Survey and Alignment for the ALS Project at LBL Berkeley

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Introduction

The Advanced Light Source (ALS), now under construction at Lawrence Berkeley Laboratory, is a synchrotron radiation source of the third generation designed to produce extremely bright photon beams in the UV and soft X-ray regions.[1] Its main accelerator components are a 1 - 1.9 GeV electron storage ring with 196.8 m circumference and 12 super-periods, a 1.5 GeV booster synchrotron with 75.0 m circumference and 4 super-periods, and a 50 MeV linac, as shown in Fig. 1. The storage ring has particularly tight positioning tolerances for lattice magnets and other components to assure the required operational characteristics.

The general survey and alignment concept for the ALS is based on a network of fixed monuments installed in the building floor, to which all component positions are referred. Measurements include electronic distance measurements and separate sightings for horizontal and vertical directions, partially with automated electronic data capture. Most of the data processing is accomplished by running a customized version of PC -GEONET.[3] It provides raw data storage, data reduction, and the calculation of adjusted coordinates, as well as an option for error analysis. PC-GEONET has also been used to establish an observation plan for the monuments and calculate their expected position accuracies, based on approximate coordinates.[4] Additionally, for local survey tasks, the commercial software package ECDS[5] is used. In this paper, the ALS survey and alignment strategy and techniques are presented and critically discussed. First experiences with the alignment of the linac and booster components are described.

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Scope and Tolerances

Objects for precision alignment in the ALS include: a), storage ring lattice magnets (36 bend magnets, 72 quadrupoles, and 48 sextupoles); b), booster lattice magnets (24 bend magnets, 32 quadrupoles, and 20 sextupoles); c), transport line magnets (8 bend magnets and 21 quadrupoles); d), special magnets (5 septa, 7 bump magnets, and 6 kickers); e), 12 storage ring vacuum chambers, represented by 96 incorporated beam-position monitors; f), 42 beam position monitors in booster and transfer lines; and g), 3 RF cavities. Typical required local placement accuracies for adjacent objects are ±15 mm in the storage ring and ±0.3 mm in the booster and transport lines. No strict global tolerance value was established, but we expect to keep all elements that have tighter local tolerance values within ±0.25 mm from their ideal locations. Tables with detailed tolerances for the elements of the two rings are given below.[6]

The arrangement of lattice magnets in storage ring and booster synchrotron are shown in Fig. 2. In cases where a significant offset between the mechanical and magnetic centers of a magnet is found the magnetic center, as resulting from magnet measurements,[7] represents the magnet for alignment purposes. Every magnet carries four fiducial posts that are welded to its upper side without attempting to achieve any precise positioning. Different exchangeable targets are used on these posts, either optical targets with engraved circle and center point on a 45°-tilted plane for surveying or tooling balls, for alignment in combination with dial indicators.

For the time being, no survey and alignment procedures have yet been established for the photon beam lines and experimental stations that later on will surround the storage ring.

Survey Concept

The locations of all position-sensitive accelerator elements are defined with respect to a global ALS coordinate system. In this system, the center of the storage ring has the coordinates {x =1500 m, y = 3500 m, z = 2500 m}. The two horizontal directions, x and z, point North and East, respectively; y points upwards. The ALS system is actually represented by all monuments that are imbedded in the building floor, see Fig. 3, rather than by one single monument. This convention has the advantage that eventual position changes of any individual monument, due to ground motion, are practically irrelevant for the determination of the accelerator position and would only have a local impact.

Table 1. Local Storage Ring Tolerances

The elements in the first column identify: B, bend magnet. QD, defocusing quadrupole. QF and QFA, focusing quadrupoles. SF, focusing sextupole. SD, defocusing sextupole. HVC, horizontal and vertical corrector magnet. BPM, beam-position monitor. The prefix ‘sr’ stands for Storage Ring. Tolerances are described in local, beam-following coordinates: w, in beam direction; u, radially away from the ring center; v, vertical. u', pitch; v', yaw; w'. roll.

Element	Δw [mm]	Δu [mm]	Δv [mm]	Δu' [mrad]	Δv' [mrad]	Δw' [mrad]
srB	0.15	0.15	0.15	./.	./.	0.25
srQD	0.3	0.15	0.15	./.	./.	0.5
srQF	0.3	0.15	0.15	./.	./.	0.5
srQFA	0.3	0.15	0.15	./.	./.	0.5
srSF	0.5	0.15	0.15	./.	./.	./.
srSD	0.5	0.15	0.15	./.	./.	./.
srHVC	1.0	1.0	1.0	./.	./.	2
srBPM	0.15	0.15	0.15	./.	./.	./.

./. means that these values are predetermined by other values in this table.

Table 2. Local Booster Tolerances

The prefix ‘br’ stands for Booster Ring. For further explanations, refer to Table 1.

Element	Δw [mm]	Δu [mm]	Δv [mm]	Δu' [mrad]	Δv' [mrad]	Δw' [mrad]
brB	0.5	0.3	0.3	1.0	1.0	1.0
brQD	0.5	0.3	0.3	1.0	2.0	1.0
brQF	0.5	0.3	0.3	1.0	2.0	1.0
brSF	1.0	1.0	1.0	2.0	2.0	2.0
brSD	1.0	1.0	1.0	2.0	2.0	2.0
brHVC	2.0	1.0	1.0	2.0	2.0	2.0
brBPM	1.0	0.3	0.3	1.0	2.0	1.0

Each monument position has been chosen in a way to allow observation of at least two other control points from any given monument. Several monuments are selected as primary control points: these are observed from the radiation shielding roofs above the storage and booster rings through special openings. The horizontal positions of all primary monuments are transferred above the roof elevation by plummets and then linked to other primary monuments by direct observations; this method improves the absolute accuracy of these coordinates. In a series of network simulations,[4] using PC-GEONET, it was determined which observations, between all primary and secondary monuments, significantly contribute to an expected point accuracy of ±0.25 mm. Only these essential measurements are included in the observation plan. A map with calculated error ellipses is shown in Fig. 4.

The mainly used survey instruments are theodolites (Kern E2, 2.4 **μrad** accuracy) for horizontal directions; levels (Wild N3, 0.15 **μrad** accuracy) with calibrated vertical scale bars for elevation measurements; nadir plummets (Wild NL, 1.5 **μrad** accuracy) to center instrument stands over monuments; and an electronic laser distance-meter (Kern Mekometer ME 5000, 1 x 10^{-7} relative accuracy) for distances.

ECDS, in comparison, uses only theodolites to determine horizontal and vertical directions. Either a calibrated scale bar or objects with a known distance between two points provide the absolute scaling factor. Another essential difference between common survey methods and ECDS is that ECDS can operate in a local network, not connected to any control points generally used to survey and position accelerator components. It is therefore free of errors which are introduced by levelling and centering an instrument above a floor monument.

Newly designed instrument stands[8] will be used; they are mechanically centered on Taylor-Hobson balls and adjusted by two support rods so that they line up in the vertical direction. Removable adapters on top of every stand provide for the different survey instruments to have their pivoting points at the same height.

There are two fundamental reasons why, in spite of the more complicated procedures, the final survey of practically all components installed in the ALS building will be performed using common survey techniques in conjunction with PC-GEONET and not ECDS. At first, ECDS can only be used in a small confined area. To determine control points for a larger survey site with the required accuracy it is necessary to separate the measurements for elevations and horizontal positions. And secondly, a tool like PC-GEONET which includes data reduction, weighting of observations, calculation of adjusted coordinates, error analysis, and data management in an automated data flow speeds up the alignment task by a huge factor and eliminates many possible sources of human error. For prealignment (either in workshops or in the ALS building), however, and in special cases where certain components cannot be properly surveyed ECDS is used instead.

ECDS data are directly sent to a mobile, dedicated AT-type computer that handles processing and storage. For work with PC-GEONET, data are captured either automatically (distances and horizontal directions) or manually (vertical directions) by portable computers and uploaded off-line into a stationary 80386 PC where the processing and archiving software is installed. An interface is currently under development that allows introduction of ECDS data into the PC-GEONET database.

Alignment Procedures

Nearly all of the lattice magnets of the two rings are mounted in groups on girders; there are 12 such girders in both the storage ring and booster synchrotron. Fig. 2 illustrates one-twelfth of the storage ring and one-quarter of the booster. The booster girders, about 4-m long, are supported by three vertical struts and held in position by three horizontal ones, offering the possibility of independently adjusting the girder positions in all six degrees of freedom. The suspension scheme for the 12-m long storage ring girders is quite similar, but two of the three struts that determine the horizontal girder position are inclined by 45°. This arrangement was chosen in order to stiffen the girder and suppress some of its vibration modes; for small corrections it only causes a reduction of the effective pitch of the strut threading.

All lattice magnets of both rings, as well as the dipoles and quadrupoles in the transport sections, are supported on their girders or stands by three vertical struts and kept in position by three horizontal ones; all struts have differential pitch threadings to provide fine corrections to less than 10 µm. The storage ring vacuum chambers are made from two solid aluminum halves that are welded together after milling out all required openings and recesses; every chamber covers an entire storage ring bend. Because of their shape, the chambers would be heavily deformed if they were held by only three vertical supports over their entire length; therefore, seven vertical struts are used. Because of the substantial thermal expansion of the chambers during bake out, the central vertical strut is built as a fixed pivot. However, its position on the girder can still be somewhat adjusted. Two horizontal struts are used to orient each chamber, at the same time forcing it into the correct curvature. Eight beam-position-monitors, each one equipped with four tooling-balls, represent the chamber for survey and alignment purposes.

All girders carry their own fiducial posts, six for the booster girders and twelve for the storage ring girders, with the nominal girder surface defined as the plane that lies exactly one nominal fiducial height below another plane fitted through the fiducial centers using a least-square adjustment. All girders are optically fiducialized before installation, using ECDS. The procedures for the booster girders and the various booster lattice magnets are described elsewhere.[9]

Details of the alignment procedures for different components vary somewhat, but ultimately all girders will be aligned to the control net in the accelerator building, using ECDS in a set-out mode. Then all components will be fine-aligned to the monument net using PC-GEONET. The lattice magnets of the first two booster girders were pre-aligned in repetitive steps, using ECDS. With these completed girders as models, templates were fabricated to position all other lattice magnets on the remaining booster girders.

To correct the positioning of each element, offset values of the fiducial centers in relation to their ideal coordinates are transformed into individual local coordinate systems, parallel to the main element axes. The correction values are applied along the element axes and controlled by dial indicators. The necessary transformations are done off-line, either using PC-GEONET or computer spreadsheets.

Actual Status and Current Results

By July 31, 1990, the entire ALS area, including the part reserved for experimental stations, see Fig. 1, has been surveyed coarsely (with about ±3 mm accuracy) by an outside contractor” in order to obtain information on the actual floor elevations and to position monuments. The booster, linac, and LTB (Linac-To-Booster) transfer sections and some BTS (Booster-To-Storage ring) monuments are now permanently placed in their designated locations.

All existing monuments so far have been precisely surveyed and adjusted at least once (twice in the linac area) using PC-GEONET, taking the measured coordinates from the earlier, coarse survey as approximate data for the first least-squares-adjustment and their resulting values as approximate data for the second adjustment. Table 3 shows statistical differences between corresponding coordinates evaluated in these three surveys. For the linac area, the similarity between the rms shift and the average shift in z-direction clearly indicates a systematic trend. Most of the differences found in the two precise surveys of 4/16/90 and 5/14/90 are to be attributed to ground settlement, caused by the erection of shielding walls and the placement of loaded booster girders on the concrete slab, in the period between the two surveys.

Table 3.
Differences [mm] between measured monument coordinates in the booster area (coarse survey and PC-GEONET survey #1) and the linac area (PC-GEONET surveys #l and #2). **ΔL,** entire shift; **Δz,** shift in easterly direction; Ax, shift in northerly direction.

Survey Area	Max ΔL	Min ΔL	RMS ΔL	Average Δz	Average Δx
Booster	7.36	0.92	3.50	0.17	-0.12
Linac	1.42	0.29	0.66	-0.54	0.12

Local ECDS surveys of the booster lattice magnets on five girders that are now located in their final positions in the accelerator building, proved that prealignment, using the templates, was already quite precise (see Table 4). Girder #3 in sector #1 has significantly lower differences in all three directions than all other girders because it was repetitively surveyed and realigned in order to build the first template. By carefully analyzing the measured differences between ideal and real fiducial coordinates for all individual lattice magnets, using spreadsheets, it was possible to identify and correct a few errors that had occurred during the mechanical fiducialization procedure.

The results of the (coarse) floor elevation survey are shown in Fig. 4. All measured values range within a span of ±23 mm, nearly twice the originally requested tolerance for the concrete slab flatness. The specified range of adjustment for all newly designed mechanical devices, such as magnet stands and photon beam line equipment, is ±25.4 mm, i.e. just sufficient to encompass the measured variation of elevations. In view of the fact that shimming of components is much easier than grinding of concrete, it was decided that the nominal elevation of the

ALS floor is regarded to be 10 mm higher than the numerical average of all elevation values measured by this survey. This convention is equivalent to choosing the mean value between the two extreme elevations as the nominal height.

Table 4.
RMS differences [mm] between measured and ideal fiducial coordinates (w, in beam direction; u, radially outward; v, vertically upward) for the booster lattice magnets of sectors 1 and 2

Girder Name	Δ w	Δ u	Δ v
BR1 G2	0.45	0.41	0.21
BR1 G3	0.20	0.20	0.09
BR2 G2	0.88	0.58	0.47
BR2 G3	0.48	0.38	0.31
BR2 G4	0.52	0.56	0.33
BR4 G2	0.48	0.41	0.60
BR4 G3	0.45	0.67	0.25

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References

1. 1-2 GeV Synchrotron Radiation Source, Conceptual Design Report, LBL Pub. 5172 Rev.), 1986

2. Illustration by E. Melczer, LBL

3. H. Friedsam, R. Pushor, and R. Ruland, SLAC-PUB-4142, Nov, 1986

4. The customization of PC-GEONET and the observation plan were created by H. Friedsam with the guidance of R. Ruland, under a collaboration agreement between LBL and SLAC.

5. Kern Instruments Inc., ECDS, Electronic Coordinate Determination System, Instruction Manual, 1986

6. R. Keller, C. Kim, and H. Nishimura, 'Alignment Tolerances for the ALS Storage Ring and Booster Synchrotron,' LSAP-070, LBL Berkeley (1989)

7. The magnet measurement activities are led by S. Marks, LBL.

8. Conceptual layout by W. Baldock, LBL (1990)

9. J. Tanabe, R. Keller, and T. Lauritzen, 'ALS Booster Synchrotron Girder and Magnet Fiducialization Procedures,' Proc. this Workshop (1990)

10. This survey was performed by "Bates & Bailey," San Francisco, under a commercial contract.

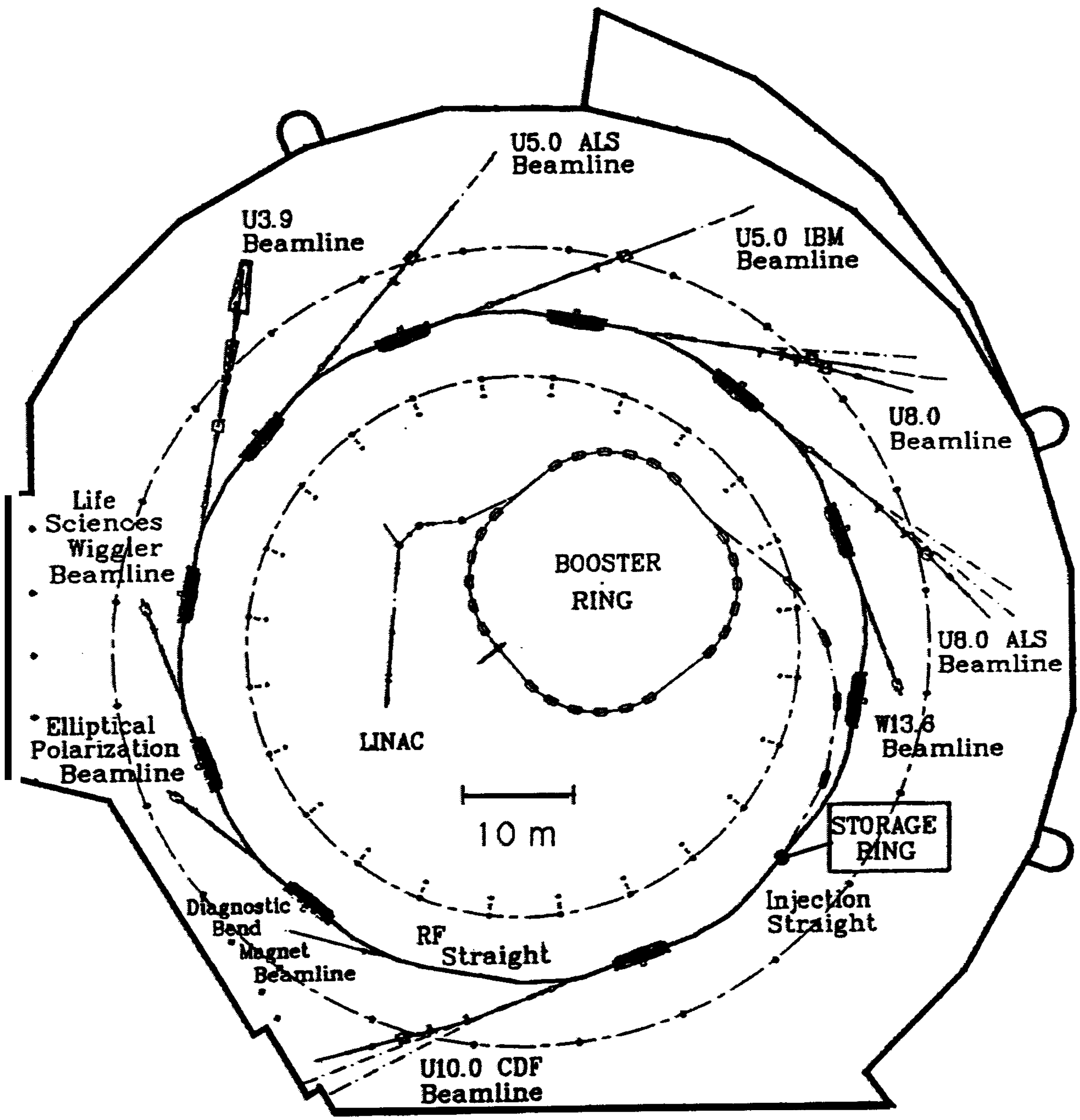

Fig. 1.
ALS building layout with the three main accelerator systems, electron beam transfer lines, and the planned photon beam lines and exnerimental stations.[2]

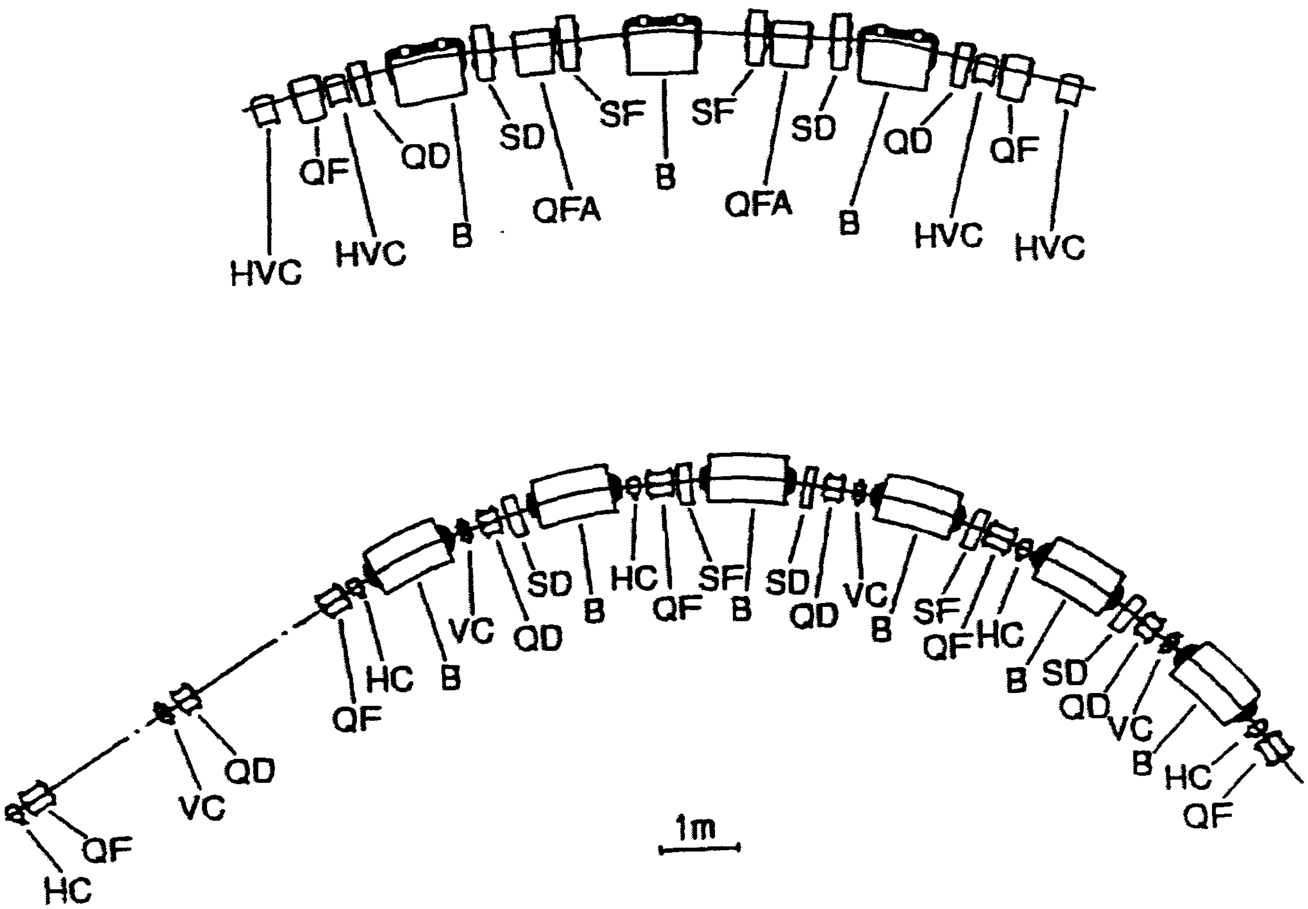

Figure 2.
Arrangement of lattice magnets on one storage ring girder (top) and in one booster quadrant, on three girders and one stand (bottom).

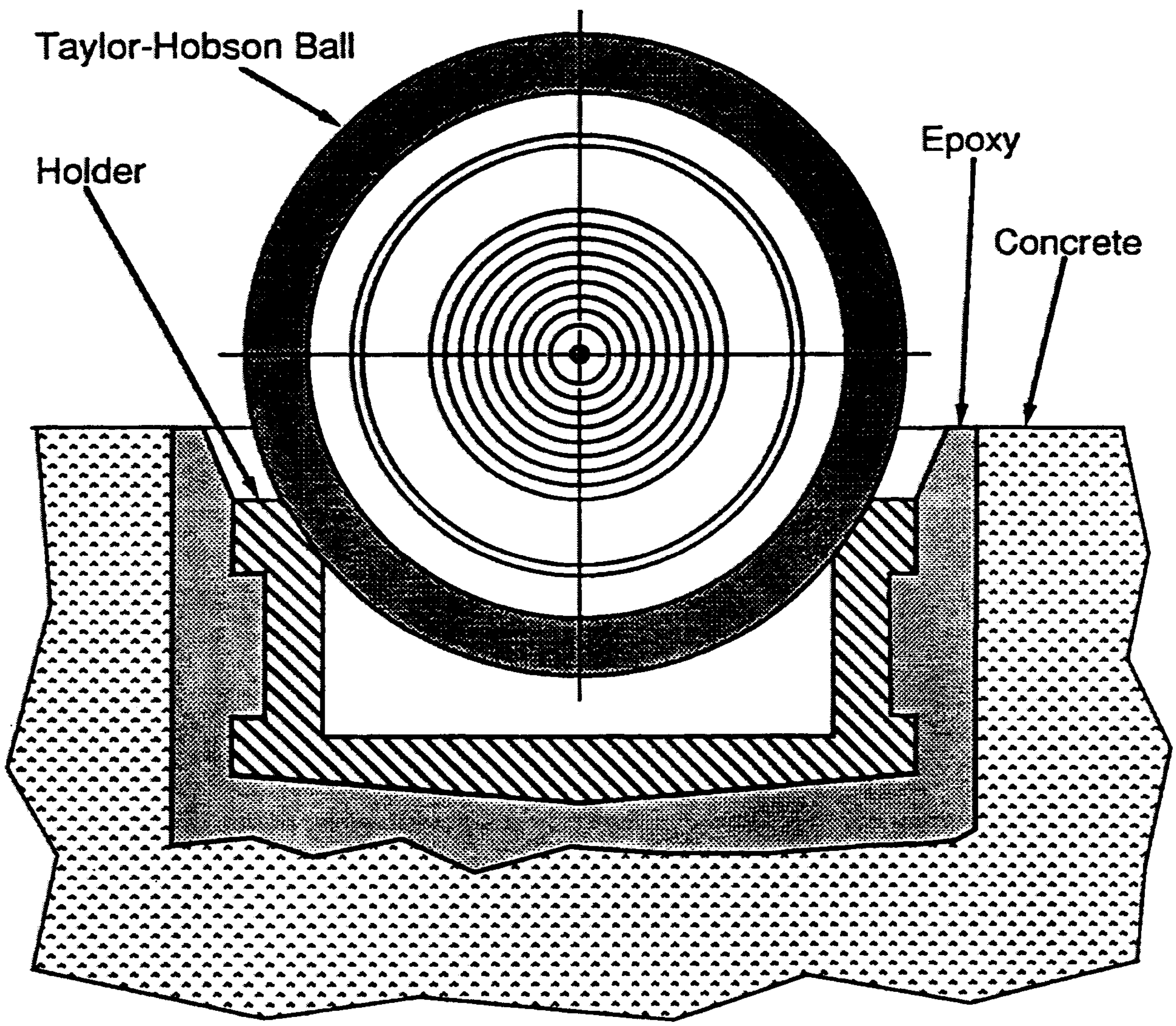

Figure 3.
ALS monuments are Taylor-Hobson balls of 88.9 mm diameter, set into a monument holder that is permanently inserted in the concrete floor. A precision-ground cone on the holder determines the ball position; the ball center defines the monument coordinates in all three dimensions.

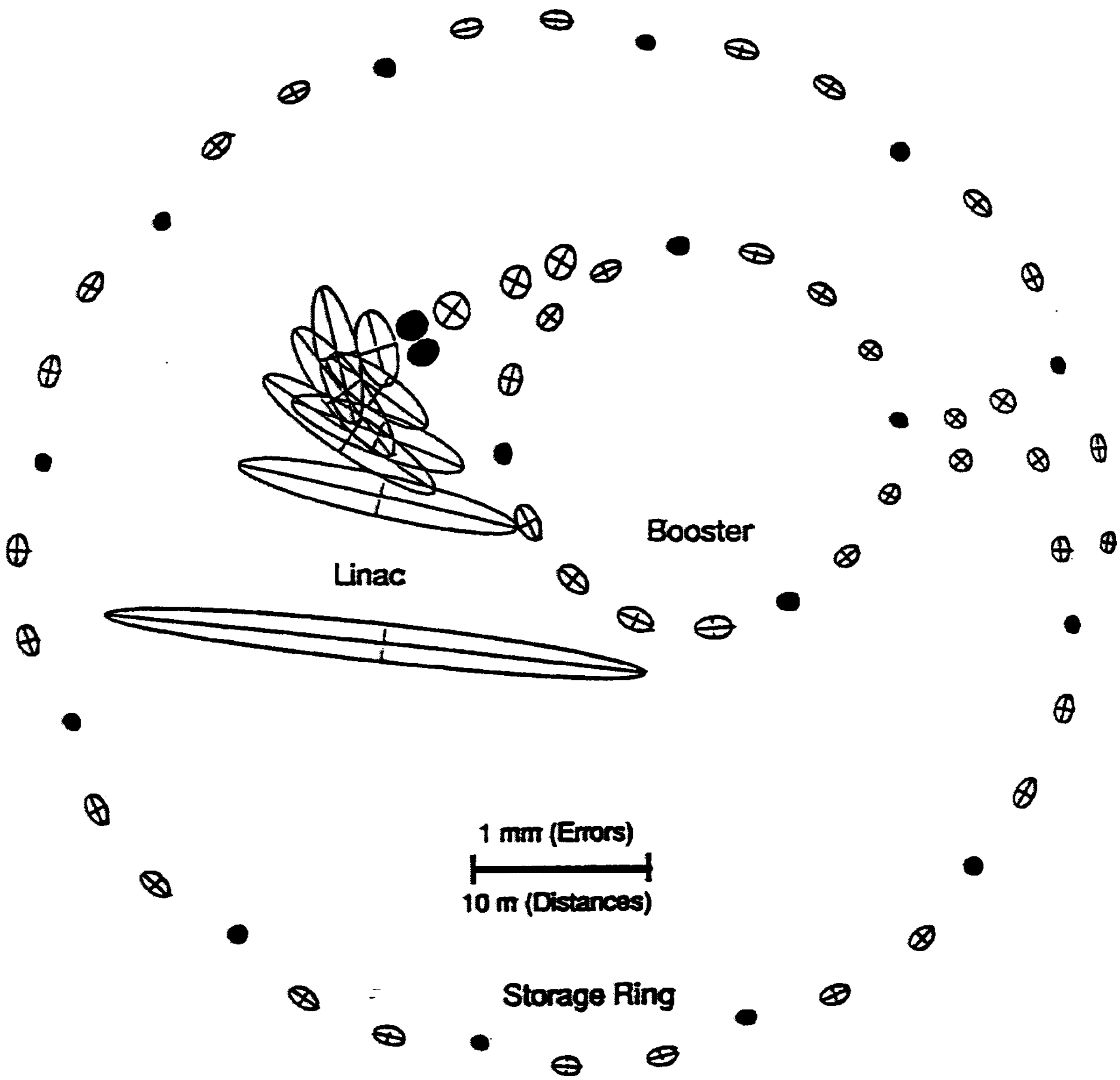

Figure 4.
Simulated absolute error ellipses for primary and secondary monument positions. Only in the linac area errors greater than 0.15 mm (up to 1.5 mm) are expected; this can be tolerated from the accelerator physics standpoint. Nearly all error ellipses associated with primary monuments (full black) are significantly smaller than the ones belonging to secondary monuments, due to the better geometry of the superior network on top of the shielding roofs.

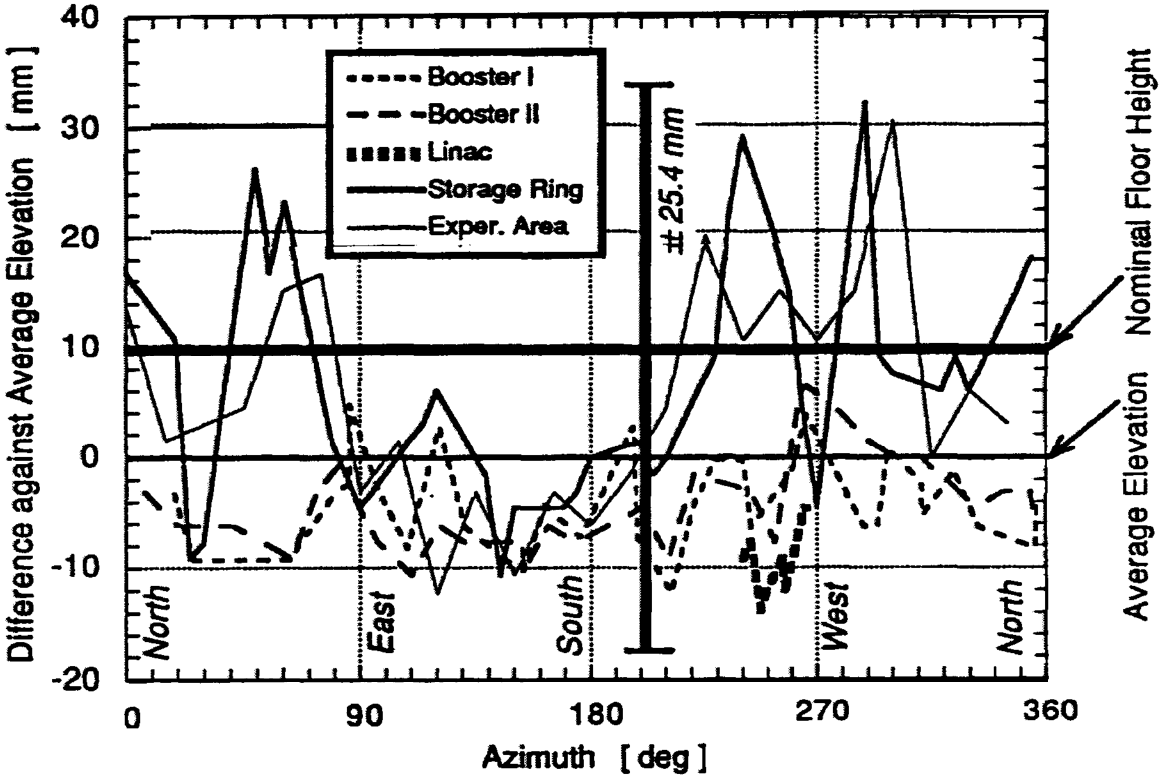

Figure 5.
ALS floor elevations, plotted as differences against the average elevation versus the azimuthal position. Azimuths are determined from the storage ring center for the storage ring and experimental areas and from the booster center for the booster and linac areas. The precision of this survey can be derived from the two sets (I and II) of data covering the booster area.