Survey and Alignment of the MIT–Bates South Hall Ring*

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Abstract

The South Hall Ring (SHR) is a pulse storage/stretcher ring with a circumference of 190m . The complex contains over 200 magnetic elements, most of which must be positioned to tight tolerances to achieve efficient injection and extraction and to obtain storage times of several seconds for internal targets. In particular, the lattice quadrupoles have transverse position tolerances of ±100 microns magnet–to–magnet, and the circumference has a tolerance of ±5mm. For the survey and alignment of the ring, we have used automated data capture, data flow and database generation. Alignment of all magnets to approximately ±1/4 mm has been completed. The final survey followed by a smoothing of the lattice will begin soon. The present status and issues of the survey and alignment program will be presented, along with the latest alignment aspects of the beam test results.

1 Introduction

The SHR, currently under commissioning, will be a high intensity pulse stretcher facility providing high quality cw electron beams with energies between 0.3 and 1.0 GeV. It can be operated in storage mode for internal target experiments and in extraction mode for more conventional experiments. A detailed description of the ring is given in ref. [1] . A plan view of the ring is shown in Fig. 1 and a list of positioning tolerances is given in Table 1.

The design requirements of high quality storage rings demand tight tolerances on the positioning of the adjacent magnets as well as on the overall circumference of the ring. To accomplish this task two options were available: conventional optical tooling and a triangulation system using a database. We adopted triangulation heavily relying on a database, software and automated data capture and data flow with an emphasis on redundancy. Our primary source for software and consulting has been the SLAC alignment group. The survey and alignment of the SHR is based on a network of floor monuments to which all the components are referenced. For data processing, storage and communication we used a customized version of PC–GEONET [2] from SLAC.

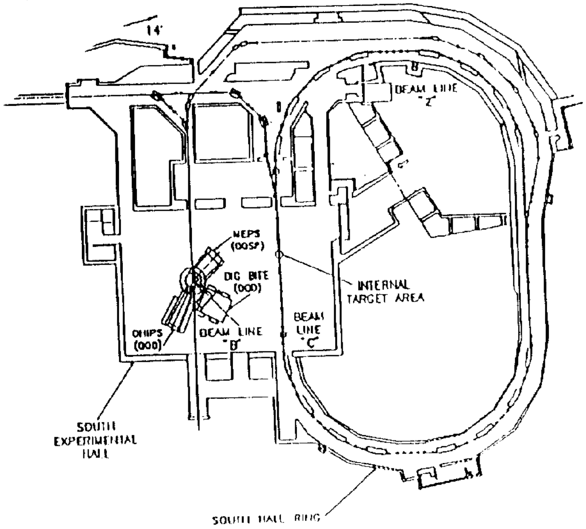

Figure 1: South Hall Ring Complex.

The main sources of errors in achieving these design goals are network errors, fiducialization, final survey and smoothing.

Table I
SHR Alignment Tolerances

Element	Quantity	Tolerance	
		X/Y	Roll
		mm	mr
Quads	128	0.1	2.0
Ring Dipoles	16	0.5	0.7
Dipoles	18	0.5	2.0
Sextupoles	32	0.2	2.0
Octupoles	2	0.2	2.0
Septa	4	0.1	2.0
Kickers	2	0.3	2.0

2 Adjustment Systems and Survey Instruments

Whenever possible, three point supports were used for all components and their stands. For adjustment, we adopted the LBL 6–strut system for all but the heavier dipoles,

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*Work supported in part by DOE contract DE-AC02-76ER03069.

0-7803-1203-1/93$03.00 © 1993 IEEE

which used three struts and three jacks. The 16 main benders have their own built-in adjustment and elevation system. The strut system provided essentially independent adjustments in X, Y and Z except for the short sextupoles, for which some coupling was evident.Motions of more than ~ 5 mm were provided by coarse adjustment systems consisting of machined stainless steel plates and push screws.

Our survey equipment included two Kern electronic theodolites (E2 and E21), a Wild NL optical plummet, a Wild N3 optical level with 10 mm micrometer, a calibrated invar scale kit, a 2m elevation rod, two HP110 laptops, a portable and a stationary 386 PC. For centering systems, we used SLAC type aluminum tripods, three sets of the CERN forced centering system, and SLAC adaptors for merging Kern plates and the CERN system. SLAC-style slanted targets with K&E bullseye targets were used throughout. During the initial survey of the geodetic network, we used an ME5000 distance meter (on loan) from CEBAF.

3 SHR Geodetic Network System

For the SHR we have chosen to separate the horizontal coordinates (X,Z) from the vertical (Y) direction. The horizontal locations of all position–sensitive elements were referenced to a global SHR coordinate system. The origin of this geodetic system as shown in Fig. 1 is at the intersection of the west straight and north straight sections. The transverse network consisted of over 80 floor monuments which provided sufficient observation points to overcome sight line obstructions caused by the large benders. The network was surveyed in the Fall of 1990 one year after the completion of the conventional construction and before any floor occupancy. The survey was accomplished with an ME5000 and two theodolites and with help from SLAC and CEBAF. An optimum measurement plan was developed using the GEONET simulation facility. A subsequent measurement of a subset of these floor monuments and some fiducials from the existing beam line was necessary for relating the orientation of the SHR network to the rest of the complex. Fig. 2 shows the monuments and their absolute error ellipses; error propagation caused the enlargement of ellipses further away from the origin. The relative errors are smaller than the absolute errors and have a more uniform size than the absolute ones shown.

A smaller geodetic network of floor monuments was installed for alignment of the Energy Compression System (ECS) dipoles and quads at the end of the linac . This network was surveyed using the SLAC Industrial Measurement System (SIMS) [3], a PC-based bundle adjustment [4] and triangulation system integrated with multiple electronic theodolites.

The SHR and ECS also have a network of elevation monuments for vertical references. This network was periodically resurveyed for seasonal changes in the floor elevation. We have noticed seasonal elevation changes of up to 0.8mm over a ~ 60m long distance in a six month period, well within the tolerances required by relative positioning.

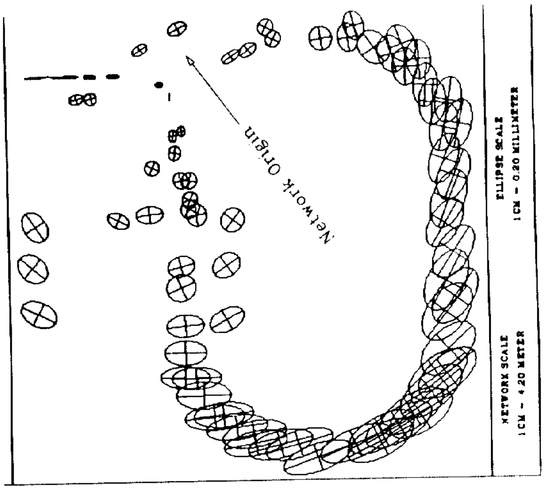

Figure 2: Absolute error ellipses for the SHR geodetic network.

4 Fiducialization

The magnetic/mechanical axes of each element were related to several fixed fiducial targets on the element as follows. Survey targets were inserted into drill bushings coarsely positioned on the top surface of the element and their positions were precisely measured using SIMS as described in ref. [5] and [6]. For the dipoles, fixtures were used to precisely position targets in the midplanes and on the design orbit. The coordinates of magnet targets, fixture targets, invar rod targets and some auxiliary targets were measured in the coordinate system of one of the theodolites positioned close to the center of the magnet. A coordinate transformation from the theodolite system to the element system completed the fiducialization. Normally, the transverse positions of survey targets were determined to better than 50 μm.

5 Database and "Ideal Coordinates"

The design position of the magnetic axes of each element in the SHR global coordinate system was specified by TRANSPORT optics codes and the output files were transferred to the PC–GEONET. Because the fiducialization files contain the relation between the coordinates of the fixed survey targets and the magnetic axes, combining the two output files with proper rotation of the fiducialization data determined the ideal location of each survey target in the global SHR system. These "ideal coordinates" were actually calculated using customized Fortran codes which also included corrections for dipoles whose measured effective field length was different than the nominal value used in the TRANSPORT calculations. The ideal coordinates were integrated into the database for use with various survey and alignment software systems.

6 Alignment Using Intersection

For alignment of ring elements to an accuracy of ~1/4mm we used triangulation based on intersection of sightlines from two theodolites. This was facilitated by an interactive software package (CLASH) [7] which provided communication between two theodolites and a laptop loaded with the ideal coordinates of the survey targets and the monuments. The accuracy achieved with CLASH is strongly geometry dependent. After a magnet was positioned to within a few centimeters of its ideal location using conventional methods, it was precisely leveled using an optical level and the CLASH database. For horizontal positioning, two theodolites were positioned precisely over two monuments at optimum locations near the element, and CLASH calculated the direction of theodolites pointing at the ideal target. The theodolites were set to those directions and the magnet was moved until the target was at the intersection of the two lines of sight. At the end of this iterative process involving several targets, all survey targets were within ±1/4mm of their ideal positions.

7 Final Survey and Smoothing

The remaining tasks are the final survey of every element and the ensuing smoothing of the beam trajectory.

Final Survey– Plans are underway for a complete precision survey of the SHR elements with SIMS, simultaneously determining both horizontal and vertical coordinates of all survey targets. The survey includes both the network monuments and the survey targets on the individual components. Overlapping regions will be surveyed in adjacent sections ensuring continuity and redundancy. The bundle adjustment will be done by keeping the nominal coordinates of two endpoint survey targets in a region fixed and letting the monument coordinates vary. If the fixed points are not at their ideal positions, this method can cause a small wrinkle in the beam line, but relative coordinate determinations of adjacent elements will be ensured.

Smoothing– The coordinates of each element determined in the bundle adjustment will be used for determining the positional adjustment necessary for creating a "smooth" beam trajectory. We have customized the SLAC smoothing software [8] which is based on a Principle Curves and Surfaces algorithm [9]; this will allow a minimization of the number and the amount of movements while satisfying the $\pm 100\mu m$ element-to-element tolerances for the quadrupoles. All necessary software has been written and survey work will begin later this year. The movements will then be made and monitored with three sets of digital dial gages registering three tooling balls on each magnet.

8 Commissioning Results

In March of this year on the first day of commissioning of the ring lattice, electron beams were stored for as long as 20 ms corresponding to over 30,000 turns, before they were lost due to synchrotron radiation with no RF cavity in the ring.

9 Conclusions

We have developed and executed a comprehensive survey and alignment plan for the SHR by adopting computer based geodetic systems. The quality of our alignment work has been tested in an ongoing commissioning of the ring by successfully storing beams without any need for repositioning a single element or excessive steering. The final survey and smoothing plans have been finalized and will begin soon. Considering all sources of errors in our survey and alignment procedure, we are aiming for overall relative positional uncertainties of $\pm 0.15mm$ for the quads. The authors would like to thank the SLAC alignment group, particularly Horst Friedsam, now at the Argonne Advanced Photon Source.

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