A New Method to Position the APS Dipoles with the Use of a Laser Tracker*

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Abstract

The alignment requirements for the synchrotron light sources have increased to the limit of today's alignment techniques. Some components such as dipoles can only be positioned after having obtained a three-dimensional outline of the as-built magnet.

The laser tracking system provides the unique opportunity to map the dipole gap and relate the information to the outside reference marks for the placement of the magnet. In this case the Leica SMART 310 laser tracker is used as a 3D coordinate measuring system that provides the necessary information of twist, roll, sag, and gap changes over the full dipole length. On the basis of this information the best fitting plane is calculated to obtain the average roll angle for the positioning of the dipole. This paper describes the basic principal of this alignment technique and demonstrates the achieved results with examples.

1. INTRODUCTION

The construction of Argonne National Laboratory's Advanced Photon Source (APS) commenced in 1990. The APS is a 7-GeV synchrotron light source facility dedicated to the production of extremely brilliant X-ray beams for research in material science, condensed-matter physics, chemistry, biology, medical research, geoscience, and soil/environmental science. The APS is scheduled to begin operations for research experiments in 1996.

2. GIRDER ASSEMBLY AND MAGNET FIDUCIALIZATION

For the magnetic lattice of the 7-GeV APS storage ring (SR) a Chasman-Green model was used. It contains two dipole magnets and 10 quadrupoles per achromatic cell to guide the positron beam. The 1104-meter-circumference storage ring consists of 40 such cells with a total of 80 dipoles. Storage ring dipoles are C-shaped steel laminated magnets, each having a mass of 6197 kg.

The SR dipole magnet and two sextupole magnets are mounted on a common rigid girder. The dipole is fastened to the girder via a four-point support system with no provision for fine adjustment. The sextupoles and vacuum chambers, however, are provided with an alignment system. The whole girder assembly is resting on two steel pedestals grouted to the floor. The girder is connected to the pedestals through three adjustable supports resulting in six degrees of freedom for final girder alignment in the storage ring tunnel.

The proper placement of quadrupoles and sextupoles is accomplished with the help of two reference cups welded on top of the laminations. These fiducial cups have a conical shape and are designed to accept regular 3.5" Taylor Hobson spheres with an inserted retroreflector or a cross hair target. The center of the Taylor Hobson ball defines the fiducial in three-dimensional space. The exact location of the fiducials with reference to the magnetic axis is determined during the magnetic mapping process. The roll of the sextupoles and quadrupoles is recorded by a level bridge that registers in the grooves of the magnet laminations [1].

The fiducialization of the SR dipoles is somewhat different. It is established during the prealignment of the dipole on the girder, independently and before magnetic measurement. Two fiducial cups, similar in design to those used on sextupoles, are mounted directly on top of the dipole laminations. These cups (A, B) are located precisely above the longitudinal mechanical axis of the poles at a fixed distance from the ends. The third fiducial (C) is positioned approximately in the center of the dipole creating a triangle (Fig. 1). In addition to the three reference points there are ten locations along the entire length of the dipole, where a level bridge can be placed directly on the lamination to monitor changes in the twist of the magnet.

3. DIPOLE ALIGNMENT PROCEDURE

3.1. Prealignment of dipoles on girders

The first step in the early assembly area is to level the

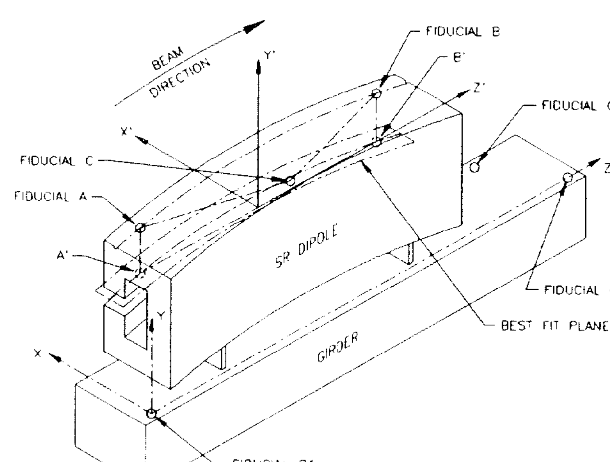

Figure 1. Location of girder and dipole fiducials

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girder. The top of the SR girder has three well-defined fiducials establishing the girder plane with respect to gravity. Optimum efficiency is achieved by maintaining this plane as a horizontal reference surface throughout the alignment process.

In the second step, the dipole is roughly positioned on the leveled girder using traditional optical tooling techniques or the laser tracker. This step is necessary to guarantee that the rest of the components can be later aligned with respect to the dipole. The adjustment range of the sextupoles and vacuum chamber is the limiting factor. Far greater attention must be paid to set the proper roll of the dipole.

3.2. Setting the roll of dipoles on girders

To obtain the required dipole roll tolerance of ±0.5 mrad and to determine the twist and sag, each dipole gap is being mapped using a SMART 310 laser tracker from Leica. This information has to be related to the outside fiducials before the vacuum chamber is inserted while the pole gap is still accessible. The Smart 310 laser tracker is a mobile 3D coordinate measuring system capable of following a moving target while simultaneously determining its position with a high degree of accuracy [2].

After positioning the dipole on the girder, the laser tracker is used to measure three girder fiducials, fiducials on top of the dipole, as well as the top and bottom poles in twenty locations. Using a special fixture (Fig. 2), two lines along the bottom pole ('bout', 'bin') and two symmetrical lines along the upper pole ('tout', 'tin') are scanned. Eighty equally spaced points give an adequate representation of the shape of the magnets. After transforming the measured tracker coordinates into the girder coordinate system XYZ, the least squares solution of the best fit plane through these eighty points is calculated (Fig. 3). The parameters defining the best fitting plane are therefore given in the gravity-referenced

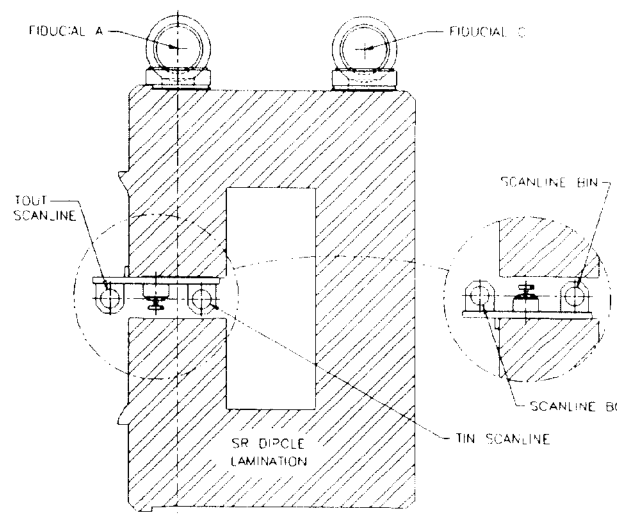

Figure 2. Cross section of dipole with scanning fixture

girder system XYZ (Fig. 1) yielding the roll and pitch angle by which the dipole has to be adjusted. After the best fit plane has been set parallel to the girder plane within the given tolerance, the coordinates of the three reference cups on top of the dipoles are calculated in the system X'Y'Z' of the best fit plane (Fig. 1). The best fit plane defines the Z'X'-plane of the coordinate system. The line connecting the projected reference points A' and B' in the Z'X'-plane establishes a line parallel to the chord of the effective field and defines the +Z direction of the coordinate system. The origin of the coordinate system X'Y'Z' is defined by the midpoint between the projected A' and B' points.

If necessary, the roll of the dipole can be adjusted by the roll angle obtained from the least squares solution of the plane. The magnet is positioned by raising the magnet at designated locations with hydraulic jacks and inserting shims. Additionally, electronic tilt meters resting on precision bridge fixtures spanning the top of the magnet are used to monitor the roll. Two iterations are usually needed to meet the roll tolerance. As a final step, ten roll values on top of the magnet are measured using the level bridge and an electronic level Talyvel. The two roll values recorded directly above the magnet supports are later used for an independent check of the leveling effort of the entire girder and magnet assembly.

3.3. Final dipole-sextupoles-chamber alignment in the assembly area

After the magnetic mapping of the SR dipole, the assembly is returned to the alignment area. The

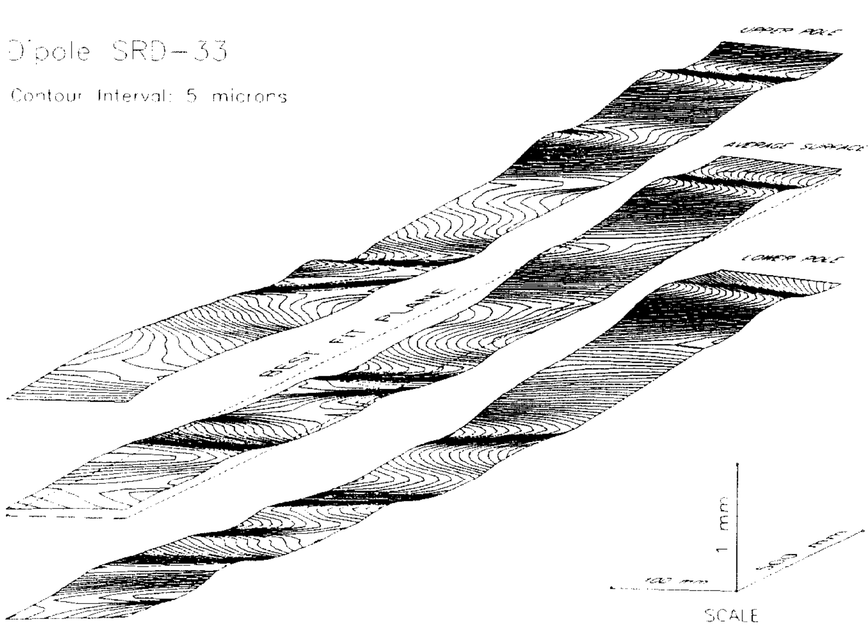

Figure 3. Example of measured poles and fitted plane

girder is leveled and the roll of the dipole is verified using the Talyvel. In the next step the two sextupoles and curved vacuum chamber are positioned relative to the dipole. Optical tooling is used to complete this part.

3.4. Final positioning of dipoles in storage ring

The laser tracking system is used again in positioning the girder as a unit in the storage ring tunnel. The laser tracker is oriented with respect to the global control network [3]. Operating in continuous tracking mode, it is used to place the girder at its ideal position.

4. RESULTS

Several tests were performed to validate this method and to obtain some indication of repeatability and accuracy of setting the roll of the dipoles.

4.1. Repeatability test

A number of dipoles were measured a second time from an independent setup or after returning from the magnet mapping area. This test was performed to verify the repeatability of the process. The roll values of the dipoles best fit plane relative to the girder in all cases repeated within 0.1 mrad.

4.2. Laser tracker versus optical tooling test

To verify these results independent of the laser tracker system, the same measurements were done with the Wild N3 precision level. The best fit plane was calculated from the laser tracker and the level data. The roll and pitch values repeated within 0.15 mrad. The example in Fig. 4 compares three laser tracker scans with the same profile measured with an optical level.

4.3. Laser tracker versus Talyvel electronic level test

The fixture used for scanning the dipole gap has a relatively short base. The horizontal distance between the two scanlines is approximately 133 mm. The accuracy of a vertical coordinate of a point measured with a tracker is limited by the resolution of the tracker's angular encoders. This test addressed the concern of how close the roll value calculated from a pair of laser tracker points only 133 mm apart agrees with an angular value directly measured with a

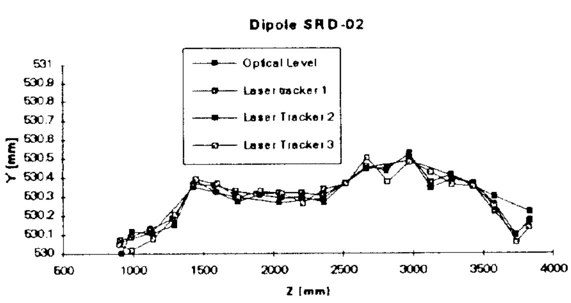

Figure 4. Comparison of laser tracker and optical level measurements of scanline 'bout'

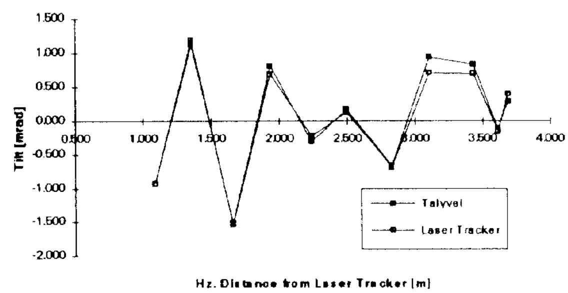

Figure 5. Talyvel versus laser tracker test

calibrated electronic level. The resolution of the Talyvel is 0.2 arc second. The test was performed along a 4-m-long table. A precision ground bar was moved along the table and its roll measured at 11 locations with both instruments. The averages of the Talyvel readings in two faces were compared with the angular values obtained from tracker points measured with the dipole scanning fixture (Fig. 5). The mean difference was 0.03 mrad with a standard deviation of 0.1 mrad.

The roll value of a plane fitted through 80 points is actually better known. The standard deviation of the least square estimate of the roll angle is in the range of 0.02 to 0.05 mrad for all dipole magnets measured.

4.4. Twist of the dipoles

The manufacturing process introduces a twist along the longitudinal axis of the dipole. Once the magnet is aligned and locked in position, the twist can be determined. The local twist of the majority of dipoles is in the range of ±1 mrad. The average twist calculated from the upper and lower pairs of scanline points generally agreed with the fitted plane within ±0.2 mrad.

5. CONCLUSION

To date, 58 dipoles are aligned on girders, and 40 completed dipole girder assemblies are positioned in the SR tunnel. The dipole girder alignment is accomplished by a two-man crew in approximately one day utilizing the laser tracker. By contrast, this same task, relying on traditional optical tooling techniques, requires a three-man crew and nearly double the time. The Leica SMART 310 laser tracking system has proven to be an effective and accurate alignment tool and contributed to a significant reduction in time and labor.

6. REFERENCES

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