Status Report
Relativistic Heavy Ion Collider*

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1. INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) construction is about 85% complete. The accelerator consists of two rings of cryogenic magnets, 3.8 kilometers in length, cooled to 4.5K operating temperature with six crossover interaction regions where the major facility halls for various experiments will be located. Approximately 1008 major components (quads, dipoles, sextuples and correctors) have been installed into the tunnel of the RHIC accelerator complex. The first sextant test was completed during the early part of 1997 and we are now aligning the final components for the machine that is due to be commissioned in the spring of 1999. This report will outline the remaining tasks to be completed and discuss our efforts to align the high beta magnets in the RHIC Interaction Regions.

2. REMAINING ISSUES

2.1 Pseudo Magnet Installation

There are one hundred pseudo magnets to be placed into the RHIC lattice. Fifty of these beam tubes encased inside of a cryostat have thus far been built, characterized and surveyed into position. The production of these components has been at a similar pace as the alignment of the components in the straight section in which they reside.

2.2 RF Cavities

Eight of ten Cern type RF cavities have been installed as part of the first sextant test. Two cavities are still at Cern as are four Large Accelerator Cavities.

2.3 Cryogenic Piping

Each of the six interaction regions has refrigerator houses and large diameter supply and return lines with complex routes to supply ample coolant to the sector. Each of these routes has to be laid out so those fixtures can be placed on the walls and ceiling of the tunnel to support these service pipes. The alignment group is responsible for the positioning of and installing of the anchors used to fasten these support structures.

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2.4 DX Magnets

Twelve DX Magnets approximately 10 meters away from the 6 IP regions are still in the design stage. These are the last magnets to be produced and the only ones not included in the sextant test. We have the location of the stand and are setting their position inside the tunnel area.

2.5 Experimental Areas

Since the early design stage we have been involved with the two major experiments, Star and Phenix. In the case of Star we went up to Gec-Alstrom in Canada to inspect the back legs and the end rings for production quality of the tight tolerance parts being manufactured there. Once the parts arrived at BNL a combination of optical tooling and ManCat were employed to bring the parts together. Parts of the Phenix Detector were first put together in Russia, then disassembled and shipped to BNL for reassembly. Once assembled, they are pre-surveyed and related to their important alignment datum criteria. Then the reference file is put aside for future use to either install the part into the actual design position, inside the detector, or to install another portion of the detector inside of the part. Inside of the Phenix Experimental Hall we have installed eighty floor and wall mounted targets and have related the targets to the RHIC coordinate system.

2.6 Conventional Magnet Fiducialization

We have or will fiducialize every component that requires alignment for the RHIC Machine. The system that we use to accomplish this is ManCat from Leica. ManCat has become our mainstay for alignment of experiments as well as pre-survey of components located inside of the RHIC Machine. To illustrate the capabilities of the system, I have taken one of the sets of data taken on CQS101 and offer a comparison of magnet fiducials (M targets) and cryostat fiducials (C targets) data. During the fiducialization process, we take a set of data, then take out the targets, reinsert them, and re-observe their values. The comparisons are below.

Note that the cryostat fiducials (C targets) repeat to about 2 mils and the magnet fiducials (M targets) repeat to about 3 mils. This is because of the different way that the targets are fiducialized. The cryostat fiducials have direct measurements to the target and the magnet fiducials are done using a hidden point bar, which requires two-target pointing and vector analysis to establish the coordinate value.

Brookhaven National Laboratory   Survey and Alignment Group   Upton N.Y.

Job name: CQS101RH   Date: 12-06-94 15:05

Coordinate system: DATUM RHR

Job ID : 23,SEPT.1994:RM,SR,DG,TC

Compare Point Sets with reference file: CQS101.REF

Point ID		X in	Y in	Z in	Total Diff in
C2	REF	7.9939	11.8227	-20.1626	
C2	JOB	7.9945	11.8215	-20.1616	
Ref-Job		-0.0006	0.0013	-0.0010	0.0017
C3	REF	7.8557	96.2844	-20.1775	
C3	JOB	7.8570	96.2858	-20.1774	
Ref-Job		-0.0013	-0.0014	-0.0002	0.0019
C6	REF	-17.3458	11.7556	-20.2319	
C6	JOB	-17.3478	11.7546	-20.2322	
Ref-Job		0.0020	0.0010	0.0003	0.0023
C7	REF	-17.4324	96.2071	-20.2512	
C7	JOB	-17.4308	96.2054	-20.2513	
Ref-Job		-0.0016	0.0017	0.0000	0.0024
M1	REF	-0.0049	0.0012	-0.0099	
M1	JOB	-0.0020	0.0009	-0.0062	
Ref-Job		-0.0029	0.0003	-0.0037	0.0047
M4	REF	0.0011	108.0091	-0.0043	
M4	JOB	0.0029	108.0100	-0.0022	
Ref-Job		-0.0018	-0.0009	-0.0021	0.0029
M5	REF	-9.6134	0.0396	-0.0081	
M5	JOB	-9.6125	0.0383	-0.0070	
Ref-Job		-0.0009	0.0013	-0.0010	0.0019
M8	REF	-9.5986	107.9993	-0.0417	
M8	JOB	-9.6022	107.9958	-0.0415	
Ref-Job		0.0035	0.0036	-0.0002	0.0050

As you can see the largest total difference of this comparison is 0.005” or 0.00013mm. The fiducialization phase of the project is approximately 90% complete.

2.7 Colloidal Magnet Fiducialization

Along with the conventional methods mentioned above, all CQS (Corrector, Quadrupole and Sextupole), High Beta (D0, Q1, Q2 and Q3), and Triplet (D0, Q1, Q2 and Q3) components magnetic centers are or will be measured using either a colloid dispersion of magnetite technique or a survey antenna system. Accuracy of the direct field centers determination is within ± 60 μm. The betatron functions inside the triplet quadrupoles in the RHIC are of the order of 1500m, necessitating additional attention in the alignment procedure. On each side of the interaction region eight cryogenic elements (six quadrupoles and two horizontal bending dipoles) are placed inside large cryostats. The signals from the “antenna” were cross-calibrated with the colloidal cell measurements of the same magnet. The positions of the fiducials are related to the magnet centers during the “antenna” measurements. Elements are positioned warm inside the cryostats, with offsets to account for shrinkage during cool down. The supports at the middle of the two central quadrupoles are fixed, while every other element slides longitudinally inside the cryostat during cool down or warm up.[1] Alignment of these components in the tunnel will be done using the ManCat system. Eight T3000 theodolites will be set up to acquire twelve secondary monuments, a least squares adjustment will be performed to get the job orientated into the ideal coordinate system. We will then look at the pre-surveyed cold mass fiducials and compare their values to ideal values and iterate until we have achieved our alignment objective (± 100 μm). About a year ago, we installed one of the high beta triplet regions near the Star detector. In order to inspect the final alignment, we did a comparison of the ideal values (Ref) minus the actual, as installed values (Job). The results of that comparison on the inside Q2 magnet, ten pre-surveyed fiducials, are printed below.

Job name: TRPLT_5G Date: 11-04-96 08:45
Coordinate system: DATUM LHR
Comment: CONTINUED SURVEY ON 5 O'CLOCK TRIPLET REGION
10/30/96 THRU 11/1/96 final survey of the triplet region at 5 o'clock.
Compare Point Sets with reference file: TRIP05.NEZ

Point ID		X M	Y M	Z M	Total Diff M
IQ2M1	REF	-0.04928	-27.72249	21.21352	
IQ2M1	JOB	-0.04927	-27.72255	21.21352	
Job-Ref		0.00001	-0.00006	0.00000	0.00007
IQ2M2	REF	-0.05094	-28.24973	21.21442	
IQ2M2	JOB	-0.05086	-28.24979	21.21440	
Job-Ref		0.00008	-0.00006	-0.00002	0.00010
IQ2M3	REF	-0.05382	-28.93032	21.21410	
IQ2M3	JOB	-0.05385	-28.93025	21.21415	
Job-Ref		-0.00003	0.00007	0.00005	0.00009
IQ2M4	REF	-0.06039	-30.74590	21.21396	
IQ2M4	JOB	-0.06045	-30.74584	21.21401	
Job-Ref		-0.00006	0.00006	0.00005	0.00009
IQ2M5	REF	-0.06452	-31.85719	21.21437	
IQ2M5	JOB	-0.06457	-31.85701	21.21447	
Job-Ref		-0.00005	0.00018	0.00010	0.00021
IQ2M6	REF	-0.39318	-27.72049	21.21282	
IQ2M6	JOB	-0.39310	-27.72051	21.21280	
Job-Ref		0.00008	-0.00002	-0.00002	0.00008
IQ2M7	REF	-0.39500	-28.24774	21.21358	
IQ2M7	JOB	-0.39491	-28.24775	21.21361	
Job-Ref		0.00009	-0.00001	0.00003	0.00009
IQ2M8	REF	-0.39757	-28.93123	21.21327	
IQ2M8	JOB	-0.39750	-28.93113	21.21326	
Job-Ref		0.00007	0.00010	-0.00001	0.00012
IQ2M9	REF	-0.40402	-30.74552	21.21334	
IQ2M9	JOB	-0.40397	-30.74530	21.21336	
Job-Ref		0.00005	0.00022	0.00002	0.00023
IQ2M10	REF	-0.40822	-31.85469	21.21361	
IQ2M10	JOB	-0.40820	-31.85448	21.21362	
Job-Ref		0.00002	0.00021	0.00001	0.00021

Please take note that the X value is orientated so that it is horizontal beam left and right and the Z value is vertical up or down. The Y value is longitudinal and therefore subject to temperature effects which blow-up the total error.

2.8 Control Survey

We have surveyed all arc region magnets and are in the process of aligning the remaining straight section magnets. We have approximately 150 straight section components remaining to be surveyed, they have been installed and are waiting alignment and hook-up by electrical and cryogenic technicians. Our historic control monumentation is the result of a trilateration survey that 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 is 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 1. They were gratifying, with absolute error ellipses major axis under 0.4 mm and minor axis under 0.2 mm. 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.

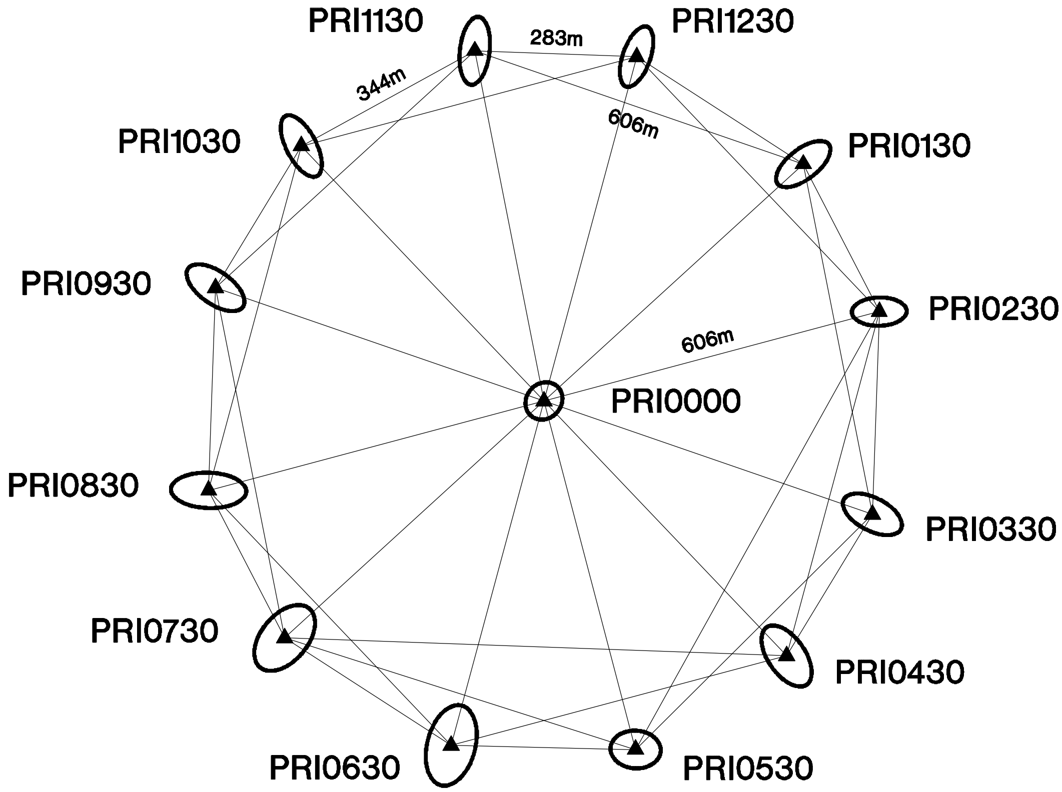

FIGURE 1: RHIC Primary Monuments

One Sigma Error Ellipses - Scale: 200,000x

Average Ellipse = 0.00028 x 0.00015

2.9 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 where magnet spacing was larger than normal. A total of 1,044 monuments make up the secondary control network.

In establishing a measurement scheme, we iterated between measurement capabilities, measurement requirements dictated by the tolerances, and time allowed for control observation by the project schedule. Trial schemes were modeled with Geonet. A final scheme was decided upon (see Figure 2) and measuring crews began the task of densifying the tunnel. The present system allows us to acquire secondary control information at the rate of four monuments per day with a two-man crew.

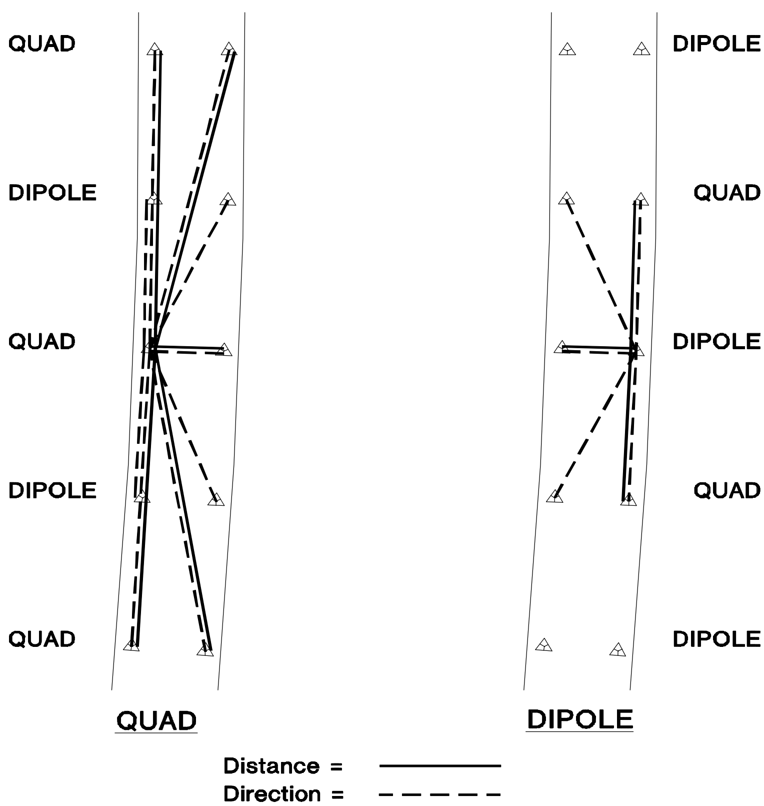

FIGURE 2: Secondary Control Observation Plan

2.10 RHIC Secondary Control Measuring Schema

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 is the three dimensional reference for the accelerator.

Observations are carried out on an aluminum tripod. 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 an office computer for reduction and analysis by Geonet and StarNet.

Figure 3 shows the one sigma absolute error ellipses at the center of an arc section (worst case) major axis 0.00047mm and minor axis 0.00015mm.

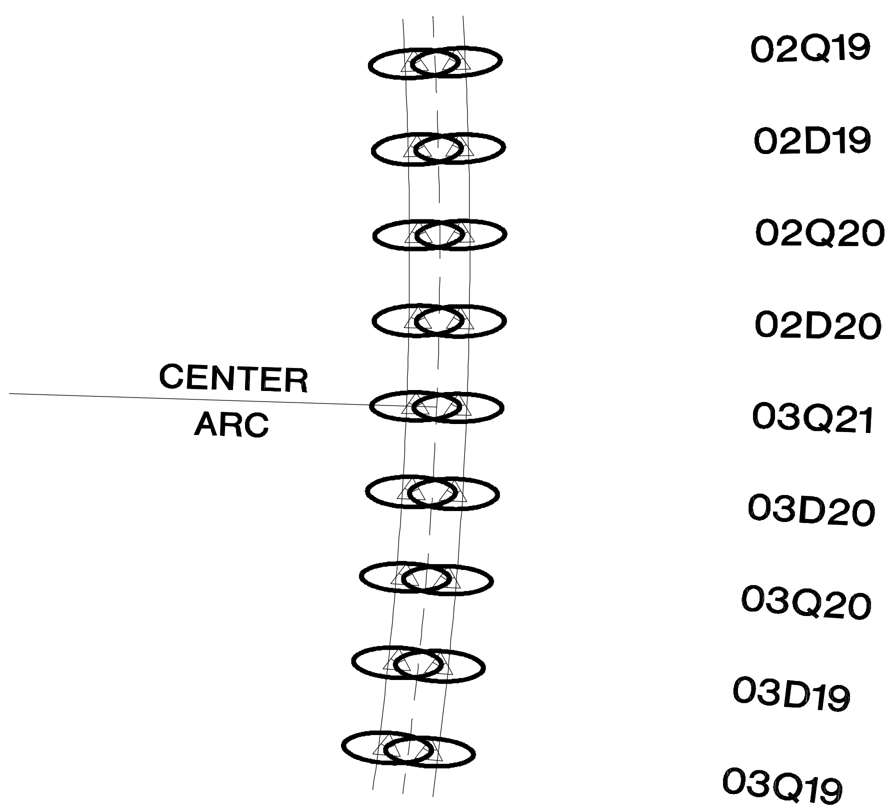

FIGURE 3: RHIC Secondary Monuments

One Sigma Error Ellipses - Scale: 1000x

Average Maximum Ellipse at Center Arc = 0.00047 x 0.00015

Figure 4 illustrates the one sigma relative error ellipses (typical) at about 0.0001mm (0.004”).

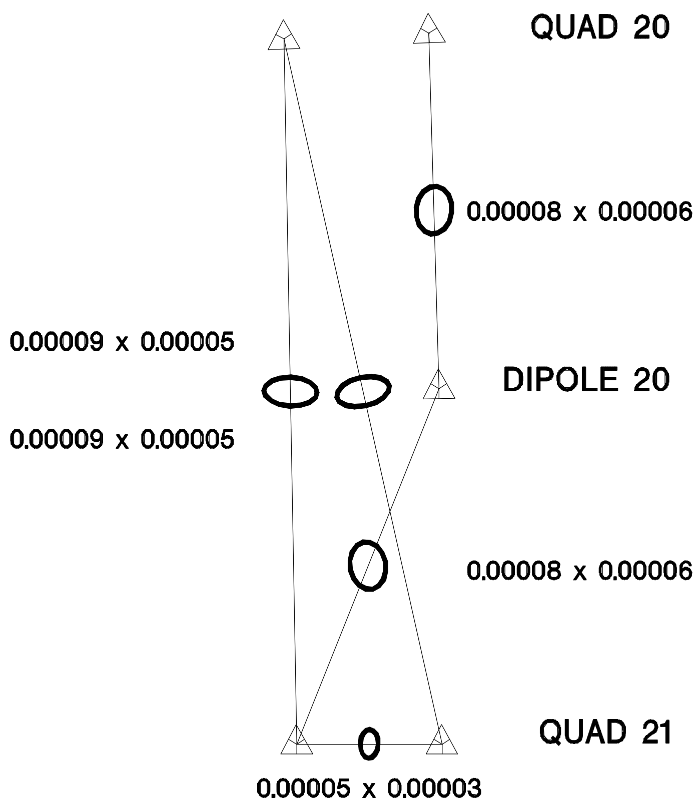

FIGURE 4: RHIC Secondary Control

One Sigma Relative Ellipses

3. Alignment of Ring Magnets

Fiducialization information from the survey group is given to the RHIC Accelerator Physicists (RAP). They interpret this information and place ideal values onto the outside fiducials located on the magnet cryostat, near its point of support. From the secondary control monuments we align the magnets.

Our scheme for alignment has been to occupy two of the secondary monuments with T3000’s and trilaterate the magnet into position after it has been set vertically using N-3 levels from Wild. This approach has served us well. Data tells us that we are setting magnet components vertically to 0.00016 meters mean standard deviation and horizontally to 0.00032 meters mean north standard deviation and 0.00033 meters mean east standard deviation.

3. CONCLUSION

Six years ago, when we started this project, it looked to be a never ending job. However as we are now getting close to completion and the end is in sight we realize that it is all doable. You have to start with sound surveying judgement in establishing a monument system that is accurate and protected from the construction about to take place. Than you must follow every important alignment element from as early as possible making sure along the way that it is characterized properly and understood as to where it belongs in the machine. Thanks goes to the dedication of the alignment group and to the RHIC accelerator physicists for establishing the positions of so many objects.

4. REFERENCES

[1] D. Trbojevic, A. Jain, S. Tepikian, R. Grandinetti, G. Ganetis, J. Wei and F. Karl, *Alignment of the High Beta Magnets in the RHIC Interaction Regions*, Proceedings IEEE Partical Accelerator Conference, 1996.

[2] D. Trbojevic, P. Cameron, G.L. Ganetis, M.A. Goldman, R. Gupta, M. Harrison, F.M. Hemmer, F.X. Karl, A. Jain, W. Louie, S. Mulhall, S. Peggs, S. Tepikian, R. Thomas and P. Wanderer, *Alignment and Survey of Elements in RHIC*, Proceedings of the 1995 PAC and International Conference of High Energy Accelerators, held May 1-5, 1995, Dallas, Texas, TAA009, pp. 2099-2101.