CURRENT ALIGNMENT OPERATIONS PROCEDURES FOR RHIC

Francis X. Karl
*Relativistic Heavy Ion Collider**
Brookhaven National Laboratory, New York, USA

1. INTRODUCTION

The Survey and Alignment staff at the Alternating Gradient Synchrotron Accelerator (AGS), has been assigned the task of defining the system and tooling up to support the Relativistic Heavy Ion Collider (RHIC) presently under construction at Brookhaven National Laboratory. We will be responsible for the precise setting of magnets, components, experimental apparatus, transport beam lines and defining geodetic concerns. It is the attempt of this document to outline the steps taken by us to achieve this task.

2. MACHINE HISTORY

High energy and nuclear physicists from around the world explore the basic structure of matter using the AGS. At 33 years of age, the AGS stands the test of time and endurance as a world class machine. With the recent addition of the Booster Accelerator, and tie in to the Tandem Van de Graaff, the AGS can accelerate protons to 33 billion electron volts (GeV), polarized protons to 22 GeV and heavy ions up to 14.6 GeV/nucleon. The AGS, in its new role as RHIC injector, will secure for itself an exclusive place in the setup of Nuclear and High Energy Physics at BNL.

The complete RHIC facility will be a complex set of accelerators and beam transfer equipment connecting them. A significant portion of the total facility either exists or is under construction. Figure 1 is a site plan showing all the major components. The two existing Tandem Van de Graaff accelerators will serve for the initial ion acceleration. Exiting from the Van de Graaff, the ions will traverse 0.8 kilometers along the Heavy Ion Transfer Line (HITL) to the Booster synchrotron.

The Booster is located between the existing 200 MeV proton LINAC and the northwest quadrant of the AGS (see Fig. 1), its circumference being one quarter that of the AGS. Beam from the Van de Graaff will be injected into the booster and stacked in betatron phase space by filling the machine with about 8 consecutive turns. Each particle bunch train transferred from the Booster to the AGS is accelerated to the top AGS energy (28.1 GeV for protons; 10.4 GeV/u for gold) and is stripped of their K-shell electrons and transferred to the collider by a magnet system installed in the existing transfer line tunnels. A total of 57 bunches are injected into each ring in boxcar fashion. Filling time per ring will be about 1 minute. The circumference of the collider is 3833.8 meters.

Bending and focusing of the ion beams is achieved with super conducting magnets, the maximum energy is about 100 GeV/u for gold and 250 GeV for protons. Maximum operational flexibility is obtained with single-layer cos magnets, which are in separate vacuum vessels. The beams in the arcs will be 90 cm apart. The cold bore beam aperture was chosen to be 73 mm in diameter.

It will be possible to produce head-on collisions as well as crossings at angles up to 7 mrad. The free space available for experimental equipment around the intersecting points is about 9 meters. The RHIC lattice configuration allows for 6 beam interaction point, two of which are slated for detectors Star and Phoenix.

* Funded by U.S. Dept of Energy

3. TOLERANCE

Magnet Position Tolerances at 4 K

Beam Position Monitor - Reference Orbit[1]	x = y = 0.25 mm rms
Sextupole - Beam Position Monitor This tolerance refers to the magnetic center of the sextupole relative to the center of the BPM, all along the axis of the sextupole.	x = y = 0.13 mm rms
Quadrupole - Beam Position Monitor This tolerance refers to the magnetic center of the quadrupole relative to the center of the BPM, all along the axis of the quadrupole.	x = y = 0.25 mm rms
Dipole - Reference Orbit Tolerance refers to the magnetic center as given by fiducial marks of the dipole relative to the reference orbit all along the axis of the dipole. The dipole magnetic center is defined as the magnetic center of its magnetization sextupole.	x = y = 0.50 mm rms
Dipole Rotation The average horizontal component of the dipole magnetic field is to be less than 0.001 rms of the vertical component of the field	= 1 mrad rms
Quadrupole Rotation	= 1 mrad rms
Longitudinal Error Refers to longitudinal position of all magnets with respect to their ideal position along the reference orbit.	s = 1.0 mm rms
Long Term Position Stability The design shall make every effort to keep the long-term position stability, including creep effects, consistent with above position tolerances.	

4. ALIGNMENT TOOLS

4.1 AGS Construction

When the AGS was in its construction stage 33 years ago, BNL used the best available equipment; Wild T3's and invar tapes were employed to shape the control network of 24 pedestal type monuments. An attempt was made to install these 24 monuments at precise locations relative to the AGS machine center; i.e. 15 degree intervals with a radius of 5165.400 inches (131.17576 meters). Once these monuments were in their design location, precision length bars were used to provide the proper offset to the line between monuments for the radial location of the 240 AGS magnets. This alignment scheme worked well for the early accelerator alignment technicians. Because of the need for larger machines, the advent of the computer age and the development of electronic survey instruments, new methods and techniques were constantly being sought to speed the alignment process and add confidence to the work performed by the alignment group.

4.2 Isabelle Construction

Historically, upgrades of equipment were only done when absolutely necessary in view of budgetary constraints and continuing operational success at the AGS. When the ISAbelle collider was planned in the early 1980's, some new equipment was purchased. At that time we developed a system for precise linear measurements by using a laser interferometer with a

[1]Reference orbit positions are based upon tunnel net and primary monument measurements.

microscope and retroreflector assembly mounted on a cart fixed with cross-slides and a tilting bracket which rolled on a rail system between points to be measured. We were able to measure 30 meter distances precise to < 10 microns. This technique was employed in the alignment of the Booster, which was commissioned in 1989. Use of this mobile interferometer rail system consumed an inordinate amount of time and so the whole linear measurement process needed to be addressed when considering surveying a machine the size of RHIC.

A few benefits were realized when the ISAbelle project was canceled. The fact that the tunnel to house the RHIC Machine has been essentially complete awaiting the installation of a machine for the past ten or twelve years is one of those benefits. The RHIC tunnel infrastructure is built on a sand and gravel base, with some areas being constructed in fill situations. At the time of design and construction, settlement of as much as five centimeters was expected to take place in these fill areas. Most of this settlement has taken place and the facility now seems stable. Another benefit to the alignment group has been the absence of competition with construction crews for access to the facility.

4.3 RHIC Primary Network

The fist task in the RHIC alignment process was to establish primary penetration monuments on the tunnel floor. ISAbelle had been constructed with 12 corrugated pipes, from 12” to 18” in diameter, set vertically and penetrating the dirt berm that provides shielding for the accelerator. A Cern type monument was set under each of the twelve penetration pipes. Seven of these monuments had been previously set and observed by the National Geodetic Survey (NGS), in the fall of 1981. They would prove interesting for comparative reasons as we proceeded. The NGS used the MA100 manufactured by Telurometer, for the trilateration of these monuments.

In early 1991 we choose to use the Mekometer ME5000 as our work-horse for the trilateration network because of its past performance at other accelerators and its ability to measure short distances. Given the nature of our design lattice, some distances of just over 3 meters were desirable. With help from Dr. Robert Ruland and his staff at the Stanford Linear Accelerator Center, we purchased Geonet as our adjustment engine and were ready to proceed.

When the ISAbelle accelerator was being built, forest was clear cut around its perimeter for approximately 100 meters to allow for conventional construction of the tunnel facility. At that time, six of the twelve penetration monuments were fitted with a suitable structure to perform the necessary survey. At the approximate center of the accelerator, a 23 meter high Bilby Tower was installed to provide line of sight to the ring monuments over the existing ground features and trees found in the center of the machine. Four of the twelve penetration monuments, had similar Bilby Towers varying in height from 11 to 16 meters installed above them. The remaining eight penetration monuments were fitted with wooden pedestal stands or wooden double towers, the outer tower for personnel and the inner tower for the instrument. The height of the wooden observation towers varies between 1.5 and 3 meters.

The trilateration survey was started in the spring of 1992. We decided to perform two complete epochs with observations being made at night. The temperature was measured to 0.1 degree Centigrade, barometric pressure measured to 0.1 millibar and relative humidity to ± 2%, in an attempt to maximize the reliability of the correction for refractive index. The observation pattern measured to the center monument and four neighboring monuments, two to either side of the occupation. The survey took two and one half months to complete by a crew of three surveyors working eight hour shifts. The results are pictured in Figure 2. and were gratifying, with absolute error ellipses major axis under 0.4 mm and minor axis under 0.2 mm. As I said earlier, we also compared these results with the 1982 NGS survey and were pleased to find that after ten years and with entirely different observation sets, the rms displacement of corresponding stations from one another was 1.5 mm.

4.4 RHIC Secondary Control Densification

With a good set of primary monuments in hand it was time to start the densification process inside the tunnel. There are approximately 850 magnet assemblies in the RHIC lattice. We decided to set one Cern type 30 mm stainless steel monument into the floor approximately 1.2 meters inboard or outboard of the center of each magnet. Additional monuments were set in areas were magnet spacing was larger than normal. A total of 1,008 monuments will make up the secondary control network.

In establishing a measurement scheme we iterated between measurement capabilities, measurement requirements dictated by the tolerances previously noted and time allowed for control observation by the project schedule. Trial schemes were modeled with Geonet. A final scheme was decided upon and measuring crews began the task of densifying the tunnel during the 1992 Christmas season. We are now approximately 80% complete with our first epoch of measurements for the entire machine. Our goal is to complete the process by the end of 1993. This goal appears achievable but certain open areas and magnet delivery tunnels now under construction might make it unattainable. The present system allows us to acquire secondary control information at the rate of four monuments per day with a two man crew.

We designed a target made from a precise 3.500” stainless steel ball which would fit uniquely into each monument. Bored into the ball is a 2.250” diameter K & E type optical target centered to 10 microns. The target is back lit with a high intensity fiber optic light source and can be viewed from the vertical as well as the horizontal. This system became the three dimensional reference for the accelerator.

Observations are carried out on an aluminum tripod, similar to that being used by Will Oren at CEBAF. Attached to the top of the tripod is our K & E type cross slide to allow us to optically plumb over the monument. The NL plummet manufactured by Leica had to be modified to allow us to stay with the Kern type forced centering system at the base of our ME5000 and T3000K’s. Distance observations are taken with the ME5000 and directions are measured using the T3000K from Leica. All data is taken and stored on Zeos 386 notebook computers. The data is then transferred to the 486 Swan computer for reduction and analysis by Geonet.

To date results obtained for secondary control surveys between primary monuments average 0.5mm major axis and 0.2mm minor axis of absolute error ellipses. Results have tended to improve for sectors most recently surveyed.

5. MAGNET FIDUCIALIZATION

The fiducialization process is formidable. We have approached it by designing fiducial bushings into the cryostat base on both sides of the magnet near its point of support. Their are four cryostat fiducials and four cold mass fiducials per quadrupole assembly, and six cryostat fiducials and four cold mass fiducials per dipole assembly. Each magnet will be pre surveyed before installation into the machine. To accomplish this, we have chosen the ManCAT manual coordinate analyzing theodolite system manufactured by Leica. We started using this system about eighteen months ago and are confident that it can make the measurements necessary to satisfy all requirements.

When the dipole magnets come to the lab from industry, we are supplied with a set of coordinate values for all ten fiducials, namely the four cold mass and six cryostat fiducials. Our first responsibility is to check to see if the magnet has arrived without any change of position. A reference file will be generated and comparisons made to achieve this end. At the same time as checking position we are generating the data needed to install the magnet into the lattice. All files are untouched by surveyors, all data is electronically captured and handled to assure accuracy of transmittal. This information will become part of the magnets history and will stay with the magnet for all future alignment concerns. This file is given to lattice programmers for their determination of its ideal position relative to its particular characteristics.

6. INSTALLATION

We are expecting our first RHIC dipole magnet from industry in January 1994, and plan on installing magnets soon thereafter. The present plan is to plumb over our Cern type secondary monuments and triangulate the magnet into position from two or three stations in the ring. Vertically, we would like to use the new electronic levels on the market, namely the NA3000 from Leica. We need some time to develop our technique, as well as our interface to laptop computers, but this technology is at hand. The fact that this accelerator is built on a sand and gravel base that is constantly moving makes one appreciate the need for fast and accurate vertical information. We think that the combination of the 30 mm Cern type three dimensional monuments and a slick vertical interface to electronic levels will lend itself to a productive and accurate solution to this problem.

After initial alignment has taken place we will go into the smoothing phase of the alignment process. I am under the impression that smoothing codes and procedures are going to be incorporated into Geonet in the near future. We are going to model our smoothing operation around the proven techniques established at CERN and SLAC.

7. CONCLUSION

The survey and alignment group has come a long way in the past two or three years. We have the personnel and the tools necessary to accomplish the goals set forth in the RHIC design manual. Many additional challenges lie ahead. The Star and Phoenix detectors require alignment techniques yet to be developed at Brookhaven and should prove extremely interesting, smoothing the magnets for final position must be formalized, understood and added to our tool box.

In August of 1989 it was my good fortune to be an attendee at the First International Workshop on Accelerator Alignment. With RHIC looming in the background and many questions to answer that workshop made it clear to me that the job of aligning RHIC was doable.

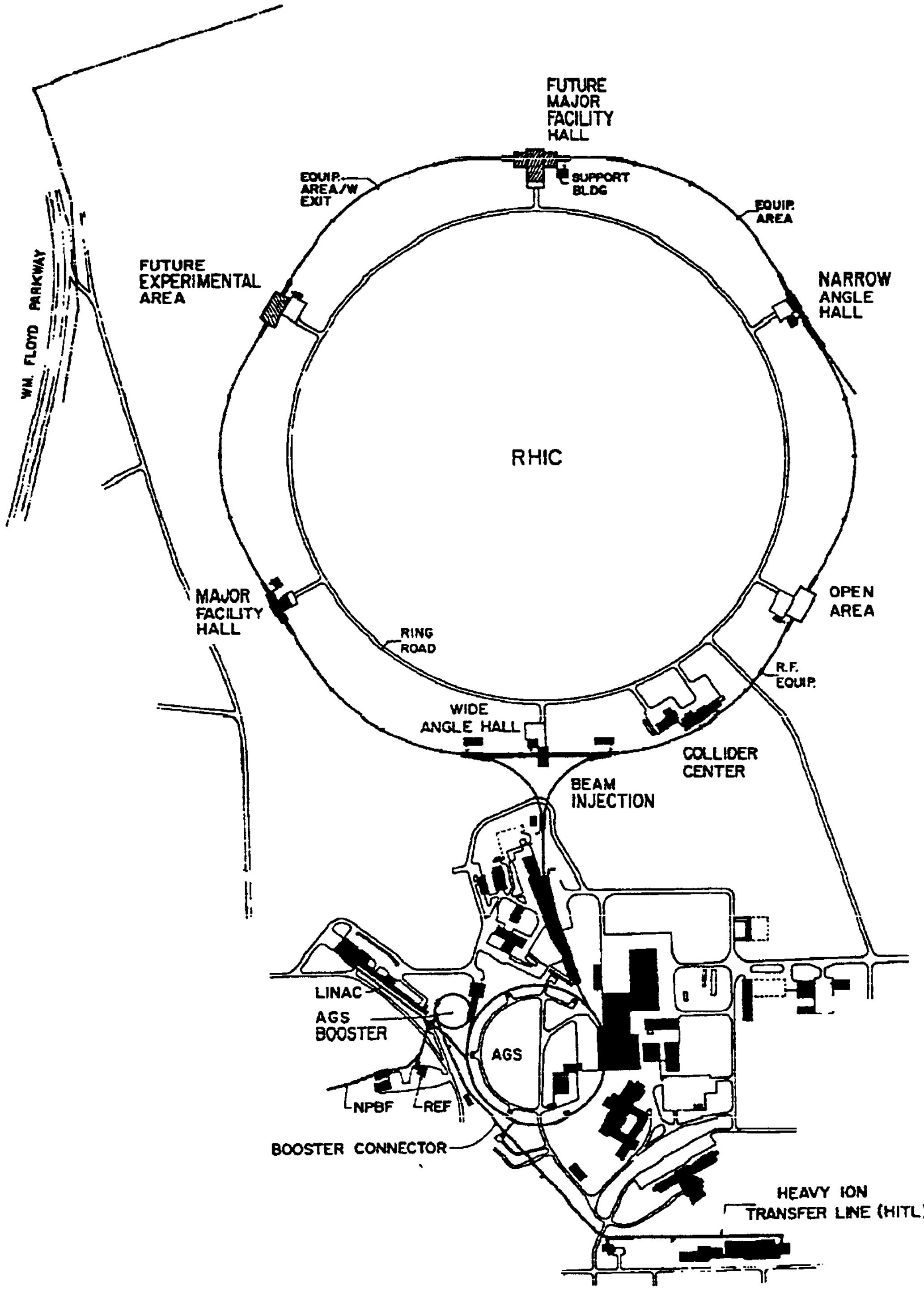

Figure 1.
Brookhaven National Laboratory
RHIC & AGS Accelerator Complex

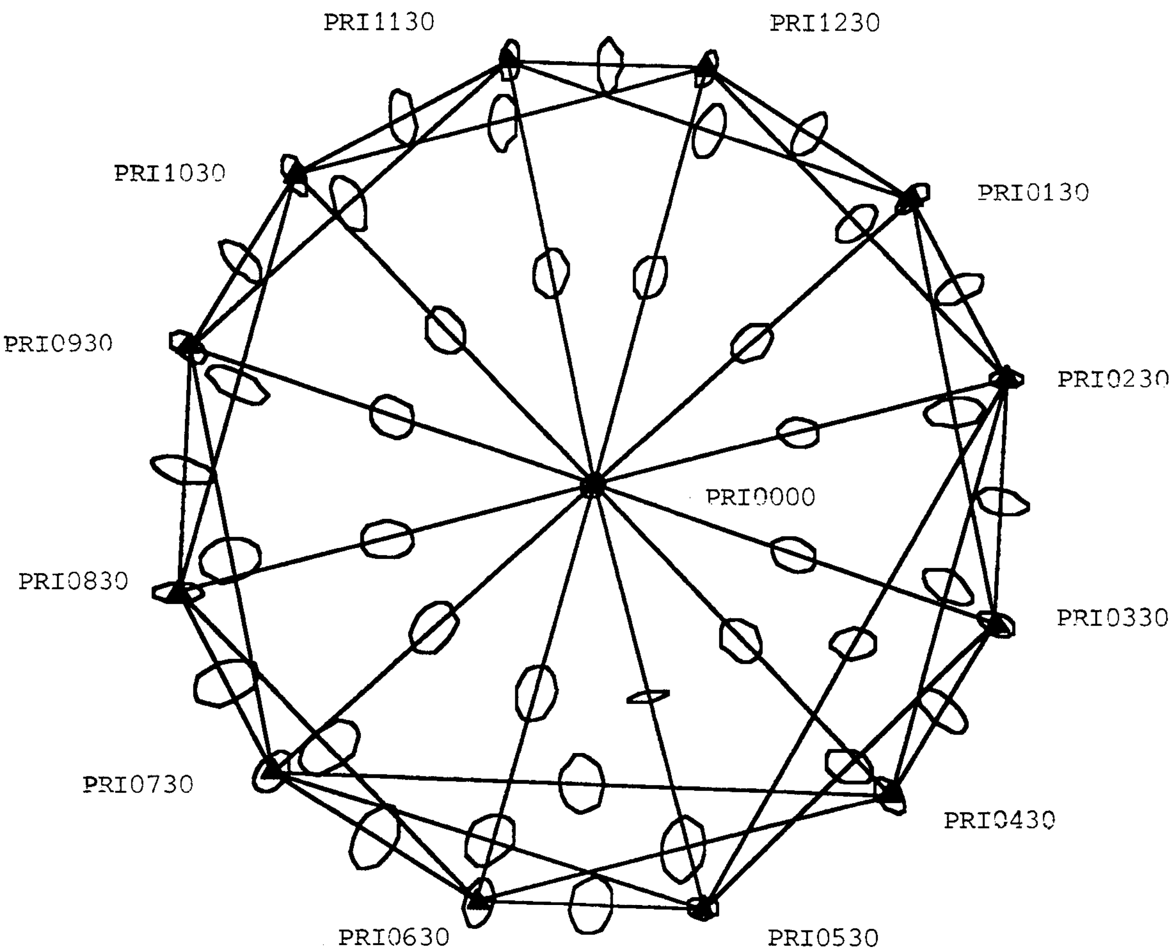

Figure 2.
RHIC Primary Control Network
Absolute Error Ellipses
(Exaggeration = 10,000X)