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**Survey, Alignment and  
Beam Stability at the  
Advanced Light Source**

Gary F. Krebs  
**Accelerator and Fusion  
Research Division**

October 1997



SCAN-9801091

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This work was supported by the Director, Office of Energy Research, Basic Energy Sciences, High Energy Physics Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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# Survey, Alignment and Beam Stability at the Advanced Light Source\*

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## Abstract

This paper describes survey and alignment at the Lawrence Berkeley Laboratories Advanced Light Source (ALS) accelerators from 1993 to 1997. The ALS is a third generation light source requiring magnet alignment to within 150 microns. To accomplish this, a network of monuments was established and maintained. Monthly elevation surveys show the movement of the floor over time. Inclinometers have recently been employed to give real time information about magnet, vacuum tank and magnet girder motion in the ALS storage ring.

## 1 INTRODUCTION

The Advanced Light Source (ALS) at the E.O. Lawrence Berkeley National Laboratory is a third generation synchrotron x-ray source[1]. The ALS, shown schematically in Figure 1, has a 50 MeV LINAC and a 1.5 GeV booster and 2.1 GeV storage ring. To produce a stable and bright electron beam, long term mechanical alignment and stability of the magnets over the 200 m circumference storage ring must be maintained. In order to track the electron beam, a system of over 100 Beam Position Monitors (BPM) are mounted in the storage ring vacuum chambers. Characteristics of the storage ring motion have been measured and are presented in this paper.

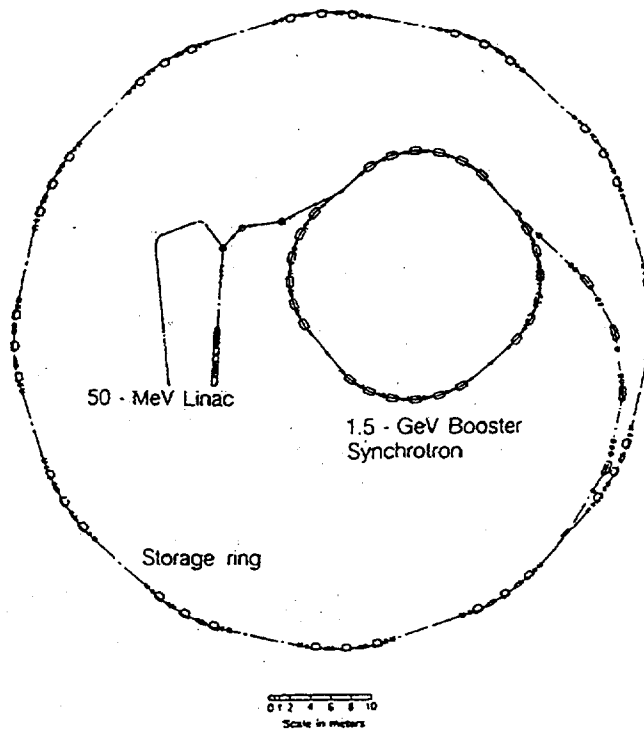


Figure 1

The ALS accelerators showing the LINAC, Booster and 2.1 GeV storage ring

## II MONUMENT MOTION

To carry out accurate alignment of the storage ring magnets, a reference network of 36 monuments was created. The monuments are imbedded in an 18 inch thick concrete floor. The angles and distances between

monuments are measured with theodolites and mekometers, respectively, to determine their coordinates relative to an arbitrary chosen origin. Starnet<sup>®</sup> software[2] is used to reduce the data. Magnet positions around the 12 sectors of the storage ring are then referenced and aligned to the monuments. Some 200 storage ring magnets are mounted on a system of 12 moveable sector girders such that after initial alignment on the girder, future storage ring magnet alignment can be achieved by aligning the girders alone.

Since September 1995 storage ring monument elevation surveys have been carried out nearly every month in an effort to characterize floor and magnet/girder motion. Monument elevations were measured with 30  $\mu\text{m}$  accuracy. The changes in elevation of the 36 storage ring monuments are shown in Figures 2a-2d from the period September 1995 to September 1997.

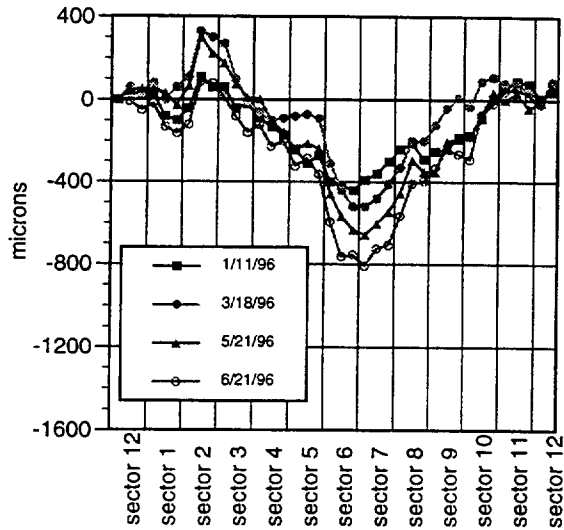


Figure 2a

Change in monument elevation from 1/96-6/96 around the storage ring.

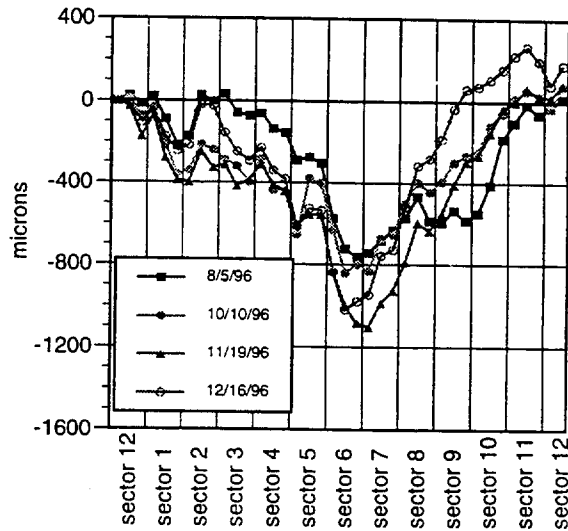


Figure 2b

Change in monument elevation from 8/96-12/96 around the storage ring.

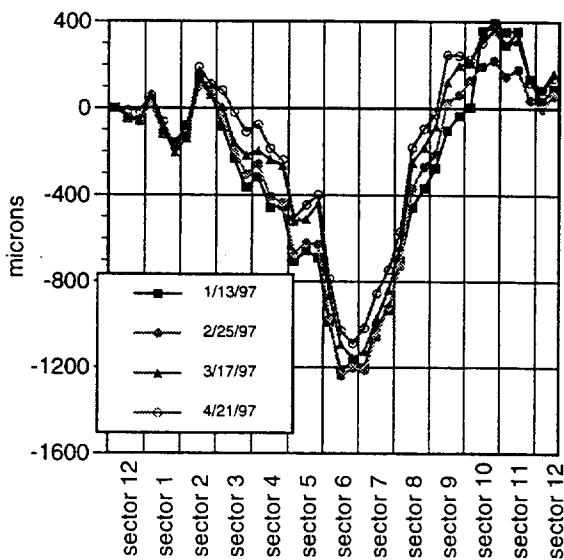


Figure 2c

Change in monument elevation from 1/97-4/97 around the storage ring.

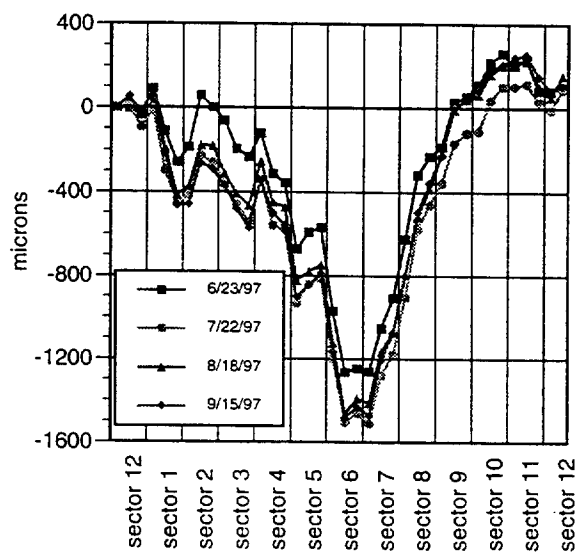


Figure 2d

Change in monument elevation from 6/97-9/97 around the storage ring.

We find the storage ring monuments have dropped in elevation as much as 1.5 mm in sectors 6 and 7, see Figure 2d. Over the period represented in Figure 2a-d, a great deal of floor loading has occurred. Insertion

devices, weighing 30 tons each, were added to the storage ring in sectors 9, 12 and 5 in 5/94, 9/95 and 4/96, respectively. In Figure 2a and Figure 2d we observe a characteristic drop followed by a rise in monument elevations during the rainy winter months for most sectors around the storage ring. Operationally, the storage ring requires smoothness magnet-to-magnet to function optimally. Since the magnets were aligned on their girders relative to their ideal position to within 50  $\mu\text{m}$  and remain stable relative to one another, what remains is to maintain girder-to-girder smoothness as floor motion occurs. Figure 2a-d shows the smoothness monument-to-monument and, by extension, girder-to-girder to be typically better than 100  $\mu\text{m}$ . A system of corrector magnets around the storage ring can correct for girder-to-girder misalignments up to a few hundred microns. As the beam corrector magnet field limits are approached, the storage ring must be realigned. In Figures 3a-3d the sectors average monument elevations are shown over the same time period. Sectors 11 and 12 are the most stable sectors as shown in Figure 3d while sectors 6 and 7, see Fig.3b-c, have dropped the most in elevation. Included in Figure 3a is the measured rainfall over the time period covered by monument elevation measurements. Again, we see a rise in most monument elevations preceded by the heaviest annual rainfall.

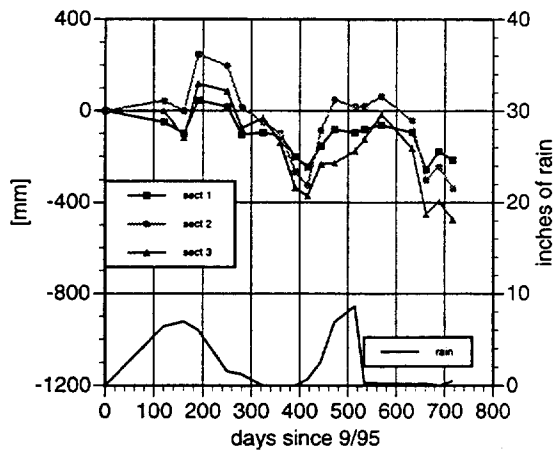


Figure 3a

The average monument elevation change for sectors 1-3 since Sept.1 1995.

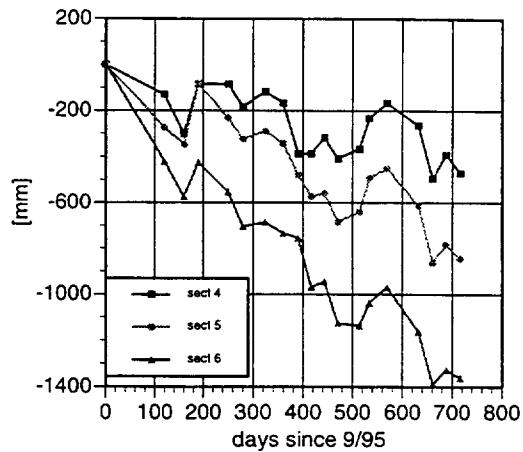


Figure 3b

The average monument elevation change for sectors 4-6 since Sept.1 1995.

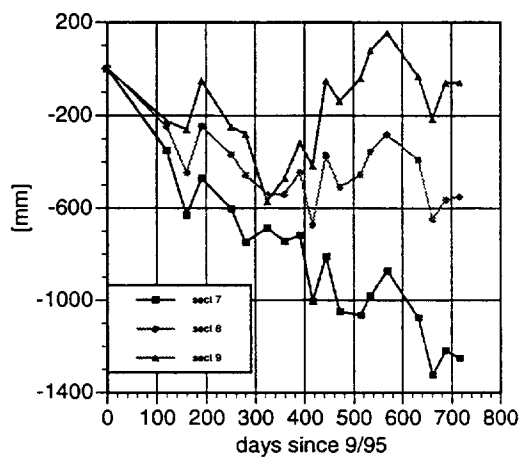


Figure 3c

The average monument elevation change for sectors 7-9 since Sept.1 1995.

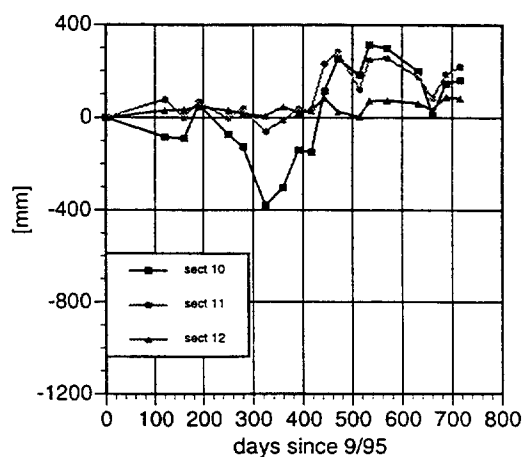


Figure 3d

The average monument elevation change for sectors 10-12 since Sept.1 1995.

### III MAGNET/MACHINE AND BEAM STABILITY

After mechanical alignment of the accelerator has been achieved, one may turn attention to maintaining that alignment under accelerator operating conditions. We have utilized inclinometers[3] and precision dial indicators[4] to measure the motion of the storage ring girders and vacuum chambers during a cold start up and steady state running. Shown in Figure 4 is the change in pitch and roll of a typical girder during a cold start up

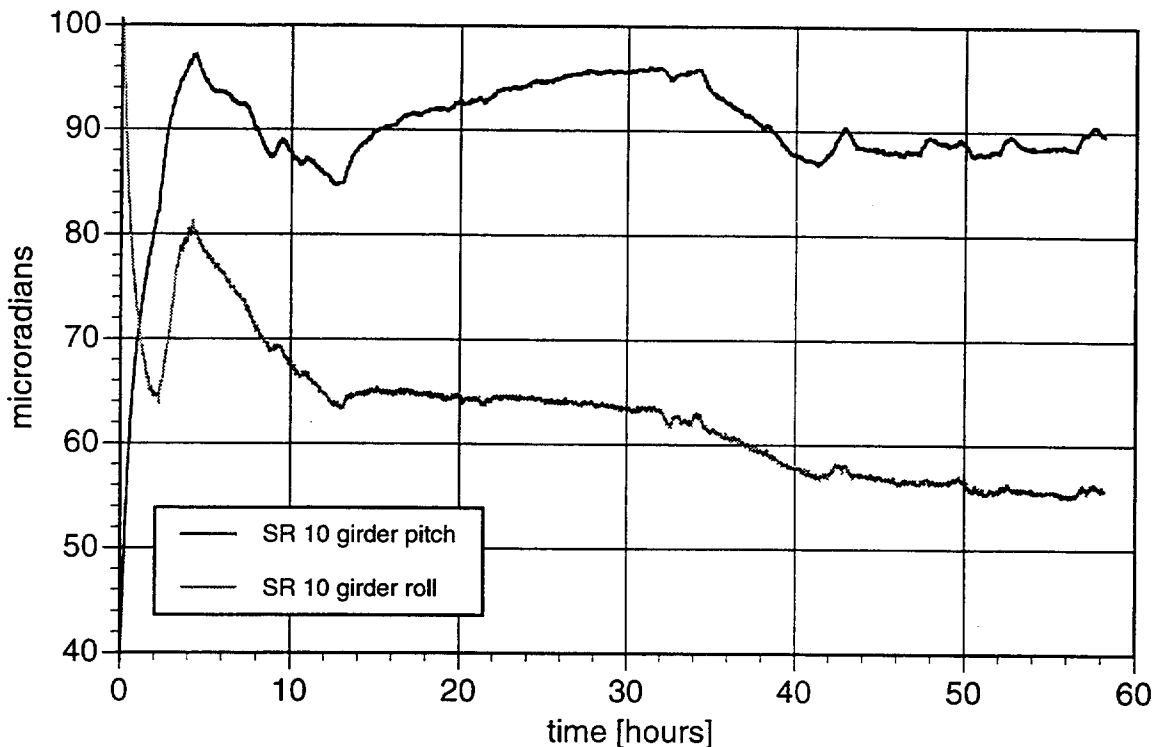
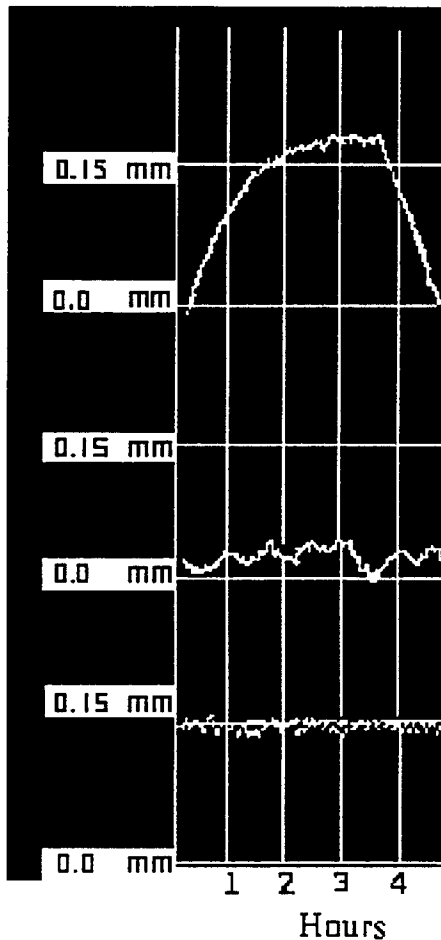


Fig. 4  
The change in pitch and roll of a girder during warmup  
and running of the storage ring

of the storage ring after a weekly maintenance shutdown. During start up, the girder pitches and rolls 50 - 60  $\mu$ radians over a period of 12 hours. From 13 hours until about 41 hours after start up, the accelerator was running a low intensity of 50 ma. After that the accelerator was in a production mode of filling to 400 ma every 4 hours with subsequent decays to about 200 ma. Changes in pitch and roll of the girder of about 2  $\mu$ radians occur during the 4 hour refill cycle. Measurements with thermocouples indicate the effect is thermal with contributions from both magnet/girder warmup and beam/synchrotron radiation.

The stability of the storage ring electron beam has been examined using the accelerators 96 beam position monitors (BPM). The BPM allow accelerator operators to track the electron beam through the magnet lattice, then carry out corrections and compare the electron beam location to various influences and models. Beam stability, as measured by the BPM, is affected by many different parameters. We have found such things as overhead crane usage, earthquakes and air temperature stability inside the storage ring tunnel to be some of the 'mechanical' influences effecting the trajectory of the electron beam. Figure 5 shows the horizontal beam position over a period of 5 hours. The top trace shows a change in position caused from a 1  $^{\circ}$ C rise in air temperature in the storage ring tunnel. Over a period of about 3 hours the beam changes position 175  $\mu$ m. When the temperature is lowered by 1  $^{\circ}$ C, the beam returns to its original position with a similar time constant. The center trace shows an hourly fluctuation in beam position of about 40  $\mu$ m caused by the tunnel air blowers turning on and off every hour during a hot day. The lower trace shows the beams horizontal position with the air conditioning system improved to maintain air temperature in the tunnel to within  $\pm 0.1$   $^{\circ}$ C. The variation in horizontal beam position is approximately  $\pm 10$   $\mu$ m. (Vertically the variation is  $\pm 4$   $\mu$ m.) These effects are caused by the change in length and reorientation of the 200 m circumference storage ring during the thermal cycles.





**Figure 5**

The horizontal position of the electron beam at the ALS. The three traces show the effect of temperature changes in the storage ring tunnel.

## V CONCLUSIONS

Monitoring the alignment of third generation synchrotron storage rings is important in order to maintain a bright and stable electron beam. Periodic realignments are typically required approximately every 24 months at the ALS. Measuring the alignment of the storage ring under operating conditions can be equally important when a high degree of electron beam stability is required by the experimenters. Beam based alignment techniques may prove to be useful and expedient when the accelerator is in a thermally stable condition.

## ACKNOWLEDGMENTS

I would like to thank the survey and alignment crew at the ALS headed by William Thur: Bill Baldock, R. DeMarco, A. Gavidia, R. Armstrong, D. Jones and H. Meyer. Special thanks go to Bill Baldock whose help was crucial in collecting the dial indicator and inclinometer data for this study.

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- [1] 1-2 GeV Synchrotron Radiation Source (conceptual design report) LBNL Pub. 5172
- [2] STARPLUS SOFTWARE, INC 460 Boulevard Way, Oakland, CA 94610.
- [3] Applied Geomechanics Inc. Santa Cruz, CA (408)462-2801
- [4] Mitutoyo digimatic indicator 543-523A

