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THE SPEAR3 UPGRADE PROJECT AT SLAC *

Catherine Le Cocq, Brian Fuss, Michael Gaydosh
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Abstract

A major upgrade of an existing synchrotron light source at SLAC was completed in December 2003. A new machine called SPEAR3 will operate at 3 GeV with a current of 500 mA. Presently it is fully operational at 100 mA. From an alignment perspective the primary goal was to fiducialize and position newly manufactured magnets and vacuum chambers in the ring to better than 250 μm globally. A critical complication was to recreate the old position of the orbital beam path in the new ring so that some existing tangential beamlines could be preserved. This paper will cover the survey and alignment techniques and results of this new ring.

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1. INTRODUCTION

The Stanford Synchrotron Radiation Laboratory (SSRL) commissioned a 2.4 GeV colliding beam facility in 1972 called SPEAR (Stanford Positron Electron Asymmetric Ring). Located on the Stanford Linear Accelerator Center (SLAC) site, the ring later had a major upgrade in 1974 to 4 GeV and became known as SPEAR2. The addition of an injection kicker in 1991 allowed the facility to routinely operate at 2.3 GeV with an improved emittance dropping from 500 nm-rad to 130 nm-rad. In 1997 a proposal was made to upgrade the ring into a third generation light source known as SPEAR3. The goal was to create a 3 GeV storage-ring using new magnets and vacuum chambers inside the existing SPEAR2 building without changing the 234 meter circumference. Beam emittance would improve to 18nm-rad while current would initially be at 100 mA but would eventually increase to 500 mA.

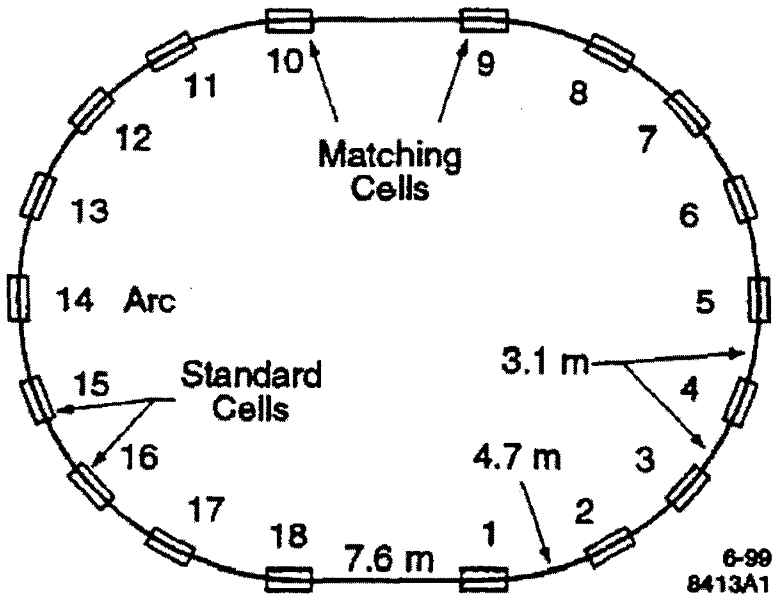


Fig. 1 SPEAR3 Cell Configuration

To minimize the cost and shorten the installation time, a new lattice with vacuum chambers were pre-assembled on steel girders that were later installed following the above configuration.

2. PREPARATION PHASE

2.1. Overview

The AEG involvement with SPEAR3 started long before the beginning of the installation. All the magnets and vacuum chambers were fiducialized as they became available. A web depository of the results was created to show the field work progress and give access to tooling ball location and selected feature data to all interested parties. In similar fashion, the status of the raft assembly was maintained to facilitate the installation process. But the originality of the SPEAR3 project as far as survey and alignment reside in the fact that this new ring had to replace the old one and assure the good connection to the remaining beamlines.

2.2. Network Consolidation

Placing new magnets and other components into the new SPEAR3 ring so that the beam orbital path will match the existing SPEAR2 path was critical to the success of the project. SPEAR2 was originally built using only optical tooling techniques without a rigorous three-dimensional survey network. Over the years since SPEAR2 was completed various new surveys and networks were completed but only for certain limited areas of the ring.

The first task necessary to establish a baseline reference to the existing ring was to gather and combine all available existing networks. Data from a September 2001 booster ring survey, a March 2002 BTS (Booster-to-SPEAR) survey, a building 130 survey and other ring surveys completed as late as February 2003 were combined into a network of 330 points and 173 stations. The total number of triplet observations (i.e. distance, horizontal and vertical angles produced either by a laser tracker or total station) was 1356. The precise levelling campaigns generated 400 height differences. A Free Network approach using only the SPEAR2 floor monuments was chosen to first analyze the combined network. The analysis of the coordinate differences showed that all these unique datums were in fact compatible and allowed a Minimal Constrained solution to be applied for generating a new set of network coordinates.

The network was constrained in position and orientation by mathematically fixing one southern monument in one direction and fixing another northern monument in all directions. Finally new levelling data was included to tie SPEAR into the rest of SLAC's coordinate system through the use of existing SLAC monuments associated with End Station A. Another opportunity was to revise the SPEAR2 component nomenclature for SPEAR3 so that the numbering scheme would have a clockwise direction which is the same as the electron beam direction. Thus SPEAR3 has a new orientation with the origin remaining at the center of the ring but with positive X being in the general direction of the booster ring. Coordinate biases were also revised so that the Z offset is now 6000 meters, the X offset is 3000 meters, and the Y offset is 500 meters. The height of the ring origin has been established as 75.7911 meters above sea level. Along with these changes existing SPEAR2 wall monuments that were expected to remain for SPEAR3 were also renamed to match this new network of survey reference points.

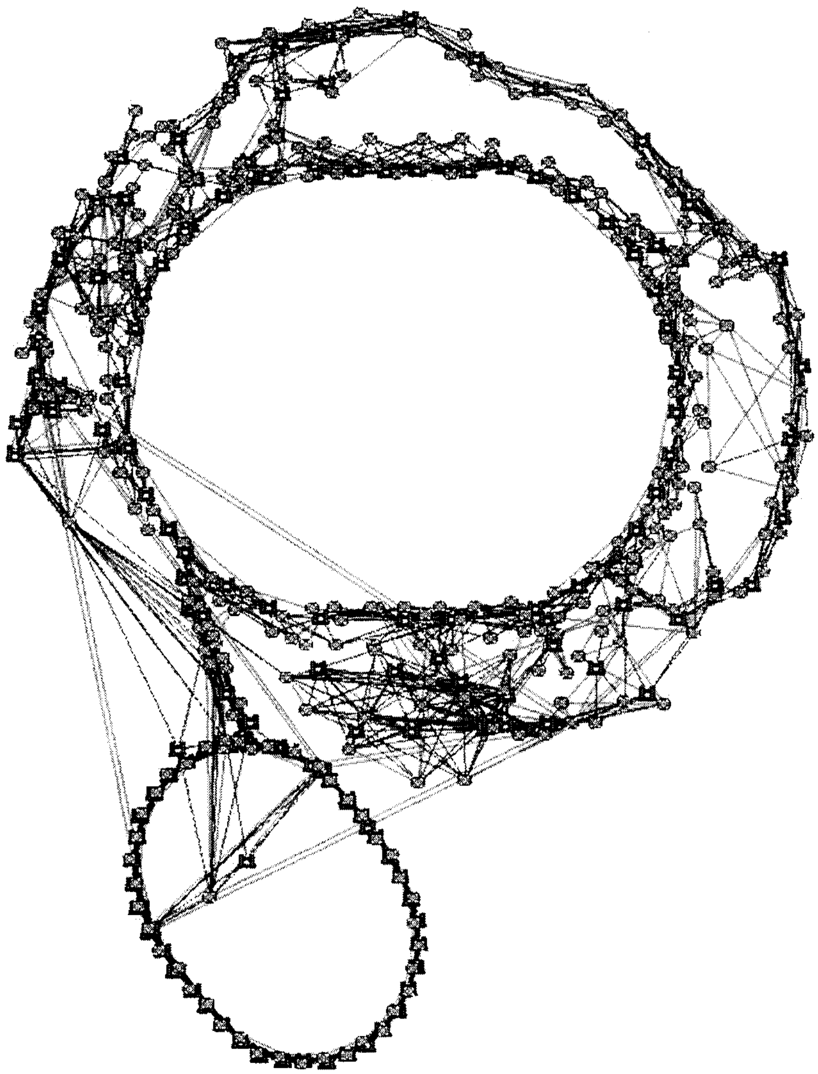


Fig. 2 SPEAR3 Consolidated Base Network

3. INSTALLATION PHASE

3.1. Overview

The removal of all the SPEAR2 ring components started on March 31, 2003. By mid June, the new ring floor was poured and ready. Due to good communication with SPEAR3 management and planning for future surveys, a design of the optimal location for the future necessary monuments to be used in the ring was ready. Using the remaining wall points of the ring, the floor points were marked with total station set-ups. Their locations were then scanned for possible rebar and adjusted if necessary to allow easy drilling. In the meantime, some wall monuments were added creating a better geometry. At the end of June, all the positions of all the anchors had been marked using templates to speed-up the process. By mid July, the ring was ready for the installation and alignment of the support plates. The actual installation of the rafts, front-ends, and other specific equipment started in August and lasted up to mid November. The final alignment task was on November 23 leaving the ring free for commissioning.

3.2. Network analysis

The first network observation occurred just after the installation of the new concrete floor. Its purpose was to assign coordinates to the freshly installed monuments in order to start the template marking necessary for drilling the support plate anchors. Of the 121 ring monuments, there were 34 new floor points and 4 old floor points located in the 2 long straight sections of the ring. The remaining monuments were located in the buildings surrounding the ring as well as in the transfer line. For simplicity we will designate these points as part of the SSRL. All floor SSRL monuments were entered in the adjustment with sigma a-priori on their 3 coordinates leading to a weighted datum solution. The quality of this solution was checked with the 4 old floor ring points.

Table 1 First Network Description

Network Geometry	Number	Comments
Points	166	121 in the ring itself
Stations	46	Laser tracker only
Observation Triplets	611	Distances: 30 µm Horizontal Angles: 50 µm / D Vertical Angles: 50 µm / D
Height Differences	144	50 µm

The second network observation occurred just before the installation of the support plates. Its purpose was to secure values for the ring monuments before aligning the support plates as this particular phase was critical in the installation process. A free network approach was chosen: it used all the floor monuments to define the datum. An analysis of the coordinate changes between these 2 solutions showed no significant floor movement and good consistency with the previous network.

Table 2 Second Network Description

Network Geometry	Number	Comments
Points	152	121 in the ring itself
Stations	47	Laser tracker only
Observation Triplets	676	Distances: 30 µm Horizontal Angles: 40 µm / D Vertical Angles: 50 µm / D
Height Differences	123	50 µm

The third and final observation set during the installation phase was original in its concept and realization. In the SPEAR3 CDR, the original decision was to proceed traditionally and perform a final map at the end of the installation followed later by the classical sequence move-map. This was in accordance with the following choices: no mover on the girders, precise positioning of the alignment pins of the support plates and tight alignment of the components on the raft. Because of some delays in the straight section and front end installation and the realization that several sections may have to be globally adjusted in height, as well as an increasing number of vacuum chambers had been moved in the process of installing the bellows, the AEG proposed several scenarios of mapping to try to match the deadline without compromising the quality of the component alignment. With the agreement of the SPEAR3 management a decision was made to perform a final survey of the monuments using laser trackers and precise levels and then survey each magnet and vacuum chamber locally using a total station and move them within tolerance when necessary. To add confidence to the individual total station set-ups, the field procedure requested that the resection be based on a minimum of 5 monuments from which at least 2 should be floor. In another effort to insure the quality to all these individual set-ups, one tooling ball on each magnet had to be mapped during the monument survey and kept as verification for the total station set-up.

Table 3 Final Network Description

Network Geometry	Number	Comments
Points	368	122 in the ring itself, 201 magnet TBs
Stations	40	Laser tracker only
Observation Triplets	636	Distances: 40 μm Horizontal Angles: 40 μm / D Vertical Angles: 50 μm / D
Height Differences	303	60 μm

The adjustment of this new network was made first in the free datum approach.

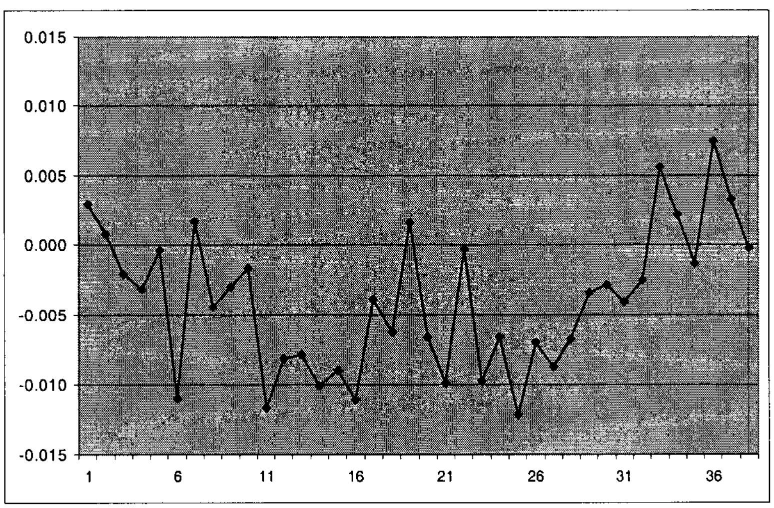


Fig. 3 Floor Monument Elevation Changes in Mils

A "mixed datum" approach was then used to easily maintain control of the coordinate system. Horizontally, it was minimally constrained using 2 floor monuments. Vertically to directly check for floor settlement, it was over-constrained by fixing 6 SSRL monuments. At this point, an analysis of the coordinate changes showed regional discrepancy between the two long straight sections. To average this effect, a 3-parameter transformation was fitted producing these graphs.

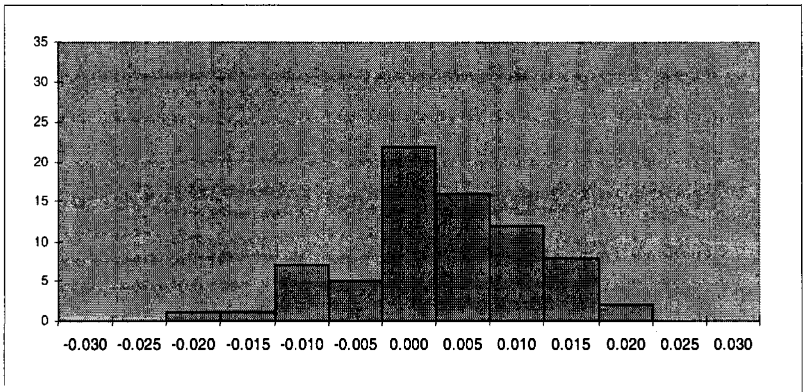


Fig. 4 Z Coordinate Change Histogram in Mils

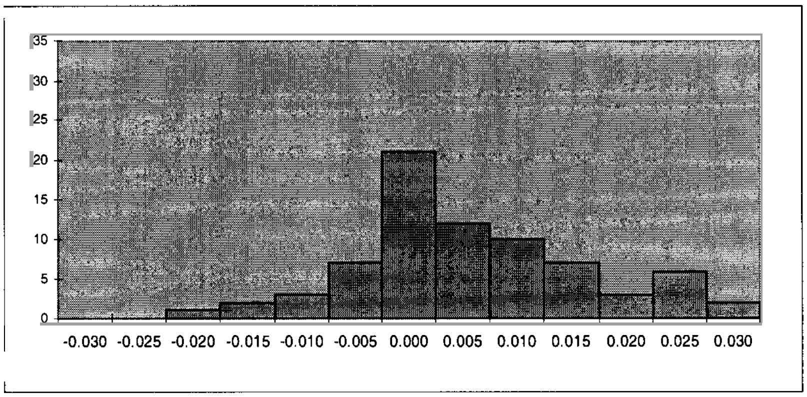


Fig. 5 X Coordinate Change Histogram in Mils

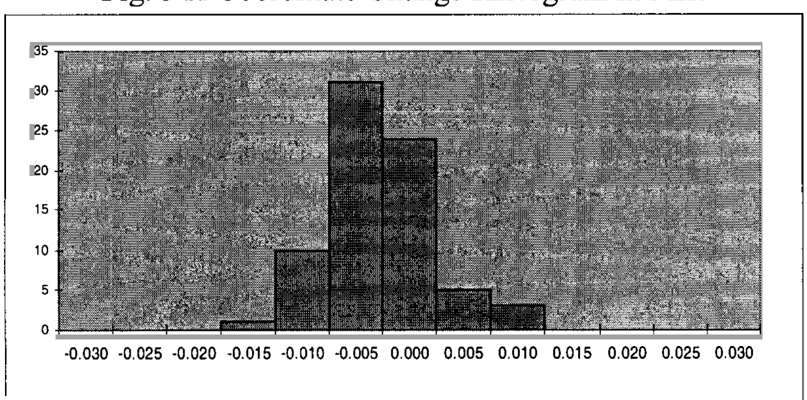


Fig. 6 Y Coordinate Change Histogram in Mils

The fine tuning of the magnets and vacuum chambers occurred between November 17 and 23. In fact half of the magnets were moved slightly. The vacuum chambers were adjusted accordingly through specific laser tracker set-ups using a 20" long extension arm and a sphere fit to produce the location of the tooling balls buried in-between magnets.

3.3. Commissioning

On December 11th, 2003 the first complete turn of an injected electron bunch was observed in the newly completed SPEAR3 storage-ring. During the following four days the RF system was operational and the ring began to accumulate beam current up to 2 mA. By January 22nd, 2004 the stored current reached the maximum allowed value of 100 mA due to existing shielding limitations. On March 8th beamline 9 was opened and the first users were operational by March 15th. Beamlines 5, 6, 10 and 11 were all opened by the end of March ready for the users.

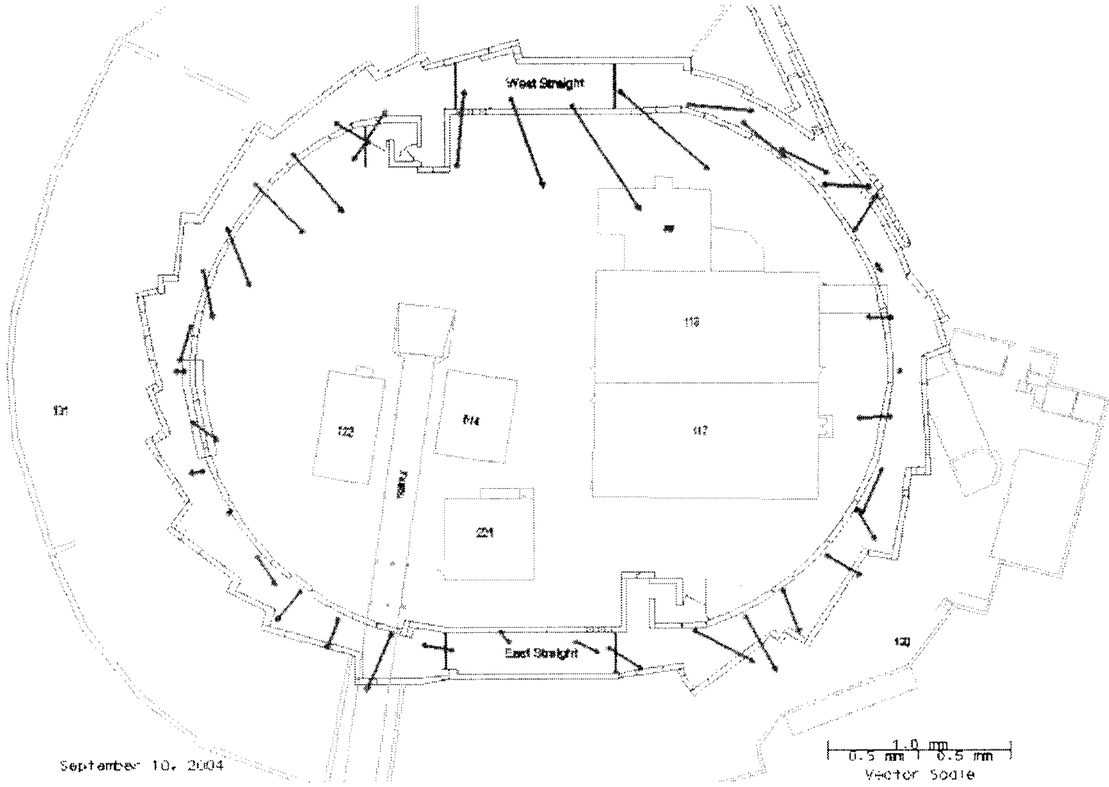
4. SUMMER 2004 DOWNTIME

This network observation was part of the 2004 Summer/Fall downtime. Its main purpose was to verify and update the ring coordinates while checking for possible floor deformations. Meetings with SPEAR3 physicists helped decide on additional goals. Thus it was decided to map both the ring monuments and the magnets but not the vacuum chambers at this stage.

Table 4 2004 Network Description

Network Geometry	Number	Comments
Points	950	143 monuments, 807 magnet TBs
Stations	44	Laser tracker only
Observation Triplets	1809	Distances: 40 µm Horizontal Angles: 50 µm / D Vertical Angles: 50 µm / D
Height Differences	270	50 µm

The same "mixed datum" approach as in the last observation campaign was applied: two "golden monuments" for horizontal control and six SSRL monuments for vertical. Then all 38 floor points in the ring were analyzed. The distribution of their variation in height followed an expected normal curve and proved that the vertical datum was well controlled as well as no significant floor movements could be detected. But the distribution of the horizontal changes showed definite regional trends. All the displacement vectors in the west straight were pointed to the centre of the ring with a magnitude approaching one millimetre. This observation had a very strange and similar flavour than the analysis for the last network survey of 2003 as shown in the following two graphs.



Figs 7 & 8 2D Coordinate Changes for 2003 & 2004 Networks

To avoid a repeated use of a 3 parameter transformation to minimize the coordinate changes in general without looking at the possible source of these changes, a complete analysis of the two networks was undergone. Several areas were identified for possible densification and/or ties to the SSRL surrounding network. A visit to the ring itself made clear what happened at the injection device for beamline 11 just before cell 16. During the first two networks of 2003, the ring was empty allowing a nice regular geometry in the layout of the laser tracker stations. The addition of the equipped rafts and their cable trays made the observations a little more cumbersome but did not change the pattern of observations. The insertion devices on the contrary reduced the width of the walkable tunnel and created a real obstacle for laser tracker observations. ID11 was particularly obstructive. To confirm the 2004 network special holes in the *Plexiglas* of the ID were drilled and a new bracket on the wall was installed to allow direct shots across the tunnel at that stage. This new station as well as other extra stations around the two long straights confirm the quality of the 2004 network and a weak spot of the last 2003 networks. The magnets and vacuum chambers from cell 15 to cell 4 were moved accordingly to the monument changes. As expected, no significant moves were made in elevation, only horizontally. To close the process the five cells with changes as well as the two neighbouring cells were re-observed using laser trackers. The two following graphs show the positions of all the magnets after the two maps.

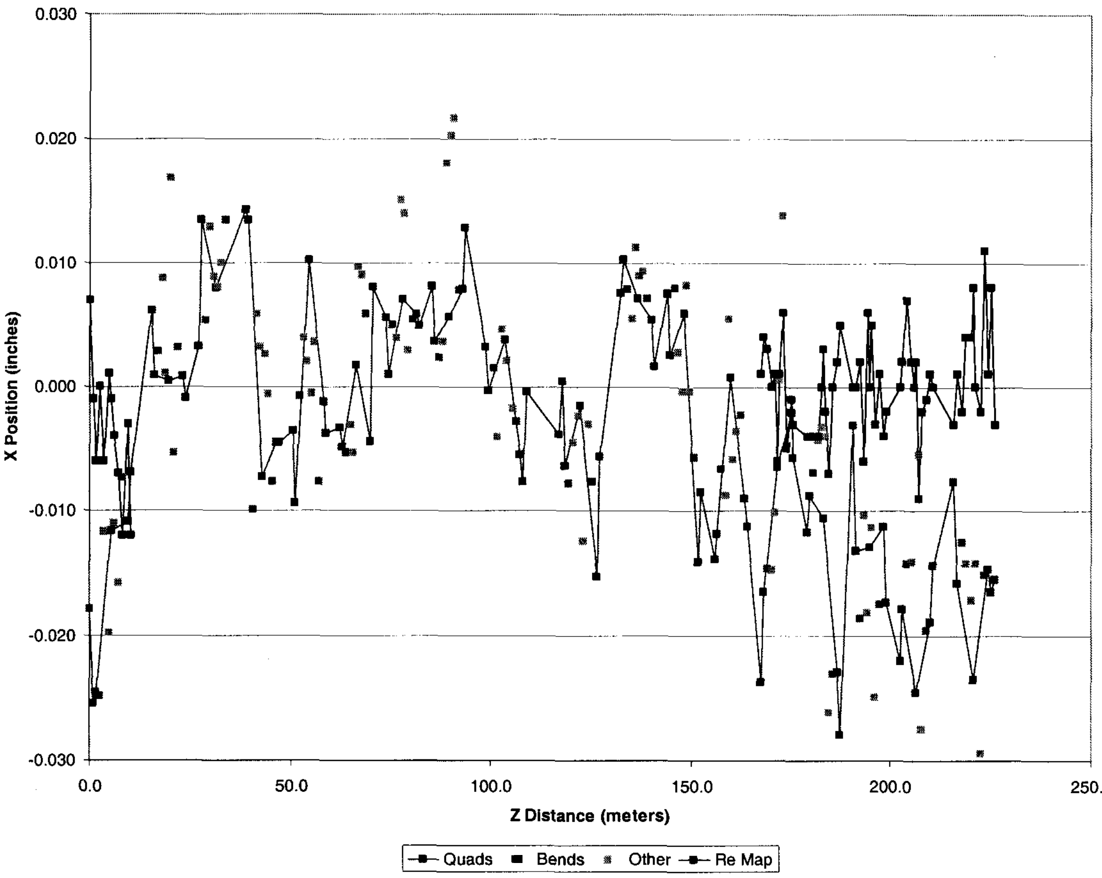


Fig. 9 Magnet X Positions

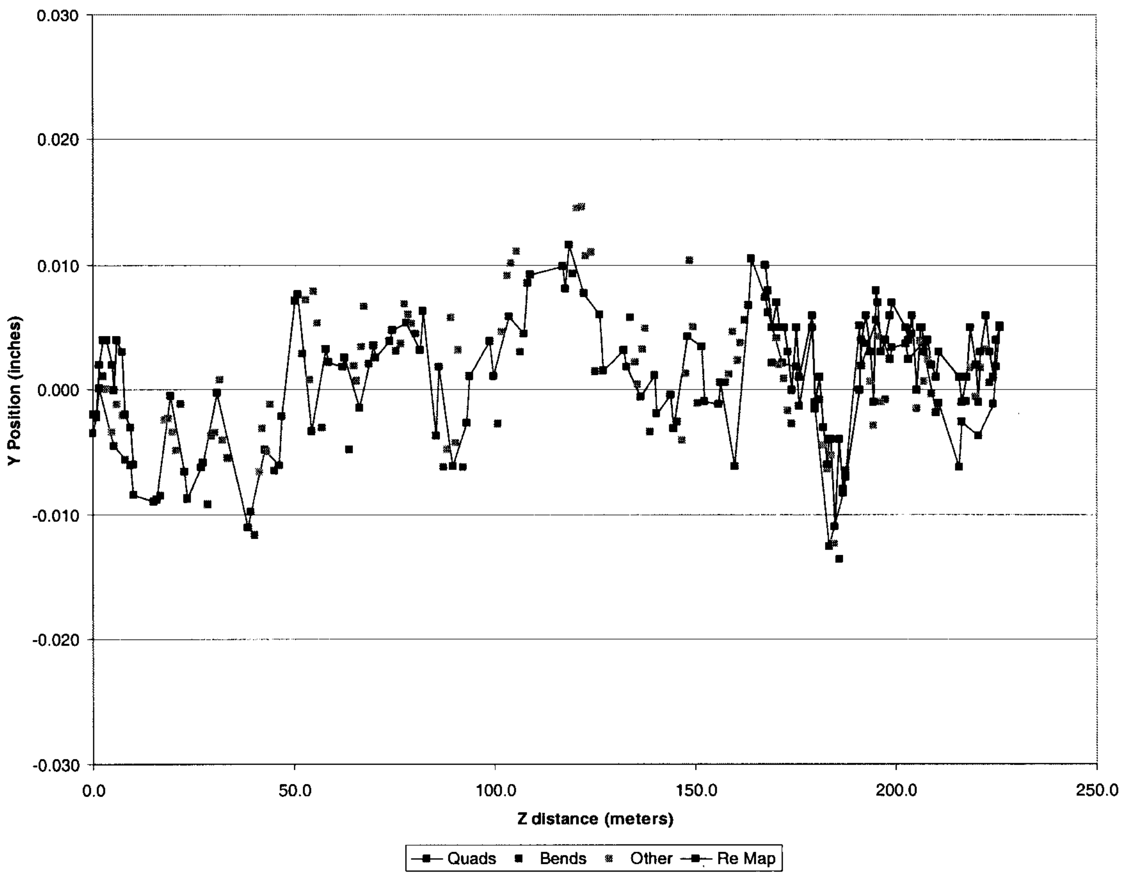


Fig. 10 Magnet Y Positions

5. CONCLUSION

The 2003 survey campaigns produced a very "smoothed" ring allowing a successful start-up. The 2004 campaigns confirmed the quality of the concrete floor and identified a weak spot in the network geometry. The subsequent magnet and vacuum chamber moves should put the ring closer to its ideal position allowing an even better steering. This statement will have to wait to be validated: the next beam to beamlines is scheduled for Monday, October 18, at 6:00AM.

6. ACKNOWLEDGMENTS

This project benefited from a very close and tight cooperation between the Alignment Engineering Group and the installation team lead by Richard Boyce from SSRL. Each member of the alignment team was instrumental in the success of this challenging project allowing on-time completion through many on the spot original contributions.

7. REFERENCES

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