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Developments Regarding Laser Tracker Calibration at SLAC

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Laser Trackers cover an ever increasing part of our daily workload. Until just recently there was a complete lack of standards and accepted procedures for checking and calibrating these instruments. At SLAC we have the capability of testing the distance measurement systems on our 30 horizontal comparator bench. For angle measurements a test stand is currently being built.

Introduction

Until recently, no formal standard for the calibration of laser trackers existed anywhere in the world. In the US, the American Society of Mechanical Engineers' (ASME) B89 Dimensional Metrology Committee has proposed a new standard B89.4.19 "Performance Evaluation of Laser Based Spherical Coordinate Measurement Systems". This proposal was developed under procedures accredited by the American National Standards Institute (ANSI) and received preliminary acceptance earlier this year as an American National Standard.

This standard is based on a test procedure originally developed by the National Institute of Standards and Technology (NIST). In this procedure, 3-dimensional distances are measured using the evaluated laser tracker and compared to their true lengths. The analysis of the lengths differences yields a qualitative "Pass" – "No Pass" performance evaluation (SAWYER)[1].
To facilitate the measurement of the spatial distances, NIST developed a portable rail system equipped with an interferometer to determine the "true" lengths.

In Europe, the Physikalisch Technische Prüfanstalt (PTB), the German equivalent of NIST has initiated a program in cooperation with partners from private industry and universities to develop a more quantitative laser tracker performance evaluation (SCHWENKE)[2]. However, results are not expected before 2009[3].

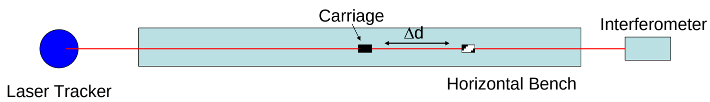
At SLAC and the accelerator alignment world in general, we are faced with ever tighter positioning tolerances. Hence, a qualitative analysis is not sufficient, a quantitative approach is required which possibly would yield correction values. It is our goal to separate the measurement errors and improve the modeling of the errors in a rigid statistical analysis. This knowledge could then be used to improve the parameter values used in the internal calibration routine which in real time translates the raw measurements into the spherical coordinates output.

[1] D. Sawyer, B. Borchardt, T. Estler, S. Phillips: Recent Developments in the Standardization and Testing of Laser Trackers, to be published in proceedings of 9th IWAA, Stanford, 2006
[2] Schwenke, private comminication
[3] Update will be given at 3rd International Workshop on Traceability in Large-Scale Metrology at PTB, Braunschweig, Germany, November 14th - 15th, 2006

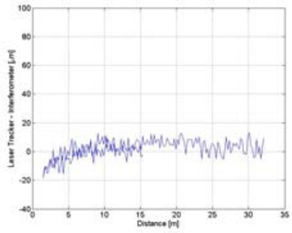
Absolute Distance Measurement

The Absolute Distance Measurement (ADM) mode of the laser tracker is the choice of operation at SLAC since it provides a more efficient measurement operation than the interferometer mode. The loss of accuracy in case of the Faro laser tracker Xi is acceptable (std: 30 µm). A calibration of the scale factor of the ADM is possible in the field with the onboard interferometer The field calibration of the scale factor has the advantage that the instrument is acclimatized. It is not practical to test for higher order deviations in the field. The tests performed in the laboratory include tests of the general performance of an instrument and tests to detect malfunctions.

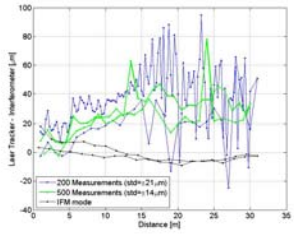
The basic setup [4] is the same as we use for our conventional distance meters:



Instrument of Company A



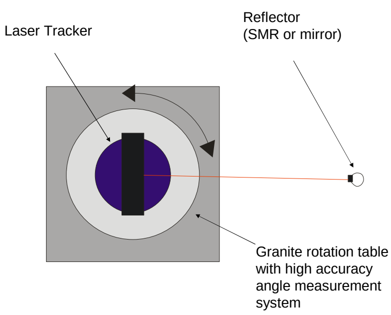
Instrument of Company B



[4] For guidance see ANSI standard B89.1.8 Interferometer Standard and in particular Appendix B "Methods for Comparing Two Interferometer Systems"

Angle Measurement

At SLAC, practice is not to level the laser tracker and assume the tracker not to be leveled for the adjustment calculations. To reference to gravity we combine laser tracker measurements with digital level measurements. This approach avoids any bias caused by vertical axis error completely.
To mitigate the effect of any errors in the collimation axis and the horizontal axis best practice is to take measurements in both faces. To calibrate the effect in the field is an option but since we usually measure one target multiple times from one setup anyway, two face measurements provide the best results. However, these methods cannot mitigate any angle encoder system problems. Test cases in the literature suggest that one needs to be aware of possible cyclic and high frequency errors [5] in the angle measurements caused by encoder biases.



[5] C. Depenthal: Automatisierte Kalibrierung von Richtungsmesssystemen in rotativen Direktantrieben, AVN, 2006, pp.305ff
[6] H. Ingensand: TPM – Ein neues Gerät zur vollautomatischen Prüfung von Teilkreisen in elektronischen Theodoliten, X. Internationaler Kurs für Ingenieurvermessung, Munich, 1988, p. A6ff

Angle Measurement Test Stand

To determine any cyclic and high frequency errors and to perform qualitative angle measurement tests of the instrument it is planned to build a test stand based on a rotation table with a high accuracy angle measurement system (0.01 arcsec resolution; 0.3 arcsec accuracy). The basic concept follows a design first proposed by Ingensand [6]. The table itself will rotate together with the instrument which is mounted on top. The target is stable and will be viewed through a collimator. In order to eliminate the error caused by the offset between the rotation axis of the instrument and the axis of the rotating table we plan to use a mirror as the laser tracker target. The challenge is to determine the rotation of the granite table with a 10 times higher accuracy than the laser tracker. We propose to use autocollimators to calibrate the table angle reading system to better than 0.1 arcsec.
By using different setups for our investigations we will be able to determine the quality of the angle measurements and we can determine the offset of distance measurements.

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