

INSTRUMENT TESTS WITH THE NEW LEICA AT401 *

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Abstract

In order to evaluate the performance of the Leica Absolute Tracker AT401 we devised a series of tests. The first was to compare the Laser Tracker distance measurements to our interferometer on a 30 m long horizontal bench. The second was a check of the horizontal angle measurement accuracy and the “level to gravity” feature. The third was to check the warm up behaviour and the instrument stability. All these tests were performed in our underground test facility at sector 10 of the SLAC linac. The air-conditioning was turned off for the duration of the measurements. The temperature in the test facility was stable to 0.1 deg C. As a test that is closer to a real world application we performed part of a simplified version of the ISO 10360-10 test in one of the experimental halls at SLAC. The instrument tested was running firmware version 1.0.373.0.

DISTANCE MEASUREMENT

For the distance measurement test we compared the Laser Tracker distance measurements to our interferometer on a 30 m long horizontal bench, see Fig. 1, [1]. Distance differences measured by the interferometer (Δd in Fig. 1) were compared to the distance differences measured by the laser tracker. Fig. 2 shows the differences for different measurement time settings of the laser tracker. This shows that in order to achieve the highest accuracy, measurement times of 2000 ms and above are required. At 500 ms and 1000 ms outliers up to 85 μ m were found in this test. A measurement time setting of 5000 ms did not improve the distance accuracy further, see Fig. 3. To check for periodicities in the measurements two 1 m distance sections were sampled with a 2.5 mm raster. No outliers could be found, see Fig. 4. The distance measurement is based on the Mekometer distance measurement system [2] with varying measurement frequencies, therefore no periodic bias was expected.

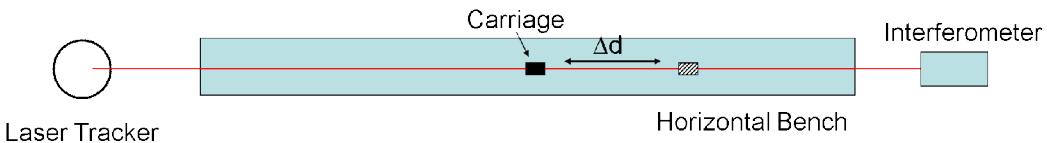


Figure 1: Distance test setup on the 30 m interferometer bench.

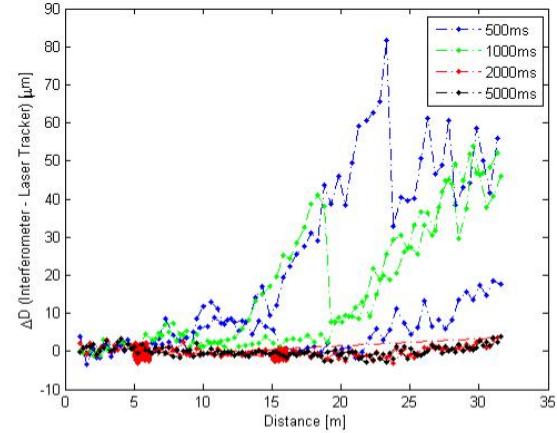


Figure 2: Distance test setup on the 30 m interferometer bench.

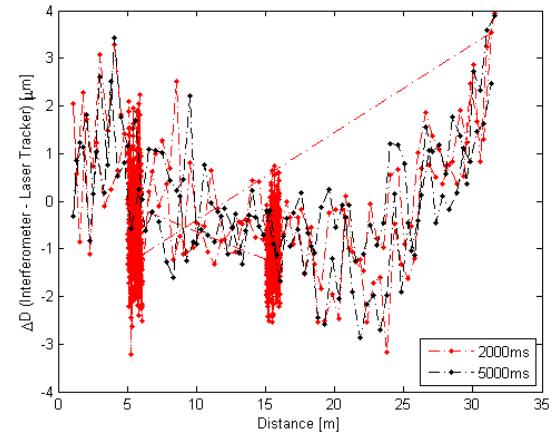


Figure 3: Distance measurement residuals of the Leica Laser Tracker compared to the interferometer bench, after applying the correct atmospheric corrections. 2 s and 5 s measurement duration (std. $\pm 1.3 \mu$ m).

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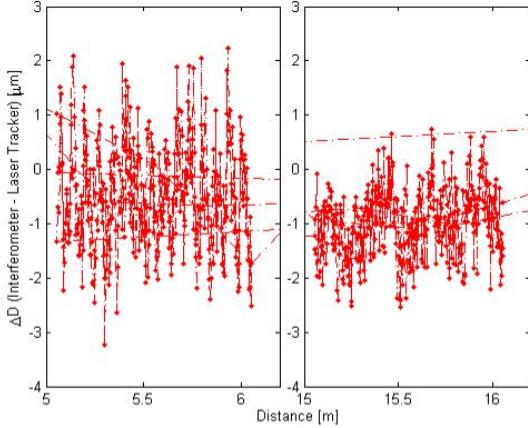


Figure 4: Distance measurement residuals of the Leica Laser Tracker compared to the interferometer bench. Parameters: 2 s measurement duration, one sample every 2.5 mm.

HORIZONTAL ANGLE TEST

In order to check the horizontal angle accuracy we set up 9 targets around the laser tracker, see Fig. 5. We measured them in a first set by manually pointing the tracker at the targets, grabbing the laser head and rotating it toward the target, and in a second set by automatically pointing the laser tracker at the targets. After the measurements the tracker was rotated by about 30 degrees and another two sets of measurements were taken with both manual targeting and automatic targeting. All measurements were taken in face one. This procedure was repeated 10 times. For the adjustment of the data the position and orientation of the laser tracker after each rotation is a new set of unknowns (including its vertical axis). The residuals of the horizontal angle shown in Fig. 6 are plotted against the horizontal encoder reading of the laser tracker. After each 30 degree rotation the laser tracker was newly levelled and initialized, Fig. 7 shows the orientation change for the vertical axis as a result of the network adjustment for each setup.

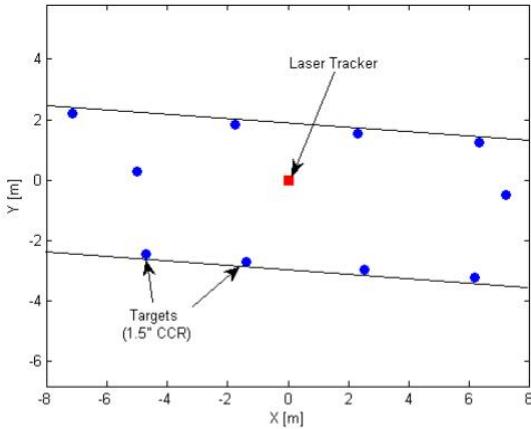


Figure 5: Horizontal test setup, the targets are at the same height as the laser tracker.

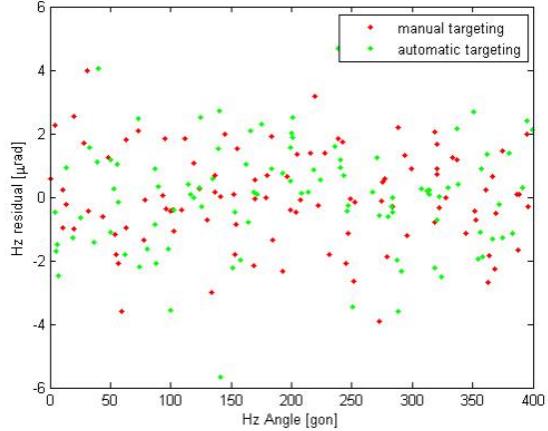


Figure 6: Horizontal angle residuals after network adjustment. Red dots are residuals of measurements taken after rotating the laser tracker manually and then initiating the measurements. Green dots are residuals in case the retroreflector was automatically targeted. The standard deviation of the Hz residuals is in this case $\pm 1.6 \mu\text{rad}$.

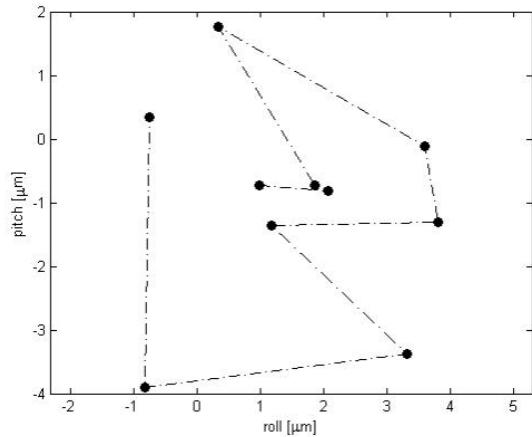


Figure 7: Vertical axis of the instrument change as a result of the network adjustment.

WARM-UP BEHAVIOR AND INSTRUMENT STABILITY

In order to determine the warm-up time of the instrument we set it up on a stand, let it acclimatize over night, turned it on and started two face set measurements. The targets were set up at different heights around the laser tracker (Fig. 8), the set measurements were repeated every 5 minutes. The data were analyzed by using the last measured coordinates as reference. The instrument translation in 3 dimensions (Fig. 9), the instrument rotation around 3-axes (Fig. 10), the scale factor of the distance measurements and the offset of the distance measurements (Fig. 11) were assumed unknown in the least square adjustment. The axes alignment changes were calculated from the front and backside measurements (Fig. 12). During the first two hours after the laser of the AT401 was turned on the instrument warmed up and the measurements changed slightly. This has to be taken into account depending on the time duration of observations

from one set up. Bringing in the instrument from a room with 5 deg C temperature difference did not change the warm up time noticeably.

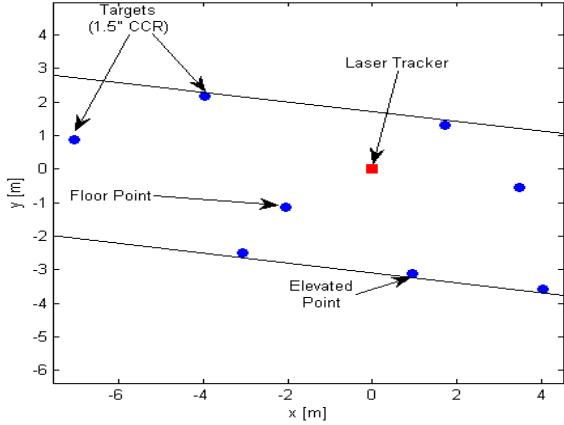


Figure 8: Warm-up test setup.

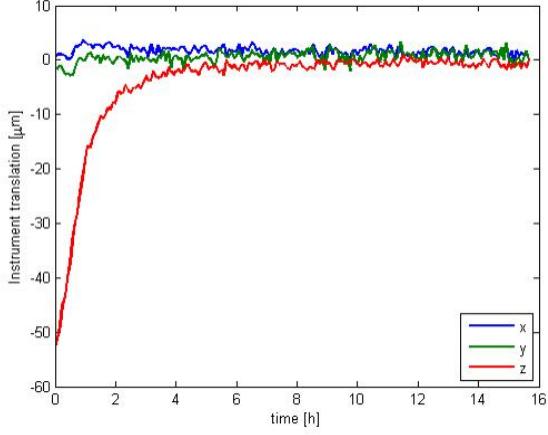


Figure 9: Translation of the instrument center as a result of the warm-up.

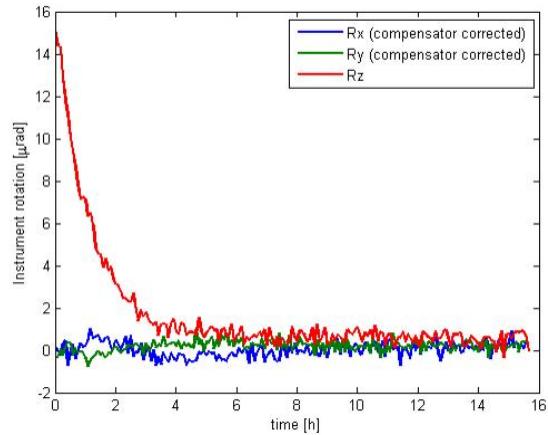


Figure 10: Rotation of the instrument center as a result of the warm-up.

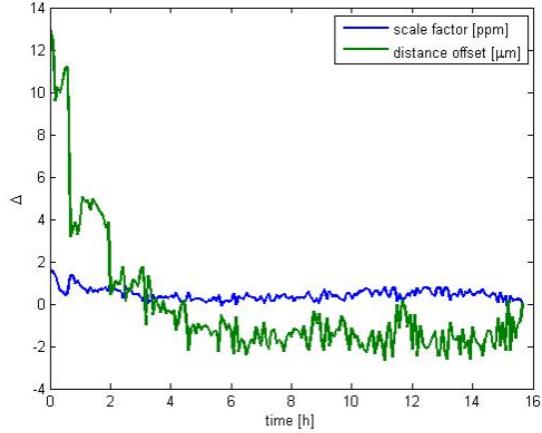


Figure 11: Distance scale factor and offset change as a result of the warm-up.

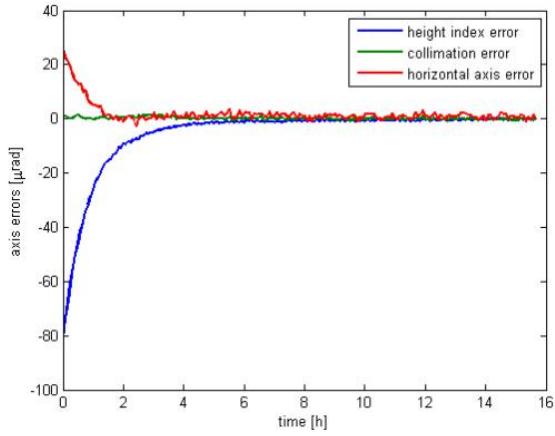


Figure 12: Change in axis alignment due to instrument warm-up.

ACCEPTANCE / VERIFICATION TEST

To get a better understanding of the instrument performance outside the laboratory in a typical accelerator setting without air conditioning, a test following a simplified version of a subset of the ISO 10360-LT norm [3] was performed. In subsection 6.4 of the norm a test is described where a multitude of 3D distances in space are measured and compared to a “known” distance. The difference is then compared to the MPE (maximum permissible error) of the manufacturer’s specifications or your own requirements. Since no traceable interferometric distance measurement device was readily available we relied on the distance measurement of the AT401 and a mirror tool (description of the mirror tool, see [4]) to establish the reference distances. The test setup was established on an inside building wall of an old experimental hall, see Fig. 13. A varying subset of the 12 points on the wall was measured from 7 positions. At each setup the measurements were taken 3 times in both faces, with the instrument rotated 120 degrees between each set.

The locations of the instrument setups should cover the measurement volume that the instrument will be used for in the field. The 3D distances were then calculated from the measured point coordinates and compared to the “known” distance. The differences between them were then compared to the maximum permissible error ($15\mu\text{m} + 6\text{ppm}$). See Fig. 14 for the front side and back side measurements individually and Fig. 15 for the two face measurements combined.

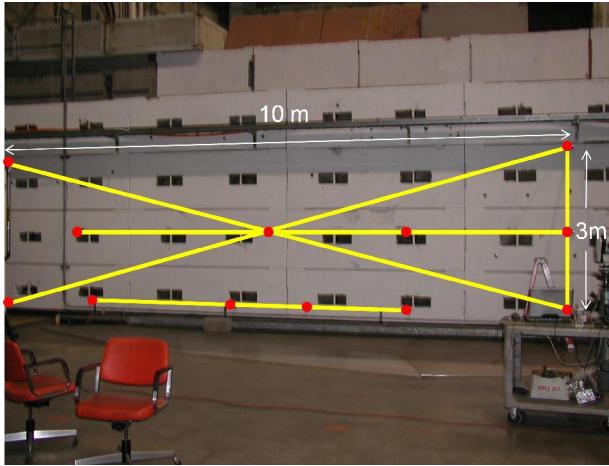


Figure 13: Verification test setup.

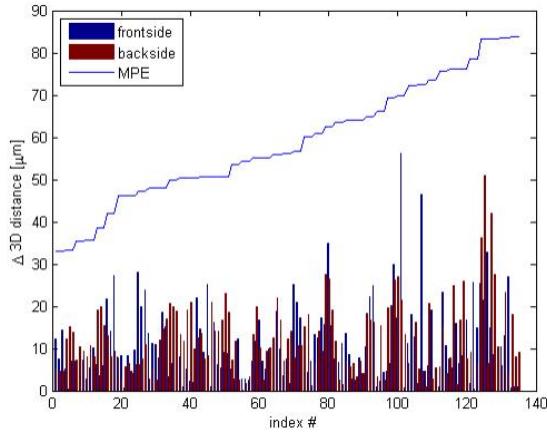


Figure 14: 3D distance deviations for separate front side and back side measurements compared to the MPE.

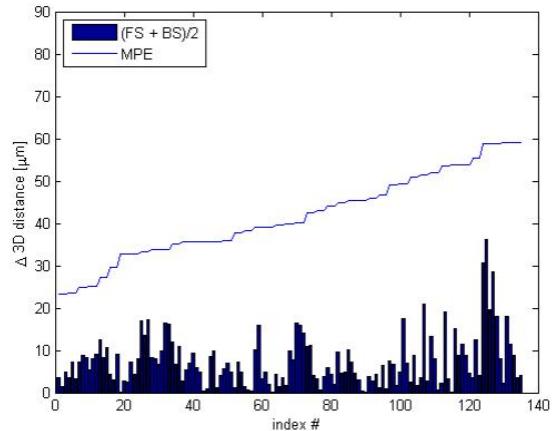


Figure 15: 3D distance deviations for combined front side and back side measurements compared to the MPE.

APPLICATIONS FOR THE TRACKER AND LIMITATIONS

The use of the Leica Laser Tracker AT401 in the field has shown several advantages over its competitors but also some limitations. The biggest plus for the use of the instrument for accelerator alignment is its portability (even allowing battery operation and wireless communication) and its short startup time while maintaining a very high accuracy. On so called “repair opportunity days” we have only a limited number of hours to get into the tunnel through ladders, setup an instrument, and align components to the beamline. This time constraint and logistic issues did not allow bringing in laser trackers for these jobs in the past.

Another advantage is the tracking capability of the instrument with the “PowerLock” feature. It allows an operator to track a target to a monument even if the line of sight is interrupted. The same feature allows manually pointing the tracker crudely to a target without the need to initiate a time consuming search for the target. This very feature can also be a disadvantage, if two targets are close to each other as seen from the laser tracker. The intended target is not always found, but rather the closer one in distance. To correct for this, targets have to be physically blocked from the view of the instrument to allow targeting another one close by. According to Leica [5] the upcoming firmware release will significantly improve this behaviour. Overall this feature saves some time setting up an instrument. At SLAC we usually use free stationing to setup an instrument. With the gravity based laser tracker only two targets have to be manually found to calculate the position of the tracker and automatically measure the remaining monuments.

Quite interesting is the integrated CCD camera which allows a user to remotely control the instrument from another building. This is useful for operations in experimental hutches when people are not allowed to be there (e.g. during beam operations).

Not as important to us is the higher range of the distance measurements, up to 80 m. Limiting is the minimum distance to the target of officially 1.5 m which can be difficult to achieve in a tunnel environment full of components. The official 1.5 m minimum distance is a “soft” minimum distance, we could measure down to 1 m but have been told by Leica [5] that there are two distances of about 2 cm unique to an instrument where it is not able to measure. A slight disadvantage is the lack of continuous measurements for stake outs, since this is an ADM (absolute distance measurement) instrument only and does not use an interferometer. There is a continuous data readout function but it is not meant for precise measurements. Every actual measurement takes at least 500 ms and if the highest accuracy is required at least 2000 ms. This is also a disadvantage for “free hand” observations where a retroreflector is held onto a surface of interest. The Leica instrument rejects measurements if the target is not stable within a certain threshold. For a 2000 ms measurement this threshold rejected at least half the measurements we were trying to take on a vertical surface. At 500 ms measurement time, almost all measurements were accepted even though we have to live with a loss of accuracy as shown before. According to Leica this feature will be changed with a future firmware update.

SUMMARY

The angle accuracy of the AT401 is comparable to total stations. The distance accuracy is in the range of interferometer based trackers in normal atmospheric conditions. The portability of the tracker and ease of operation allows applying laser trackers in areas previously to cumbersome to reach. And finally the power lock function which does not require an uninterrupted path between Point A and Point B speeds up operation

and eliminates the need to awkwardly track a retroreflector around components, thus making the operation safer.

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