A New Accelerator Alignment Concept Using Laser Trackers*

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Abstract

This paper outlines the basic principle of the laser tracker and the new and simplified alignment concept for the APS based on the use of these laser trackers. The presented alignment concept will be especially valuable when considering the alignment of small scale accelerators.

1. INTRODUCTION

Currently the Advanced Photon Source (APS) is under construction at the Argonne National Laboratory. The APS is a 7-GeV synchrotron light source which will be used for basic research in material science, chemistry, physics, biology and medicine.

The required alignment tolerances for the APS are at the limit of today's possible alignment techniques. New alignment methods such as the use of recently developed laser trackers are employed. These instruments not only provide the necessary accuracy for the positioning of beam components but are also reducing the time and manpower requirements for the alignment of the beam elements.

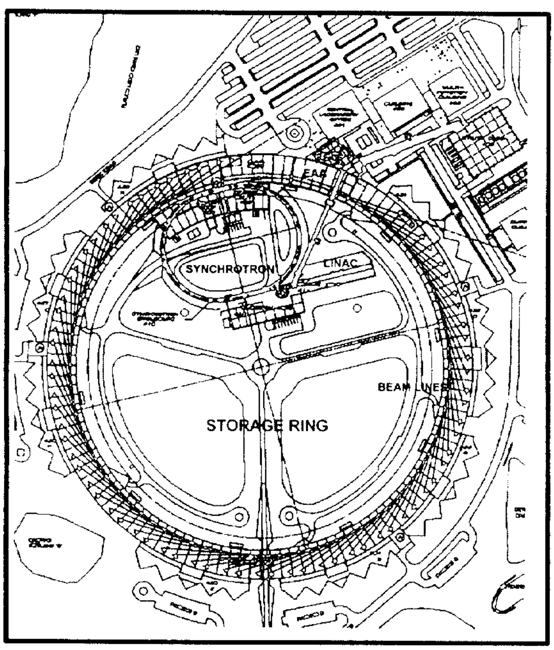

Fig 1 APS site overview

The APS consists of a 70m-long linear accelerator, a positron accumulator ring (PAR), a synchrotron ring (SY) with a circumference of 368m, and the storage ring (SR) with a circumference of 1104m (Fig. 1). The 40m electron linac uses 200-MeV electrons for the production of positrons. In the 30m-long linear accelerator section following the electron linac the particles gain a mass of 450 MeV before entering the positron accumulator ring. From there the beam is injected into the booster synchrotron which accelerates the positrons from 450 MeV to 7 GeV before entering the storage ring. The storage ring can accommodate up to 68 experimental beamlines.

2. RELATIVE ALIGNMENT TOLERANCES

The relative alignment between beam elements depends on the type of component and its location in the accelerator system. The following tables summarize the alignment tolerances for dipoles (Table 1) and quadrupoles and sextupoles (Table 2) for each accelerator subsystem. The maximum tolerable displacements horizontal, vertical, and in beam direction are shown as well as the tolerance for the roll angle of each component [1].

Table 1
Maximum tolerable displacement for dipoles relative to adjacent beam components

	Horizontal/ Vertical	In Beam Direction	Roll Angle
PAR	±0.5mm	±1mm	±0.5mrad
SY	±0.5mm	±1mm	±1mrad
SR	±0.2mm	±0.5mm	±0.5mrad

Table 2
Maximum tolerable displacements for quadrupoles and sextupoles relative to adjacent beam components

	Horizontal/ Vertical	In Beam Direction	Roll Angle
Linac	±0.5mm	±1mm	±5mrad
PAR	±0.5mm	±1mm	±5mrad
SY	±0.3mm	±1mm	±0.5mrad
SR	±0.15mm	±1mm	±0.5mrad

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3. The Alignment Concept

3.1 Primary control network

The primary control network consists of two solid concrete monuments located in the infield of the storage ring and ten connecting points to the secondary control network. The purpose of the primary control network is to ensure the correct position of all accelerator subsystems to each other. Therefore connections between the primary and secondary control network are provided for the linac, booster synchrotron, and the storage ring.

The primary control network has been measured with the ME5000 distance measurement system. The results show an accuracy of ±0.3mm for all control points of the primary control network [2].

3.2 Secondary control network

The secondary control network consists of approximately 600 survey points for the whole APS project. Each control point is measured in elevation and position. The design of these control points is based on the 3.5" Taylor Hobson sphere resting in a conical receptor grouted into the floor.

The secondary control network is used for the global positioning of the beam elements.

For the measurements of the secondary control network, theodolites and the ME5000 distance measurement system were used. The results show an accuracy of ±0.3mm for all secondary control points.

3.3 Girder assembly

For the placement of beam elements with respect to the ideal beamline given by the lattice, each component has been provided with fiducial marks referenced to the mechanical centerline of the beam element. In the early assembly area the beam elements are assembled on girders which are then positioned in the storage ring tunnel. The storage ring contains forty identical sectors with each sector holding five girders.

3.4 Positioning girders in the tunnel

For the positioning of girders relative to the control network in the storage ring tunnel a laser tracker is being used. The laser tracker's advantage over the usual alignment procedure is in its ability to survey the actual position and align the girder instantaneously in one step. The position of the laser tracker with respect to the control network can easily be determined by a three-dimensional resection using several control points.

3.5 Girder smoothing

Assuming that the internal alignment of the beam components is undisturbed after the girder has been transported into the storage ring and positioned, only girders have to be part of the beamline smoothing process. In this step the control network is abandoned. Using the Ecartometer for offset measurements, the relative alignment between girders will be determined using principal curve analysis [3].

4. The Laser Tracker Principal

The laser tracker is a dynamic three-dimensional measurement system with an accuracy of 0.7μm for distance and 5μrad for angular measurements. This results in a position accuracy of ± 50μm in a range of up to 10m from the laser tracker head.

The tracker head contains a Heterodyn-Interferometer, a mirror which can be tilted around the two major axes, and a two-dimensional position detector (Fig. 2). The motion of the motor-driven mirror is recorded by angular decoders. To measure points in space, the laser has to track a movable retro-reflector. The interferometer measurements are done relative to the starting point which is usually the "Bird Bath" attached to the laser tracker head [4].

The same laser beam used for the interferometer is also used to track the position of the retro-reflector. A beamsplitter deflects parts of the laser beam to a two-dimensional position detector which records the motion of the reflector. A feedback loop monitoring the deviations from the zero point on the position sensor is used to update the motor positions such that the center of the reflected beam is always in close proximity to the zero position of the sensor. This implies that during dynamic measurements exact angular measurements are not possible.

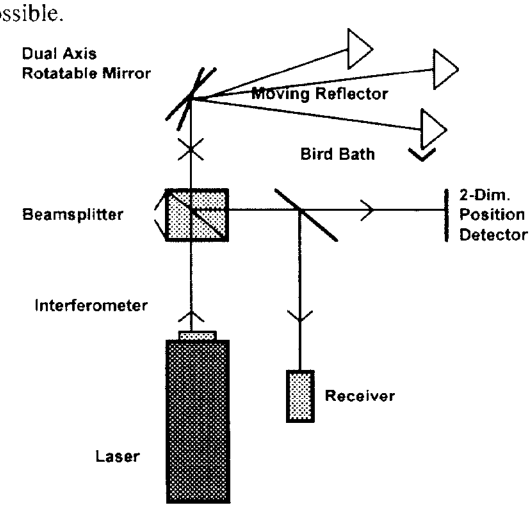

Fig. 2 Optical path of the SMART 310 Laser Tracking System

In order to achieve the required tolerances for the positioning of the APS beam components the laser tracker system is used in a static mode. This means that the retro-reflector is fixed during the measurement process thus providing the 5-10ppm accuracy. In order to maintain these tolerances, a temperature stabilized laser beam providing a gaussian intensity distribution for the measurement of the centroid of the beam location at the position sensor is required.

5. Alignment Results

All beam components of the booster synchrotron were aligned both in position and elevation relative to the control network using the laser tracker system. For the beamline smoothing, a traverse on top of the beam elements was established.

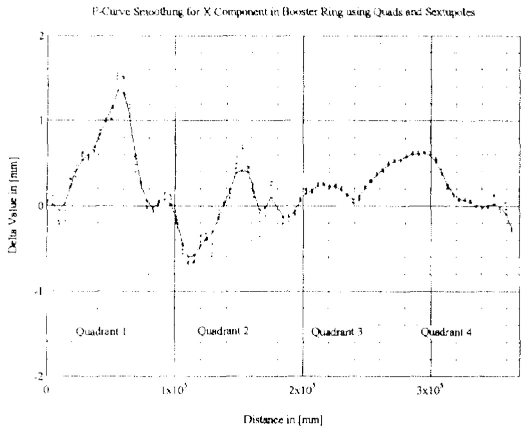

Fig. 4 Lateral displacements

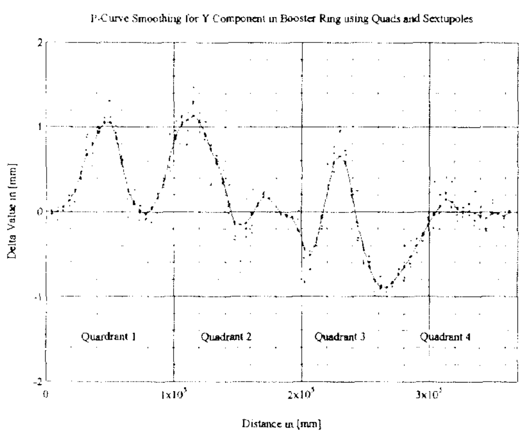

Fig. 5 Vertical displacements

The results of the smoothing process can be seen in Figures 4 and 5 for the lateral and vertical deviations from the ideal position. One can see that the smooth curve deviates from the ideal position by ±1.5mm, well within the confines of the envelop for the absolute positioning of beam components. It is also obvious from the graph showing the lateral deviations that the residuals from the smooth curve fit are much smaller for quadrants 3 and 4 then for quadrants 1 and 2. This can be attributed to a change in the measurement procedure.

During alignment of the first two quadrants only the points of the secondary control network in the booster synchrotron were used to reference the laser tracker in the global coordinate system. For the last two quadrants, additional fiducial marks from previously aligned beam components were used. This provided more information for the determination of the laser tracker positions and tied previous tracker setups together. Therefore the residuals to the smooth curve for the last two quadrants are virtually non-existent. This improved alignment procedure is now being applied for the positioning of girders in the storage ring.

Finally Figures 6 and 7 show the histograms for the deviations of the quadrupoles and sextupoles from the smooth beamline. All components have been placed within the 2σ range and out of 160 quadrupoles and sextupoles, only 10 have been placed in the vertical direction between the 1σ - 2σ range.

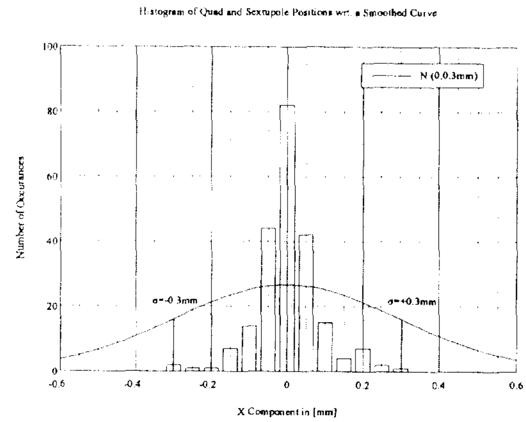

Fig.6 Histogram of the lateral displacements of quadrupoles and sextupoles of the booster synchrotron

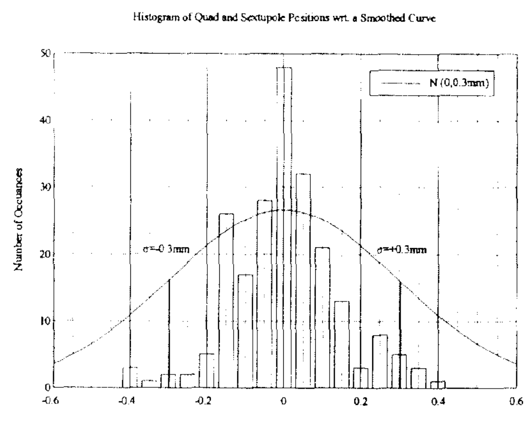

Fig. 7 Histogram of the vertical displacements of quadrupoles and sextupoles of the booster synchrotron

6. References

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