Quality Control Survey Measurements at the MINOS Far Detector

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Introduction

The components of the MINOS far detector are surveyed with the Vulcan Spatial Measurement system during the detector assembly. This system measures x, y, z coordinates by means of a pair of receptors in a hand-held wand, which sense diffused laser light from a pair of transmitters located in the hall. Figure 1 shows a conceptual setup of the Vulcan. The system's software determines the position of a probe attached to the wand by analyzing the signals received by the sensors and downloads the coordinates to a hand-held computer. Different probes may be attached to the wand to accommodate different measurements. The nominal precision of the system is 1 – 2 mm, depending on the distance and orientation of the sensors to the transmitters. One reason for making these measurements is to determine the relative positions of the scintillator modules with respect to each other and the structure of the detector. A second reason is to monitor the positioning of the detector components as they are installed. The detector positioning is referenced to a set of measurements made by a survey team from Fermilab to establish a local reference frame for the detector construction. Eventually, this system will be tied into the NuMI beam frame of reference using GPS and other measurements taken near the Soudan mineshaft.

Surveyors from the Fermilab Alignment and Metrology Group returned to the Soudan Underground Laboratory in December 2001 to make a set of quality control measurements. The purpose of these measurements is three-fold: a) to check the reference points established for the local coordinate system; b) to check selected structural components of the detector while they are actually supporting the weight of the detector planes; and c) to compare Vulcan measurements of selected points with measurements made with a much more precise laser tracker. The nominal precision of the laser tracker is 0.05 mm.

Checks of the Local Coordinate System

The original measurements made to establish a local coordinate system in the MINOS far detector hall are described in another note.[1] A subset of these points was re-measured on December 4, 2001. The results are shown in Table 1. The x and z coordinates do not show any significant changes, but the y (vertical) coordinates show a fairly consistent increase in the floor's elevation ranging from 1 to 3 mm. The points shown in Table 1 are those used for the Vulcan calibrations. They are Dijak bolts embedded in the floor of the supermodule areas and construction blocks mounted on the columns. Dijak bolts mounted in the walkways or plane construction areas were not resurveyed. Two construction blocks, CP_E2 and CP_W2, were inaccessible and not resurveyed. The locations of the MINOS hall monuments are shown in Figure 2. The changes in floor height between July and December are shown in Figure 4 and Figure 5.

NAME	X (in)	Y (in)	Z (in)	Comments	X (m)	Y (m)	Z (m)
EI_01	-129.347	-186.363	12.811	Floor point E side between columns	-3.285	-4.734	0.325
EI_035	-129.418	-186.504	213.142	Floor point E side between columns	-3.287	-4.737	5.414
EI_065	-128.510	-186.288	413.578	Floor point E side between columns	-3.264	-4.732	10.505
EI_10	-128.844	-185.910	623.606	Floor point E side between columns	-3.273	-4.722	15.840
EI_125	-128.770	-186.084	823.658	Floor point E side between columns	-3.271	-4.727	20.921
EI_155	-128.815	-185.843	1023.724	Floor point E side between columns	-3.272	-4.720	26.003
EI_18	-129.410	-186.544	1213.528	Floor point E side between columns	-3.287	-4.738	30.824
WI_01	129.429	-186.347	11.543	Floor point W side between columns	3.287	-4.733	0.293
WI_035	129.240	-186.178	212.479	Floor point W side between columns	3.283	-4.729	5.397
WI_065	128.944	-186.214	412.171	Floor point W side between columns	3.275	-4.730	10.469
WI_10	129.294	-186.145	622.468	Floor point W side between columns	3.284	-4.728	15.811
WI_125	128.820	-186.305	822.699	Floor point W side between columns	3.272	-4.732	20.897
WI_155	129.321	-186.301	1023.038	Floor point W side between columns	3.285	-4.732	25.985
WI_18	129.217	-186.665	1214.169	Floor point W side between columns	3.282	-4.741	30.840
CP_E11	-167.423	-19.182	708.423	Point on E column	-4.253	-0.487	17.994
CP_E14	-167.800	-20.114	924.723	Point on E column	-4.262	-0.511	23.488
CP_E17	-167.919	-20.177	1140.481	Point on E column	-4.265	-0.512	28.968
CP_E2				Point on E column			
CP_E5	-167.606	-20.226	298.236	Point on E column	-4.257	-0.514	7.575
CP_E8	-167.739	-19.728	514.258	Point on E column	-4.261	-0.501	13.062
CP_W11	167.921	-19.668	709.232	Point on W column	4.265	-0.500	18.014
CP_W14	167.714	-19.889	925.305	Point on W column	4.260	-0.505	23.503
CP_W17	167.750	-19.719	1140.811	Point on W column	4.261	-0.501	28.977
CP_W2				Point on W column			
CP_W5	167.882	-20.512	299.588	Point on W column	4.264	-0.521	7.610
CP_W8	167.764	-20.329	515.288	Point on W column	4.261	-0.516	13.088

Table 1 New coordinates of reference points in the MINOS far detector hall as measured in December 2001. Monuments were originally placed and measured in July 2001, as described in reference 1.

Checks of Detector Structural Elements

Figure 3 shows one side of the MINOS detector support structure. The survey crew took measurements of the rail height at positions directly above the support posts. These data were measured relative to a selected position, Station E18 (the northernmost column on the east side). They are compared here with measurements taken in July 2001. Figure 4 shows the change in rail height tracked against the change in floor height over the same period. North of Station E3, a change in rail height follows the rising of the floor fairly closely. However, the first three stations on the east side show a dip in the rail elevation. At the time the measurements were made (December 5, 2001) planes up to number 66 had been hung on the rails. For plane 66, z = 3.93 m, which is the approximate location of station 3. This is consistent with the weight of the planes causing sag of 5 mm or so in the rail. Data for the west rail, as far as they are available, are also consistent with this conclusion, as shown in Figure 5. Figure 6 shows the east and west rail height changes side by side.

A question arises as to whether the sag in the rails occurs all at once when the planes are hung or whether it increases over time. Eight steel studs are welded to the edges of every fifth plane for later quality control measurements. These studs are surveyed with the Vulcan soon after the plane is erected. If the sagging of the rails continues over an extended time, one would expect the elevation of the studs found in the December QC measurements to be generally lower than the Vulcan measurements. Figure 7 shows a comparison of the Vulcan and laser tracker measurements for one of the stud positions. The studs are located on the steel plane only to within a cm or so of a nominal position at the time they are welded onto the steel, hence the overall "waviness" of the lines in the figure. On plane 52, the studs on the "ears" of the plane (#1 on the west side and #7 on the east) were placed well away from the nominal position, which is the reason for the sharp dip in the curve. The nominal positions for these two studs are typically just above the support rails.

The laser tracker data required a correction, which is described in the following section. The data show no evidence of continued sagging after the Vulcan measurements were made.

Comparison of Laser Tracker and Vulcan Measurements

As mentioned in the previous section, approximately every fifth plane in the far detector is augmented with a set of eight steel studs welded to the edges of the steel at positions around the plane. Each stud is 0.5" × 0.5" × 3.0", with a 0.25"diameter hole on one end. The positions of these studs are measured with the Vulcan at the same time as the module alignment holes. During the early period of supermodule 1 construction, the stud measurements with the Vulcan were made using the same 0.75" tooling ball probe that is used for measuring the module positions. The Vulcan measurement yields the coordinates of a point at the center of the tooling ball, approximately 9 mm from the end of the stud. The laser tracker measurements, however, were made with a 1.5" diameter mirror, which was mounted on a nest that fitted into the 0.25" hole on the stud. This arrangement allows for a more stable measurement. The raw data from the laser tracker measurements were the coordinates at the center of the 1.5” sphere. The survey team adjusted their data to allow a comparison of the Vulcan and laser tracker data by extrapolating the coordinates to the point where the center of the 0.75” sphere would have been. However, the Vulcan tooling ball does not fit easily onto the edge of the steel stud and obtaining a stable measurement with it was sometimes difficult. The consequence is that the extrapolation introduces an additional uncertainty, which is difficult to estimate precisely but is probably small. Subsequent measurements of the studs use a 1.5” tooling ball on the Vulcan with a nest identical to that used by the survey team. However, there is at this time no laser tracker data to compare with those measurements.

A comparison of several of the stud positions used data averaged over eight planes from 31 – 65. The differences between the Vulcan measurements and the corrected laser tracker measurements are shown in Figure 8. In spite of the additional uncertainty introduced by the data adjustment, the Vulcan still performs reasonably well. The first three columns of data are the average differences in the x, y, and z coordinates. Because of the placement and orientation of the Vulcan transmitters, the z coordinate is the one expected to have the greatest uncertainty. The 3-dimensional spatial uncertainty, labeled “magnitude” in Figure 8, is the sum in quadrature of the x, y, and z coordinate differences. The important number for measuring module positions is the linear uncertainty in the x-y plane. This is shown in the column “abs xy”, in which the bar heights are given by $\sqrt{x^2 + y^2}$. The average differences range from 2.4 to 4.1 mm.

<u>Conclusions</u>

The survey measurements made at Soudan in December 2001 by the Fermilab Alignment and Metrology Group accomplished three goals. The local coordinate system described in Reference 1 was checked and some shifting of the cavern floor was observed. A new set of local coordinates for the survey monuments, which are used for calibration of the Vulcan, was derived from these measurements. Measurements of the detector structure itself were made and indicate some sagging of the detector support rails under the weight of the detector planes. The maximum sag is approximately 5 mm. The sagging does not appear to increase over time once all of the planes have been mounted in a given region. Finally, a comparison between the laser tracker and the Vulcan has been made. The precision of the Vulcan is found to be in the range required for the construction of the MINOS detector. Other assessments of the Vulcan’s performance have been documented elsewhere.[2,3] All assessments of the Vulcan to date indicate a good overall performance and that it is an appropriate system for measurements on the MINOS detectors during their construction.

Future visits by Fermilab surveyors for the construction of supermodule 2 are under consideration. As the Vulcan has been demonstrated to be an adequate tool for the detector construction, the primary purpose of another surveyor visit would be to re-check the survey monument positions for evidence of continued shifting of the cavern. Experience with the Soudan 2 hall showed that shifting essentially ceased after two years or so. The survey monuments are used to calibrate the Vulcan; so significant shifting might affect the instrument’s accuracy. However, a recent measurement of the survey monuments with the Vulcan was fitted to the December 2001 set and no significant shifting that might affect the Vulcan calibration was found.[4] Therefore it does not seem necessary to conduct another Fermilab survey during supermodule 2 construction, although it would be advisable to have the survey team visit once again at the completion of the detector so that a final set of measurements can be made and tied in with the surface monuments and hence locate the detector in the frame of the NuMI beam.

Acknowledgements

Gary Crutcher and Chuck Wilson, of the Fermilab Alignment and Metrology Group, made the laser tracker measurements, which were analyzed by geodesist Virgil Bocean. Soudan mine crew Brian LaFreniere, Irene Kolakowski, Mike Muhvich, and Mike Raj made the Vulcan measurements, with direction from Andrew Godley (University of South Carolina). Edmund Pendleton, of ArcSecond, Inc., advised us on the setup and use of the Vulcan Spatial Measurement System.

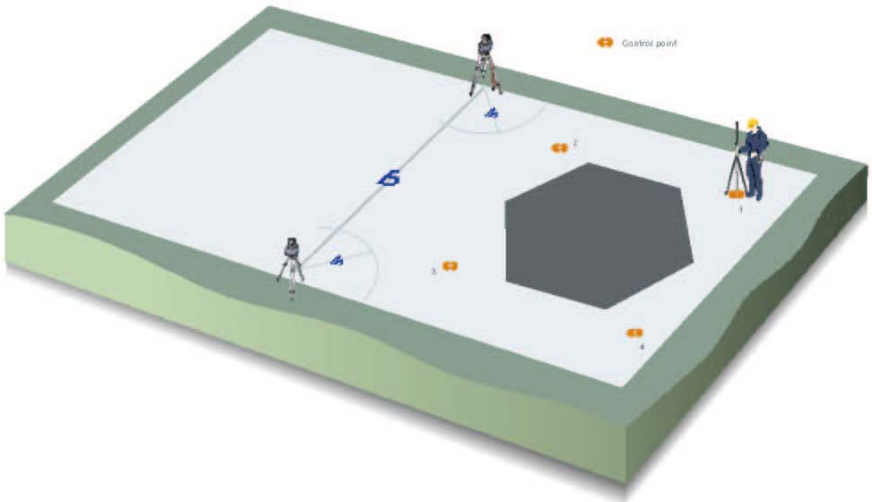
References

[1] D. Boehnlein, *The Placement of Survey Monuments in the MINOS Far Detector Hall*, NuMI Note 784, November, 2001.
[2] L. Mualem, *First Use of Module Survey Data from the MINOS Far Detector*, NuMI Note 828, April 3, 2002.
[3] B. Becker and A. Godley, *Surveying the Construction of Super Module 1*, NuMI Note 866, September 2002.
[4] E. Pendleton, private communication

Vulcan Setup Best Practices

Resection Setup

B	Threshold	M
10 m	600-1000	4 m
16 m	1000-1300	7 m
25 m	1200-1400	7-10 m



Notes:

1. Points 1-4 should surround the object being measured.

2. The x,y,z coordinates of each point should be known to the highest practical accuracy since Vulcan will use these points as references.

3. The BEST location of the points is on a horizontal surface easily accessible by the Vulcan tool.

4. Line of sight is needed from each point to each transmitter, but the tip of the tool will allow access to points that may be 2-3 feet from clear line of sight -- i.e., the sensors are on the top of the measurement tool, not at the tip.

5. The points should be on a stable surface that doesn't move -- or moves very little. Periodic checks may be necessary to check movement.

6. Other techniques for setup are available, so the control points are not required to use the system. However, these points will help provide a check for the system and will enable the different data sets to be tied together more easily.

Figure 1. A conceptual view of the Vulcan Spatial Measurement System. Two laser transmitters are shown on tripods, while a surveyor uses the Vulcan wand, shown here attached to a bipod for additional stability. A small computer, battery pack, and other accessories are attached to a belt worn by the surveyor. In practice at Soudan, the transmitters are mounted on the support columns of the detector structure. Since most measurements at Soudan are made on a vertical surface, often from a man-lift, the bipod is impractical and unnecessary except for calibrations of the tool. Illustration courtesy of ArcSecond, Inc.

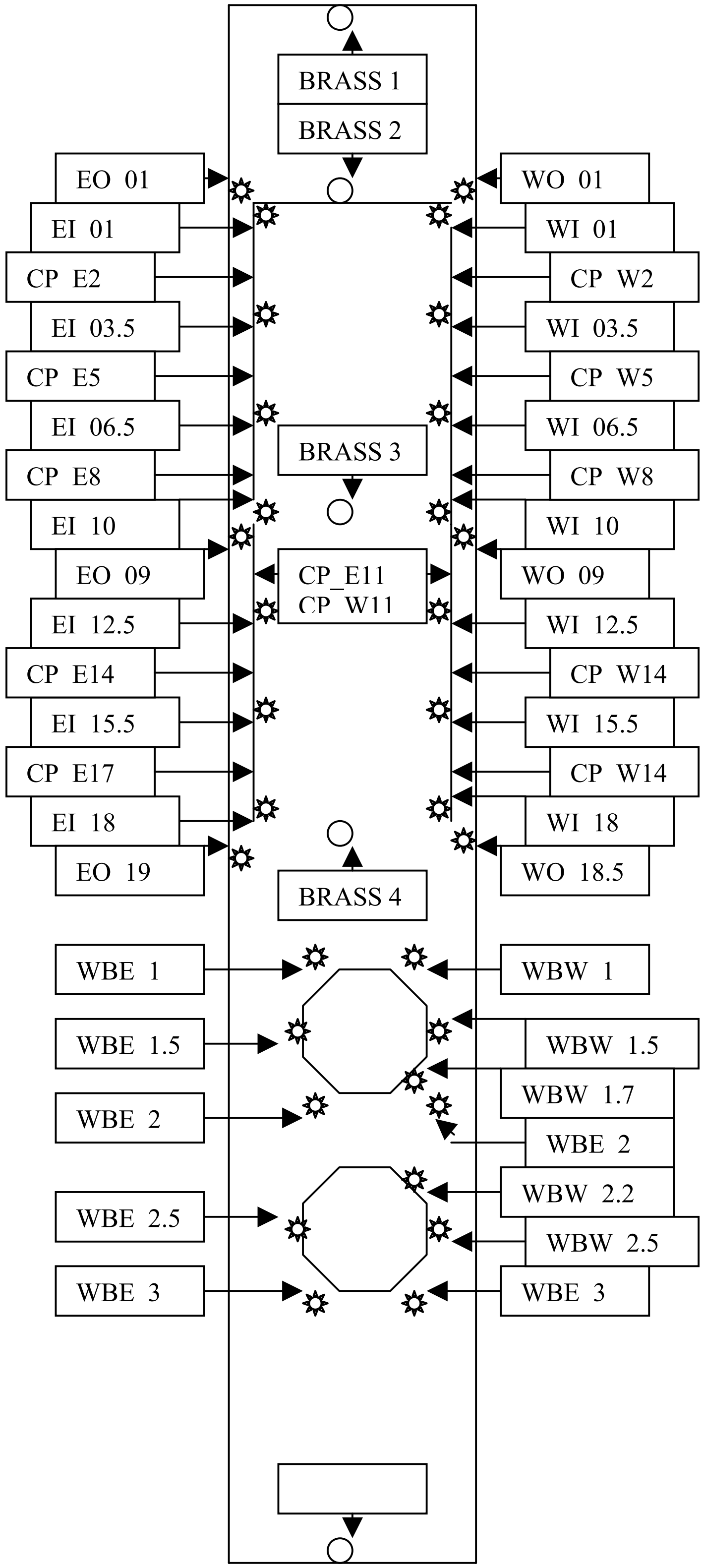


Figure 2 Approximate layout of the survey monuments in the MINOS cavern at Soudan. South is toward the top of the page.

Figure 3. The MINOS Far Detector support structure. This photo shows the west side before any planes were erected. The white tape crosses on selected columns indicate where construction block survey monuments are to be welded on. Survey stations on the horizontal support rail are located above each column. Photo by Jerry Meier.

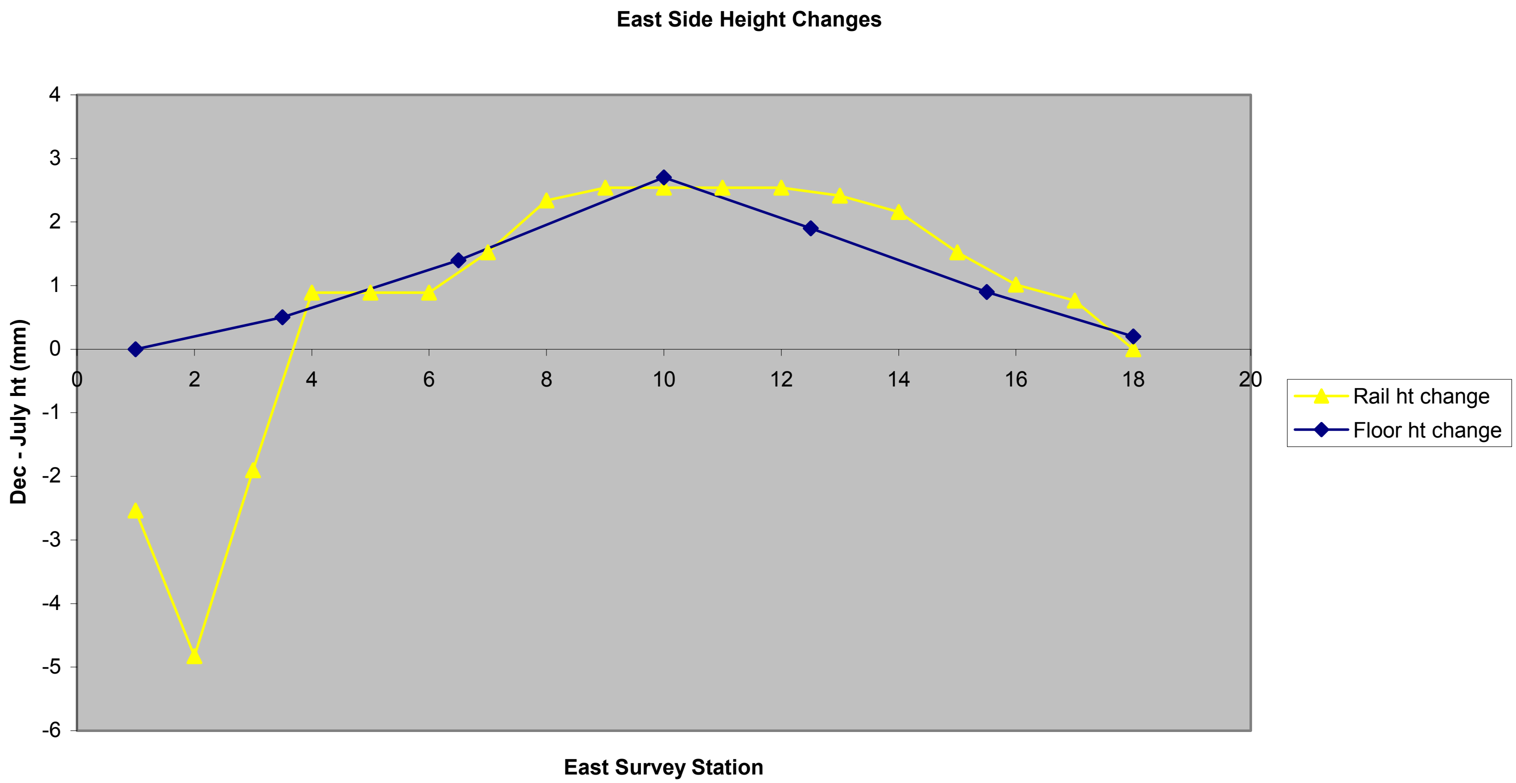


Figure 4. Elevation changes in reference points on the east side of the MINOS hall floor and on the east detector plane support rail. At the time of the measurements, supermodule 1 planes extended to survey station 3 (plane 66). Note that while the floor is rising underneath it, the rail elevation at survey stations 1-3 has sunk, indicating sag under the weight of the hanging planes.

Figure 5. Elevation changes in reference points on the west side of the MINOS hall floor and on the west detector plane support rail. At the time of the measurements, supermodule 1 planes extended to survey station 3 (plane 66). Although data are not available for stations 1 and 2 on the west side rail, the data are consistent with the sag found in the east side measurements.

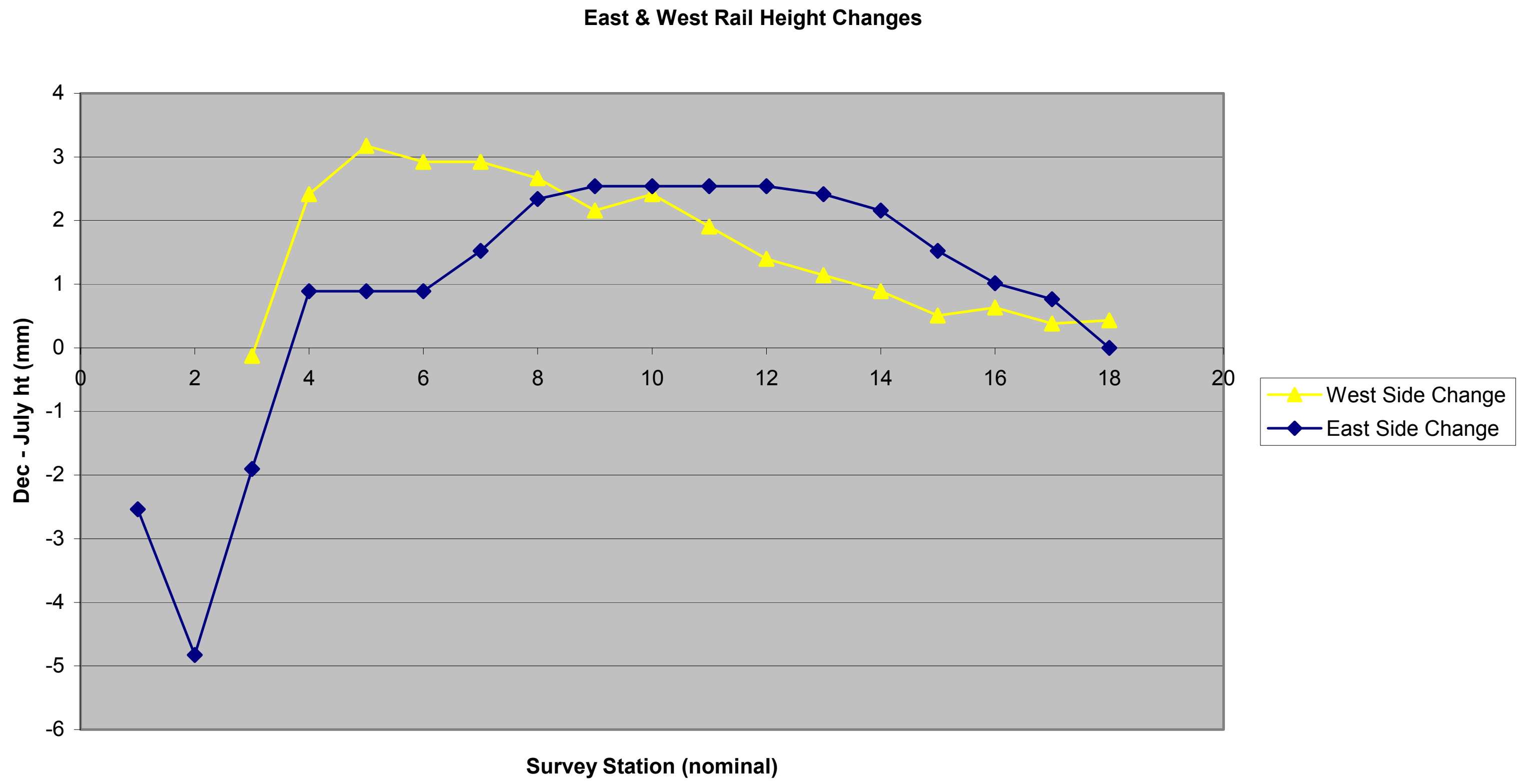


Figure 6 Comparison of east and west side rail height changes from July 2001 to December 2001.

Figure 7 Stud 7 is welded onto the east side "ear" of the steel plane and is roughly just above the east side rail. The laser tracker data are corrected for the difference in the sizes of the Vulcan tooling ball and the laser tracker mirror.

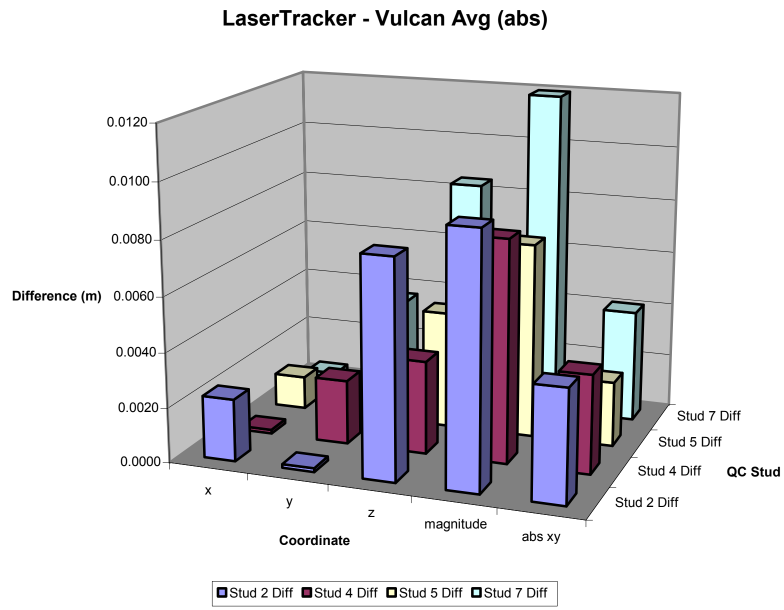


Figure 8. Average differences between the laser tracker and Vulcan measurements for four stud positions. The z coordinate is that in which the Vulcan is expected to be least accurate. The magnitude is the sum in quadrature of the x, y, and z differences. The abs xy is that for x and y only. The abs xy columns are indicative of the expected resolution in measuring module positions. Note that the use of the 0.75-inch tooling ball for the Vulcan measurements might have contributed to the differences.