and skew sextupole harmonics from a sample of dipoles.

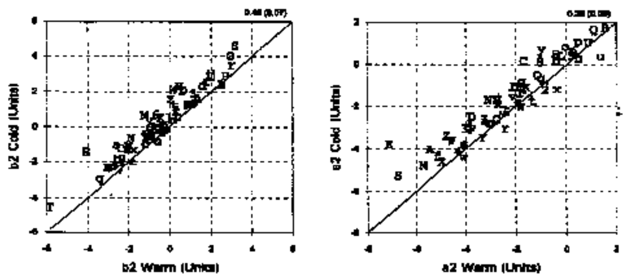

Figure 4. Warm-to-Cold correlations of the magnetic field harmonics for the dipole magnets.

An analysis of the complete data set demonstrated that after compensating for yoke saturation effects, good warm/cold field correlations can be obtained.

The distribution of field harmonics for the full set of dipole magnets is shown in figure 5. The magnet set demonstrates excellent field quality with very small

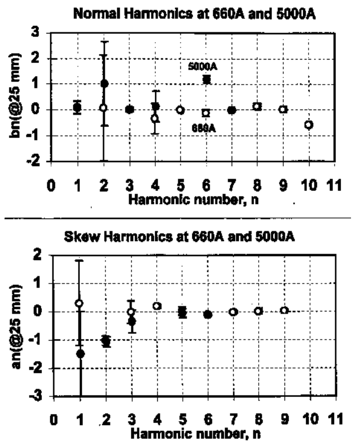

Figure 5. Dipole magnetic field harmonics.

random filed components by virtue of good mechanical tolerances on the cable dimensions. The systematic component of the field harmonics is optimized for low field performance with yoke saturation apparent in the allowed harmonics at high field. During collisions the dynamic aperture is determined by the triplet quadrupoles with a beta maximum of 1400m. In order to optimize the field quality in these elements a technique of using magnetic shims to compensate the lower eight harmonics has been developed. This has proven effective in adjusting the field quality to within several parts in ten thousand across 2/3rds of the coil aperture.

The quench performance of the 8cm dipole magnets is shown in figure 6, which shows the minimum and plateau quench currents for a set of 60 dipole magnets. Since only 20% of the magnets are measured cold, it was important to demonstrate sufficient operating margin to make limited testing viable. None of the magnets tested to date have had an initial quench current less than the nominal operating level. The plateau quench level demonstrates a healthy 30% operating margin. For the lower number of interaction region magnets, with less predicted margin, 100% vertical dewar cold testing will be used.

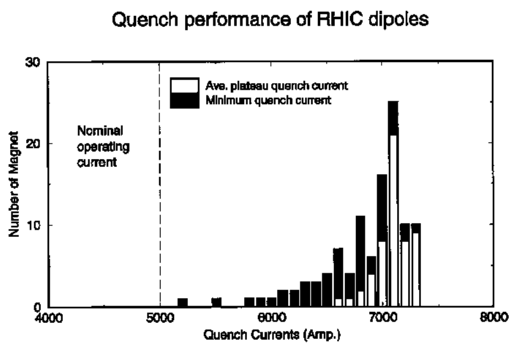

Figure 6. Dipole magnet quench current distributions.

4 CONSTRUCTION STATUS

With the delivery to the tunnel of over 600 cryogenic magnets installation activities are proceed at full speed. All of the magnets are in place for the arc sections (Q10->Q10) and initial magnet interfacing has started on these regions. Joining two magnets together requires 7 pipe connections together with heat shields, instrumentation leads, vacuum ports and super insulation. The present rate of 1 interconnect per day will be doubled shortly which will result in the all 8cm magnets installed by the spring of 1998. In addition the first of the interaction region quadrupole triplets and beam separating dipoles are presenting under construction. The lateral separation in this region requires that two cold masses are in a single cryostat. The physical size of this cryostat necessitates that it be constructed *in situ* with the magnets transported to the tunnel as cold masses. In addition to magnet installation, work is proceeding on other systems. Cryogenic distribution piping is a significant effort. The connection between the central refrigerator and the tunnel has been completed and work is in progress to complete the first sextant of the machine. The main 5KA power supplies are installed and the first of the superconducting buss connecting to the magnets is in place.

During the past 12 months the machine construction has progressed to the point of allowing the first major system testing. The cryogenic refrigerator has been completed and has been operated in a test mode on several occasions. Overall system performance has been at or beyond nominal specifications though numerous minor problems were encountered and resolved.

The beam extraction system from the AGS and the injection line was completed during the summer of 1995 and several months later gold beam was transported down the line to an internal beam dump [1]. This was the first of a series of integrated systems tests planned for Project. The first step in this test required the commissioning of a new AGS fast extraction system and was operated in a parasitic “cycle stealing” mode during normal AGS heavy ion operations. The injection line was the first demonstration of several of the final designed RHIC systems; controls, vacuum, instrumentation and power supplies. Measurements were made of the beam line optics and beam parameters and revealed good agreement with the nominal design parameters [2]. Presently scheduled for late 1996 a major test of the accelerator systems will be attempted when a complete sextant of the machine will be operated. The first step will be a cooldown and powering of the elements and then subsequently beam will be transported through the magnet string. This test will require a subset of essentially all of the accelerator components and will be a significant step in validating the machine hardware designs. Attempts will be made to commission the first application software with low level rf beam synchronization and ramping and storage conditions as major goals in addition to beam and optics measurements.

5 CONCLUSIONS

Although a significant amount of work remains to be done, the RHIC project is on track to start commissioning at the beginning of 1999. The machine design is stable and the component installation is in full swing. Upcoming major systems tests will be used to exercise the accelerator components during the next 12 months which is expected to provide a validation of the basic machine design.

6 REFERENCES

[1] RHIC to AGS Transfer Line: Design and Commissioning. W. MacKay, et. al. These Proceedings.

[2] Physics During the 1995 AGS-to-RHIC Transfer Line Commissioning. T. Satogata, et al. These Proceedings.