SURVEY, ALIGNMENT AND FIRST BEAM TESTS OF A NEW 1 GEV ELECTRON STRETCHER RING AT MIT

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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 for nucleon and nuclear physics research. 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 SHR complex 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.

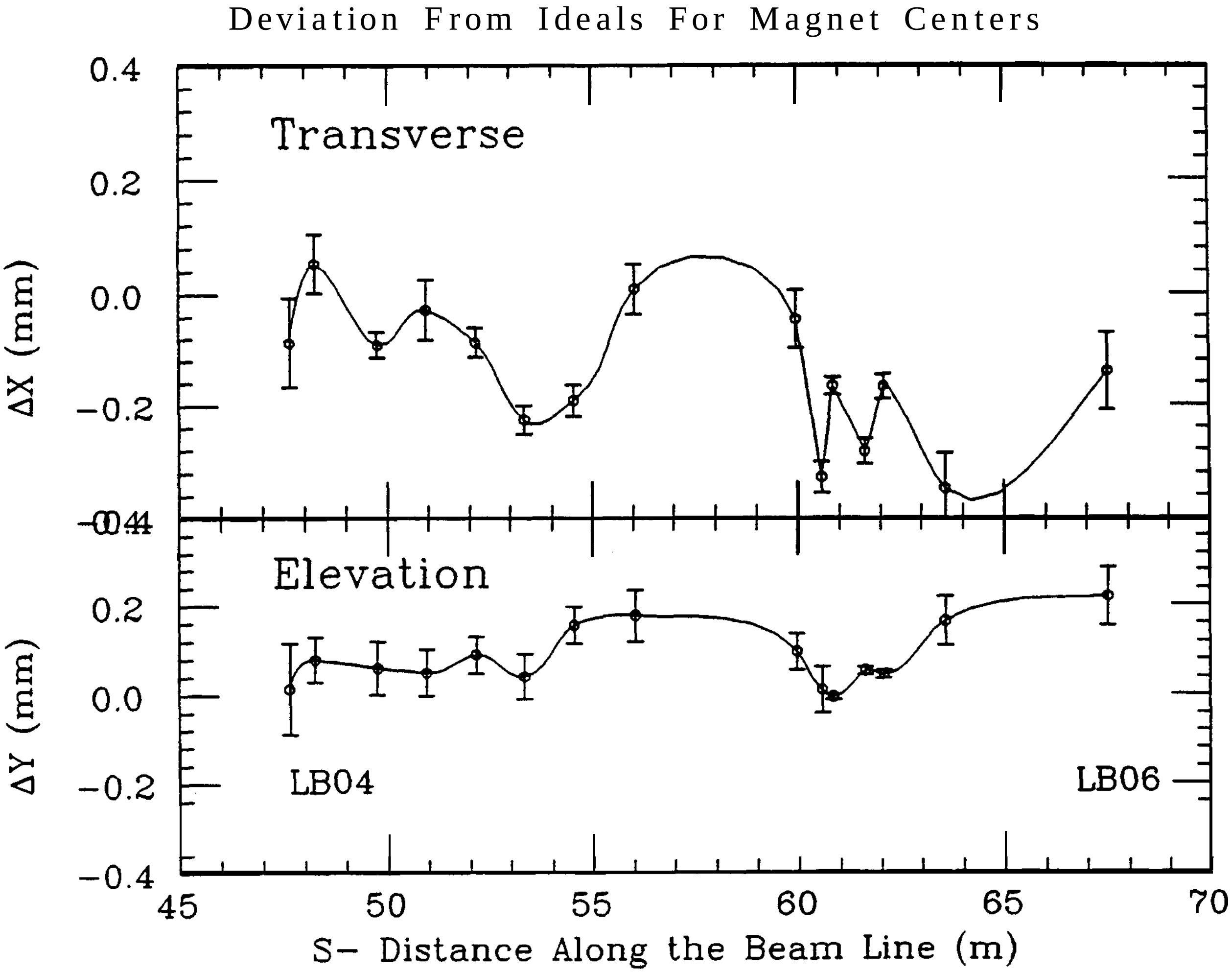

Figure 3: Results of a test survey of South straight section with SIMS plotted are the differences of the ideal and measured coordinates of the center of magnets in transverse plane, (a) sideway and (b) vertical directions. A floor monument and one survey target at either ends are kept fixed.

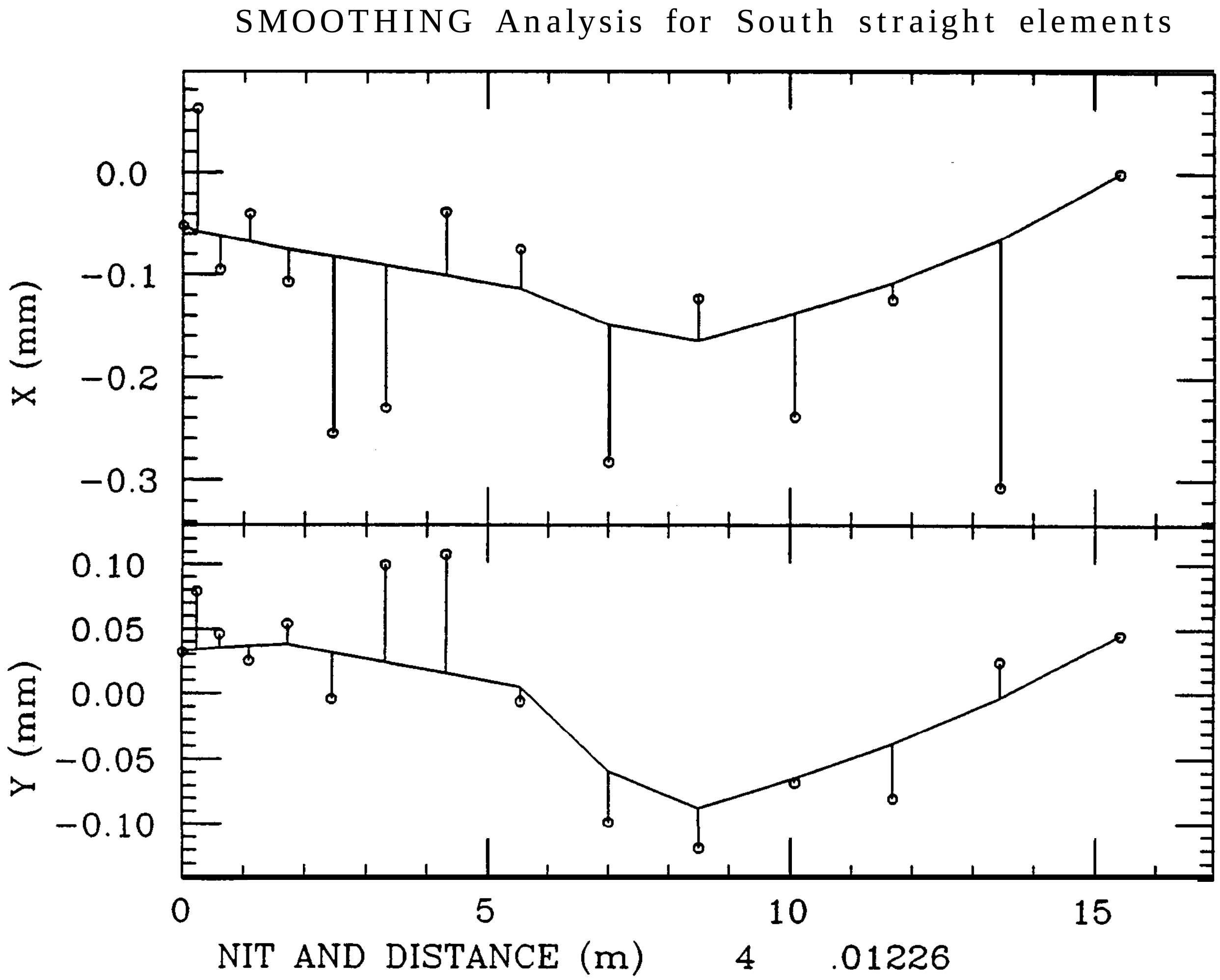

Figure 4: Results of a smoothing analysis on the test survey using the Principle Curve routines form SLAC. The vertical line at each element location is the minimized movement of center of the element needed for maintaining a “smooth” path. Shown are the final fitted Curves in X and in Y. The unsmooth look of the curve is a result of uneven scales on the plot axes.

To accomplish this task two options were available: conventional offset surveying and a triangulation system using a database. As was described in the 1990 Alignment Workshop [2] we adopted triangulation heavily relying on a database, software and automated data capture and data flow with an emphasis on redundancy. For our applications, this choice proved to be very flexible as during the project a 5 mm change of circumference became necessary to accommodate a different number of bunches, and a reduction of circumference by 2 mm was needed at a later time due to differences between the measured and the design magnetic lengths of the main benders. the former was accomplished by shifting the south arc by 2.5 mm and the former by moving the north arc by 1.0 mm after the south arc alignment was complete. This was a rather straightforward change of the database and the ideal coordinates.

The survey and alignment of the ring was primarily carried out with a core staff of nuclear physicists and technicians with no in house survey engineer and with limited outside consulting . The same group was also responsible for magnetic measurement and fiducialization of all the elements. This concentration of the activities clearly increased the efficiency in communication between the magnetic and survey efforts. The modern survey systems employ statistical aspects, data analysis, redundancy, least square adjustments and automation with which the physicists are familiar, and after a short intense learning period we were able to carry out the project.

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 [3] from SLAC.

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	Z	Roll
		mm	mm	mr
Quads	128	0.1	1.	1.0
Ring Dipoles	16	0.5	1.	0.2
Dipoles	18	0.5	1.	2.0
Sextupoles	32	0.3	1.	2.0
Octupoles	2	0.2	1.	2.0
Septa	4	0.1	1.	2.0
Kickers	2	0.3	1.	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, which used three struts and three jacks similar to DESY's system. 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. The beam line in the east straight section passes through an existing experimental hall which is lower then the tunnel floor by 70 centimeters; this made the beam line elevation in this region about 210 cm high and the survey and installation of elements difficult.

Our survey equipment included two Kern electronic theodolites (E2 and E2I), 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 parallel-line bullseye targets were used throughout. During the initial survey of the geodetic network, we used an ME5000 distance meter (on loan) from CEBAF.

3 Survey and Alignment

3.1 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 SHR has an inhomogeneous construction with old concrete structure and both cut-and-fill as well as exposed portions of tunnel.

The origin of this geodetic system as shown in Fig. 1 is at the intersection of the west straight and north straight sections with one axis parallel to the injection line. 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 monuments can accommodate 1/4 inch shaft tooling balls or slanted targets. 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;

Due to a lack of in house ME5000, the network has not been completely resurveyed after occupancy; however, several spot checks and indirect distance measurements between monuments during fiducialization of the benders as well as monitoring of small cracks in the concrete walls and the floor strongly indicated that any possible movement are submillimeter. In addition a Deformation Analysis of a recent survey of the south straight section which included the floor monuments and the aligned elements suggested that no noticeable monument movement occurred. And finally, the smoothing of the beam line at the end will eliminate any strong dependence on the monument location. 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) [4], a PC-based bundle adjustment [5] 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. The largest vertical motions of the floor tunnel occurred primarily on the east straight section, which is partially exposed tunnel structure

3.2 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 surfaces of the element and their positions were precisely measured using SIMS as described in detail in Ref. [6]. An integral part of our fiducialization system is a Harmonic Analyzer (HA) which is used for magnetically measuring the quadrupoles and is described in ref. [7]. The elliptical apertures of the quad did not permit defining the mechanical axis with a simple centering spindle. By fiducializing the HA (measuring the distance from the bobbin axis to fixed targets on the bobbin support) we eliminated a need for determining the mechanical axis of the quads.

Transverse errors of the order of 50 microns were achieved for most of the quads. During the initial precision survey and alignment of the quadrupoles in the injection line area, the presence of a random but significant roll and pitch was detected. The problem was soon traced to an oversight in the fiducialization of the quads and usage of a Harmonic Analyzer system which is insensitive to small rotations. These random rotations were as large as 10 mr, well outside the rotational tolerances. We were able to correct these undesirable rotations by correcting our database without any need for refiducialization. This was possible, primarily because the direction of gravity was implicitly defined by the vertical angles of the theodolites which were recorded in each fiducialization file.

SIMS was also used for fiducialization all the dipoles and other position sensitive elements. For the dipoles [8], fixtures were used to precisely position targets in the midplanes and on the design orbit.

3.3 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.

3.4 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) [9]. 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 then vertically positioned to better than 100 microns using an N3 optical level with the CLASH database, rods and elevation network. For horizontal positioning, two theodolites were positioned precisely (to 50 microns) over two monuments at optimum locations near the element, and CLASH calculated the direction of theodolites pointing at the ideal target. At the end of this iterative process involving several targets, most of survey targets were within ±1/4mm of their ideal positions. The high density of our monument network allowed finding an optimum pair of monuments for any given region of the lattice. For some magnets we had multiple setups which allowed for cross checks.

In order to minimize the residual movement of elements needed in the final smoothing process, we expended the extra effort in CLASHing needed to achieve ±1/4 mm accuracy.

3.5 Final Survey and Smoothing

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

Final Survey- For a complete precision survey of the SHR we have evaluated two options:

- GEONET- requiring direction measurements from the monuments, distance measurements with an ME5000 and a complete elevation survey of all elements,
- SIMS- requiring 3D direction measurements from arbitrary locations and the use of scale bar.

We have chosen SIMS which simultaneously determines 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 to ensure 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. A test survey of the South straight section was performed with SIMS, and the differences between the ideal and measured transverse coordinates are shown in Fig. 3.

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 [10] which is based on a Principle Curves and Surfaces algorithm [11]; 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. Results of a smoothing analysis on the result of the test survey in the South straight section are shown in Fig. 4.

4 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.

5 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 ±0.15 mm for the quads.

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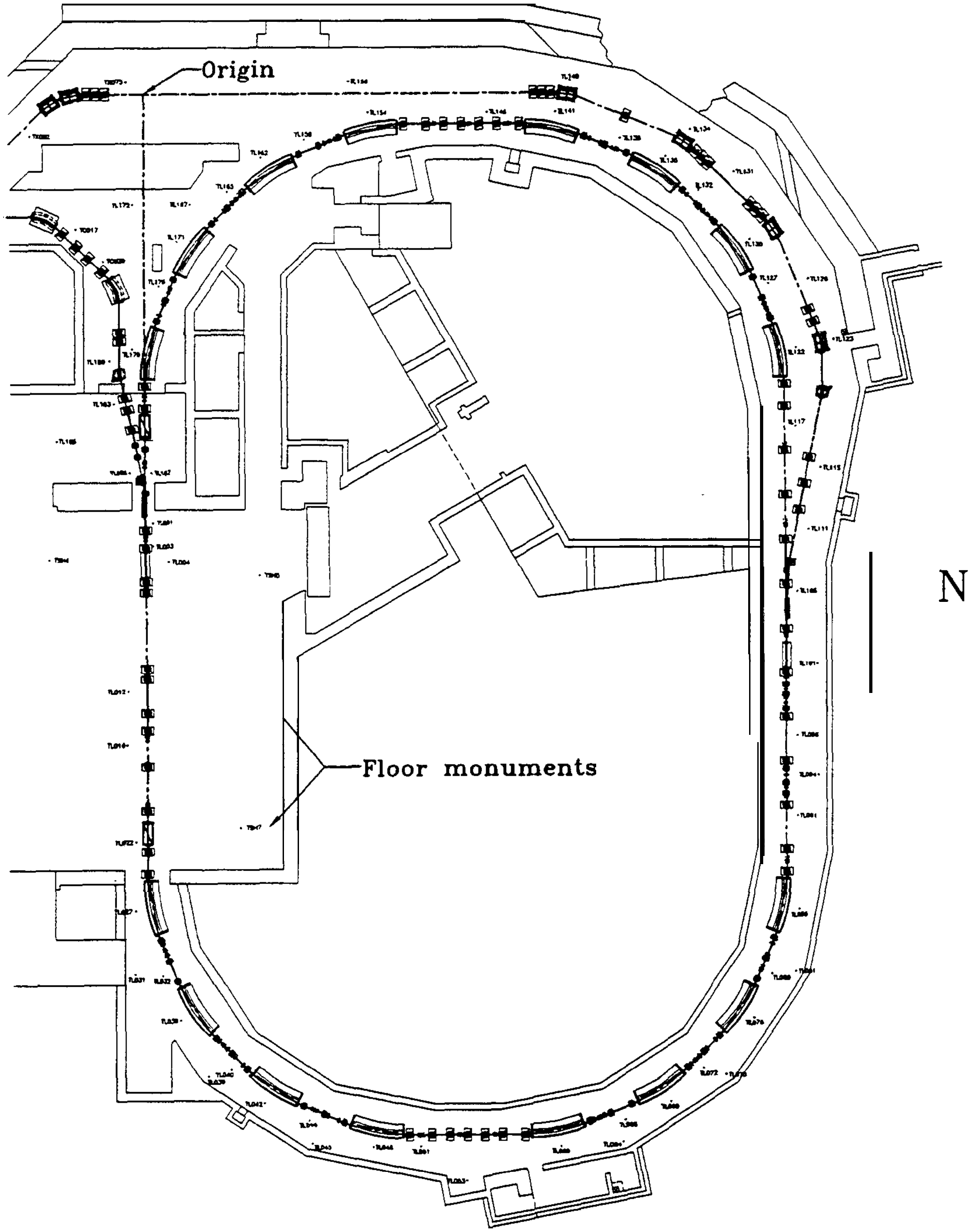

Figure 1: South Hall Ring Complex

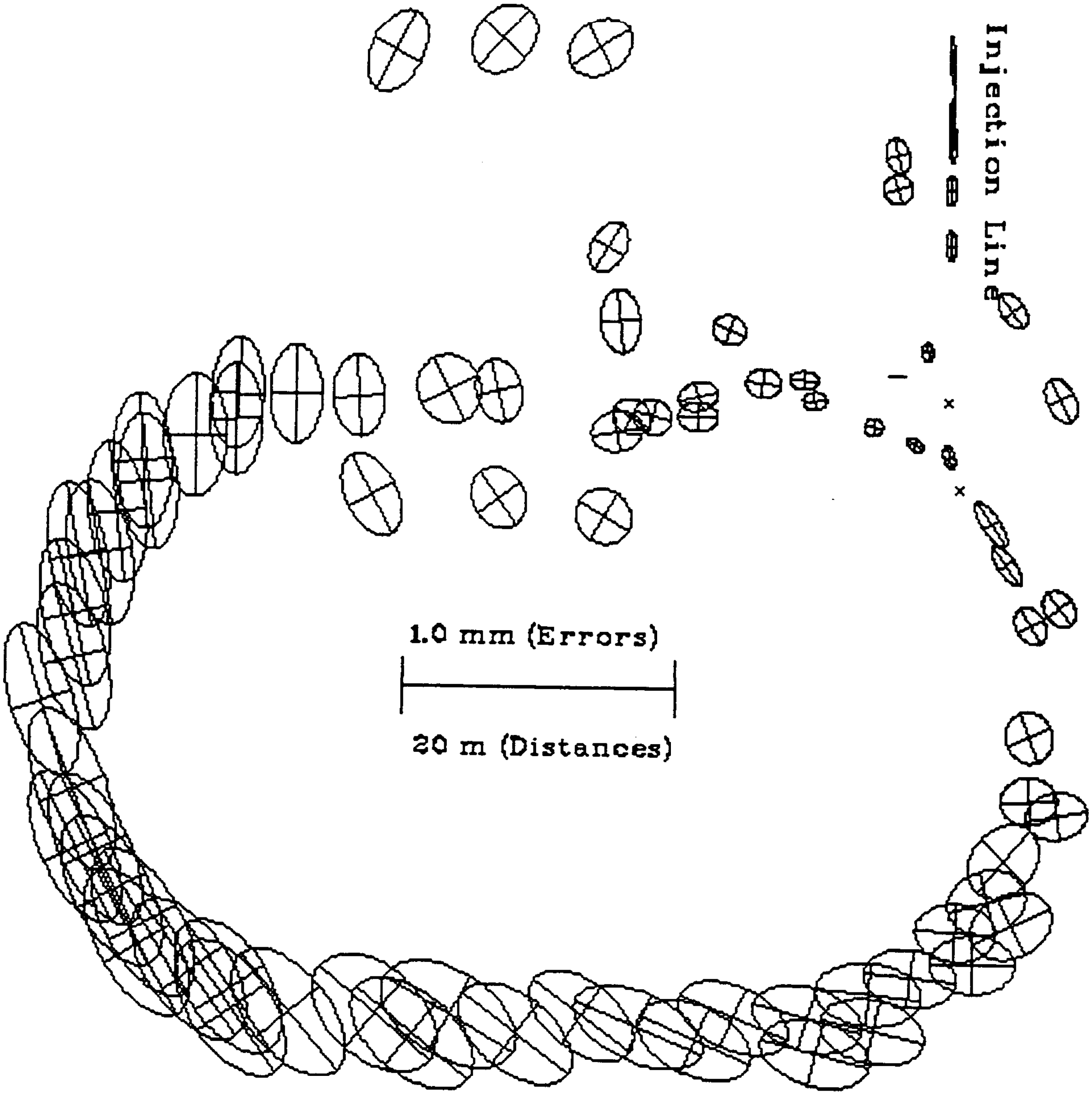

Figure 2: Measured absolute error ellipses for the SHR geodetic network. Two points near the injection area are kept fixed in the least square adjustments.