RHIC SURVEY AND ALIGNMENT*

F.X. Karl, R.R. Anderson, M.A. Goldman, F.M. Hemmer,
D. Kazmark,Jr., T.T Mroczkowski, J.C. Roecklein
RHIC Project, Brookhaven National Laboratory, Upton, NY 11973

Abstract

The Relativistic Heavy Ion Collider consists of two interlaced plane rings, a pair of mirror-symmetric beam injection arcs, a spatially curved beam transfer line from the Alternating Gradient Synchrotron, and a collection of precisely positioned and aligned magnets, on appropriately positioned support stands, threaded on those arcs.

RHIC geometry is defined by six beam cossing points exactly in a plane, lying precisely at the vertices of a regular hexagon of specified size position and orientation of this hexagon are defined geodetically.

Survey control and alignment procedures, currently in use to construct RHIC, are described.

1. OVERVIEW OF THE RING SURVEY PROCEDURE.

The RHIC survey is performed in local BNL coordinates, directed (for historical reasons) along the BNL road network, at known orientations to the machine lattice and the geodetic (Long Island) NY State Plane Coordinate System [Fig. 1]. The geometry of the RHIC ring and AGS-RHIC transport line are described in [6,7,10].

To generate RHIC geometry, we use a network of control monuments, grout-cemented into the tunnel floor. Each monument is a hollow stainless steel cylinder, of CERN type [Fig. 3], placed into the floor with its axis locally vertical. The monument sockets can receive and precisely locate either a cylindrical bushing holding a centered surveyor's target or a 3.5"diameter steel ball containing a microscopically centered target. The ball connects to a fiber optic jack, to supply bright diffuse target illumination. The ball can be rotated, on the monument bushing, to view its target from either a horizontal or vertical direction, without change of position of its target's cross hair intersection point. The ball target can then be viewed from above, for example, from an exterior survey tower or from the side inside the tunnel.

External control is established by: twelve survey structures spaced around the RHIC ring, with pipe penetrations into the tunnel; towers and penetrations along the injection arcs; and a tall central tower, having clear sight lines to the other towers. Control from the end of the injection bend arcs, into the AGS machine, is established internally, by survey along the beam transport line into AGS.

Survey structures range from simple 4 ft. platforms, to 12 foot wooden double signal platforms, to National Geodetic Survey steel Bilby towers of up to 70 foot height.

The survey structures contain survey instrument support platforms; an aluminum plate bolted onto each platform serves as a support deck of two horizontal motion translation stages. The upper stage holds a tribrach, to locate either a ME-5000 Mekometer EDM, prism retro-reflector, or optical plummet. An opening in each stage allows downward viewing, through the plummet's tribrach support and berm penetration pipe, to the ball target in the tunnel. The aperture available through the tribrach limits the optical resolution in setting the survey instrument directly above the tunnel survey target at the tunnel primary control monument. Vertical drops to tunnel targets are measured by use of steel tape, with correction for temperature and tape weight. Survey work was done after sundown, when stable atmospheric conditions were available. At each tower station and tunnel monument, temperature was measured to 0.1 deg. C, barometric pressure to 0.1 millibar, and relative humidity to 2%, to allow for correction of refractive index.

The external survey was a terrain trilateration of the twelve towers above the tunnel, and the central tower near machine center. The purpose of the survey was to geodetically locate twelve primary control monuments in the tunnel, below the vertical earth berm penetrations, to generate a primary control monument net inside the tunnel. Distances were measured to first and second nearest neighbor towers, and to-and-from the central tower, using the ME-5000 Mekometer. One exception was a line-of-sight blocked by the RHIC office building. Horizontal distances between nearest neighbor towers, and between the ring towers and central tower, were each approximately 610 meter. Adjusted standard error of the distance determinations was one and a half millimeters, with near-circular error ellipses, as expected from the nearly symmetric survey geometry.

A previous survey of seven of the primary monuments and central tower, was performed by the National Geodetic Survey, in 1982, as part of the CBA program at BNL. Adjusted positions of the eight monuments common to the two surveys, separated by ten years in time, were compared by means of a Helmert Transformation, using GEONET survey codes [1,2]. The rms displacement of corresponding stations from one another was one and a half millimeters. This suggests that earth shifts were insignificant, during this time.

2. TUNNEL MONUMENTATION AND SURVEY.

To locate position within the tunnel, and to control placement of magnets and support stands, a secondary monument control network has been established in the tunnel, connected to the twelve primary monuments located during the primary external control survey.

The control net configuration is a chain of braced quadilaterals. Trilateration and triangulation measurements are both used in the control survey. Monuments are installed, typically, opposite centers of ring quadrupole and dipole magnets in the arc sections, and more densely in the insertion sections.

Distances along the tunnel are measured with the Kern (LEICA) Mekometer-5000 [4, 5]. Directions along intermonument lines are measured with the Wild (LEICA) T-3000 theodolite. Each of these instruments is provided with digital electronic readout and an option for either manual or electronic control. The distance mode gap bands, in the Mekometer's, response were calculated in advance,

*Work performed under the auspices of the U.S. Dept. of Energy

to insure that forbidden distances were not to be measured among the shorter survey distances.

A ZEOS laptop computer, loaded with GEONET [1,2] control and data uplink software, is used for data acquisition, in a format suitable for data basing and reduction by GEONET. Data processing is carried out after data file transfer to a 486 PC or other work station; a local area link allows data transfer to the BNL VAX Cluster mainframe computers, to provide additional data storage and processing capability. When used for control survey, the Mekometer and theodolites are mounted on special tripod stands, bolted to the tunnel floor, at the monuments to be surveyed, on 2-axis horizontal cross feeds. A Kern instrument mount allows each survey instrument to be levelled and force-centered so that the instrument axis coincides with the mount axis. In this way a Mekometer, theodolite or optical plummet can be mounted at the same horizontal position above a monument. The instruments can be located above the target ball at the monument to a horizontal rms radius of two milli-inches.

Magnet stands are installed using the following procedure. A template was fabricated with a circular hole pattern which is the horizontal floor projection of the bolt pattern of the magnet support stand, together with the plan projection of two magnet cryostat fiducial target balls, which will lie adjacent to that stand when the magnet is installed. The template is surveyed into place by surveying the fiducials' floor projection circle centers to their proper horizontal locations. The stand bolt locations are then stencilled onto the tunnel floor from the template. To help in initially locating the magnet on its stand, the centers of the adjacent magnet fiducial ball projections are also located with fine cross marks on the floor. To do the latter operation, one uses an optically-centering transfer punch device (Scribe-Rite, Tool Components, Inc., Gardena CA) to transfer the prism target axis to the punch axis and floor point.

From the magnet-design-specified locations called out for the cryostat fiducial balls on the magnet and the magnet lattice coordinates, a data base set of horizotal survey coordinates for the cryostat fiducials is computed. View directions for theodolite sighting of the floor projections of the cryostat fiducials are computed. Also the slant distances are computed, of a Distomat EDM mounted on the theodolite, to small retro-reflector prisms mounted on the template above the fiducial ball projections. The computed distances and directions are a data base to allow the template to be surveyed into place, from the control monument net.

Survey data acquisition, reduction and adjustment is done using GEONET survey codes [1,2]. After inital data reduction, an independent adjustment is done using STAR*NET survey codes[3]. The latter codes are convenient for blunder detection and survey graphical presentations, and are a useful complement to GEONET. Model control surveys are simulated using the ERRORP codes of GEONET when control survey procedures are to be examined.

3. MAGNET FIDUCIALIZATION AND ALIGNMENT

RHIC dipoles and quadrupoles are provided with two sets of fiducial markers: cold mass fiducials and cryostat fiducials. The cold mass fiducials are balls which seat in fixed position relative to survey notches cut into the magnet cold mass steel plate. These fiducials are well defined relative to the bore circle of the magnet steel. Cryostat fiducials are split balls on shafts which seat onto bushing sleeves on the magnet cryostat body. Cryostat fiducial balls are externally accessible at each end of the magnet. Cold mass fiducials are accessible to survey only before the magnet is fully assembled. Cold mass and cryostat fiducials are surveyed relative to one another before final assembly of the magnet. The ManCAT electronic coordinate measuring system (LEICA Gmbh, Heerbrugg, Switz.) will be used to survey cold mass fiducials relative to cryostat fiducials. Magnetic measurements of field center, and field roll orientation relative to cold mass fiducials will be made before magnet assembly. Alignment of magnets in the RHIC tunnel will be made relative to the survey of the cryostat fiducials relative to cold mass fiducials, which in turn relate to the magnetic center and roll of the magnet. The process of aligning magnets in the tunnel consists of setting cryo fiducial marks to lie at their computed locations. Those locations are generated in turn by the lattice, magnet design, measured fiducial point positions relative to the physical structure of the individual magnet, and survey control station absolute positions as determined by tunnel control surveys. This process of setting magnets into position takes no account of relative misalignment of neighboring magnets caused by random error introduced in the installation of individual magnets. Ideally, when ring magnets are installed, the beam closed orbit would be a smooth curve of low degree, within our individual magnet, and would be an arc which joined continuously, to a sufficiently high order of derivative, curve segments though adjacent magnets. But, local relative dislocations and tilts of the axes of successive magnets can cause more serious beam-dynamical problems than global long scale radial or vertical magnet displacements. One then needs a smoothing adjustment of magnet locations to set magnets onto a smooth curve, which lies globally within a tubular envelope of allowable radial and vertical error bounds about the beam trajectory curve specified by the accelerator lattice. The shape of the smoothed curve follows from the particular magnet installation data set to be fitted, rather than from an analytical formalism. Studies of smoothing procedures were carried out at SLAC and CERN [8,9]. SLAC smoothing codes and procedures are being incorporated, into GEONET software; it is expected that they will be available to users in 1993. It is anticipated that a smoothing procedure similar to that used at SLAC will be used at RHIC.

References:

1. H. Friedsam, R. Pushor, R. Ruland, A Realization Of An Automated Data Flow For Data Collecting, Processing, Storing And Retrieving - GEONET. Stanford Linear Accelerator Center SLAC-PUB-4142, Nov. 1986.
2. H. Friedsam, Notes (unpublished), Survey And Alignment Workshop On Data Processing Using Geonet For Accelerator Alignment, Stanford Linear Accelerator Center, Stanford, March 1992.
3. STAR*NET 4.01, Starplus Software, Inc., Oakland, CA. 94610.
4. D. Meier and R. Loser, Das Mekometer ME5000 - Ein Neuer Prazisions-distanzmesser. Allgemeine Vermessungs-Nachr. (AIN), Vol. 93, pp 182-190 (1986).
5. T.W Copeland-Davis, The KERN ME5000 Mekometer and Short Distance Measurements, CERN Report LEP/SU 89-2, Feb. 5, 1989.
6. J. Claus and H. Foelsche, Beam Transfer From AGS To RHIC, RHIC Technical Note No. 47 , BNL Accelerator Division Report AD/RHIC-47, 1988. See also Jan. 9, 1990 Addendum.
7. R.E. Thern, Injection Line Geometry, AGS To RHIC Beam Transport Line. BNL Data Fikle ARHIC13, Sept. 12, 1988.
8. T. Hastie, Principal Curves And Surfaces, SLAC Report-276, STAN-LCS-11, UC-32 (M), Stanford Linear Accelerator Center, Nov. 1984.
9. Applied Geodesy For Particle Accelerators, CERN Report 87-01, Geneva, Feb. 9, 1987.

10. M.A. Goldman, The RHIC Reference Geometry, RHIC Project Report AD/RHIC/RD-43, Brookhaven National Laboratory, Aug. 1992.

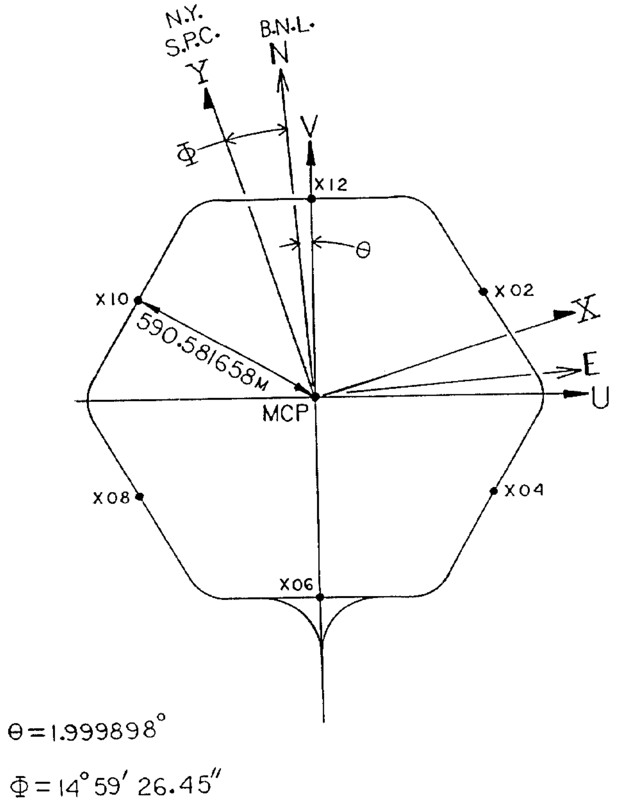


Fig. 1 The RHIC Ring Geometery

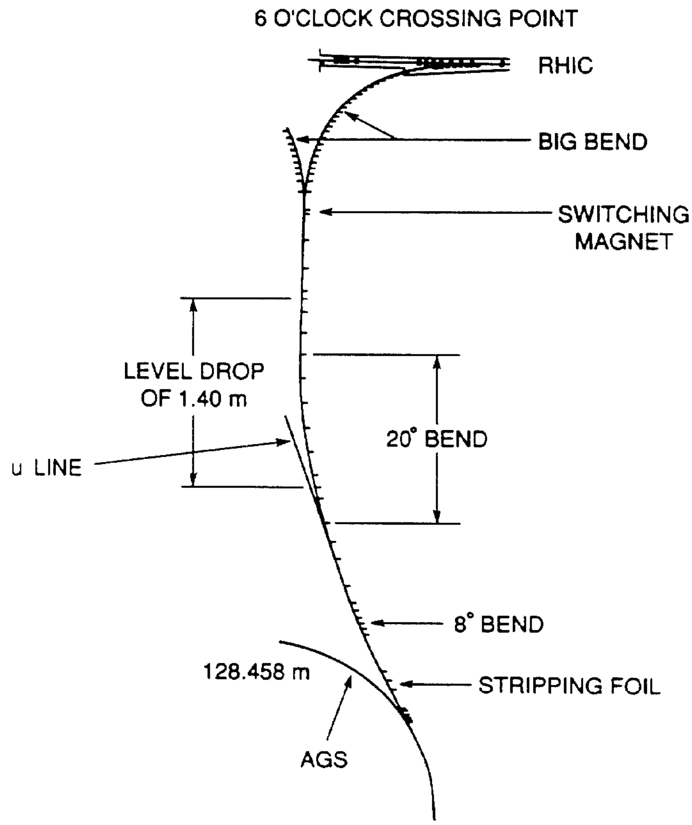
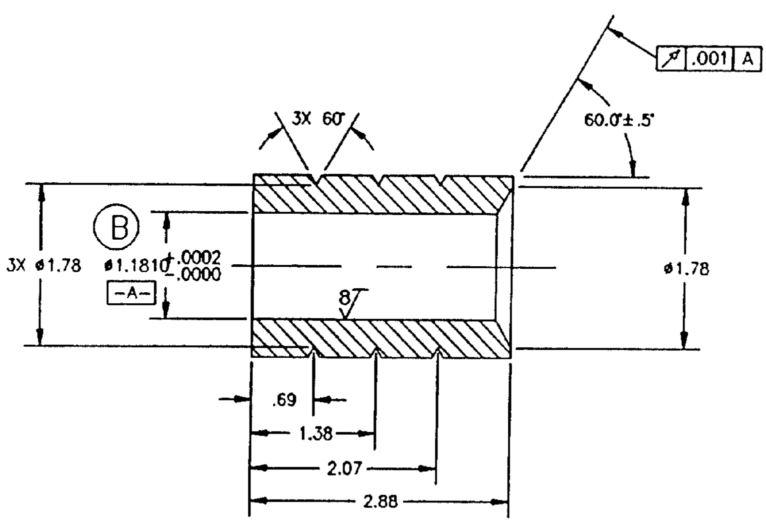


Fig. 2. The AGS to RHIC Transport Line



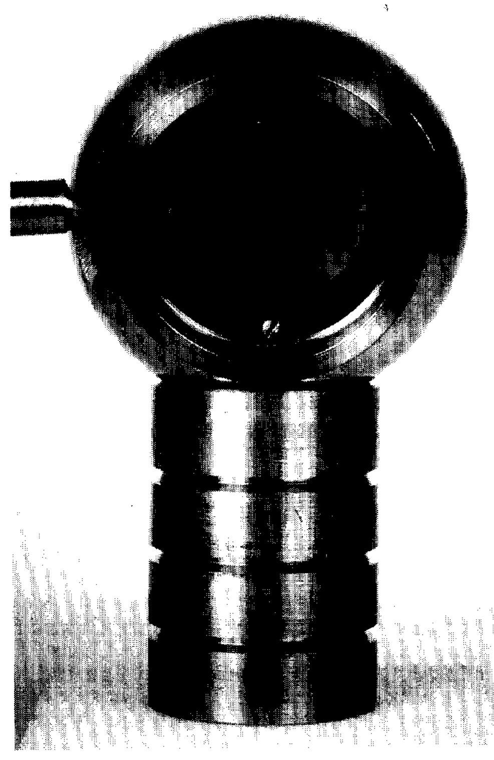


Fig. 3. The Ring Monument and Target Ball