

Laser Tracker Calibration - Testing the Angle Measurement System -¹

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1 Introduction

Physics experiments at the SLAC National Accelerator Laboratory (SLAC) usually require high accuracy positioning, e. g. 100 μm over a distance of 150 m or 25 μm in a 10 x 10 x 3 meter volume. Laser tracker measurement systems have become one of the most important tools for achieving these accuracies when mapping components. The accuracy of these measurements is related to the manufacturing tolerances of various individual components, the resolutions of measurement systems, the overall precision of the assembly, and how well imperfections can be modeled. As with theodolites and total stations, one can remove the effects of most assembly and calibration errors by measuring targets in both direct and reverse positions and computing the mean to obtain the result. However, this approach does not compensate for errors originating from the encoder system. In order to improve and gain a better understanding of laser tracker angle measurement tolerances we extended our laboratory's capabilities with the addition of a horizontal angle calibration test stand. This setup is based on the use of a high precision rotary table providing an angular accuracy of better than 0.2 arcsec. Presently, our setup permits only tests of the horizontal angle measurement system. A test stand for vertical angle calibration is under construction. Distance measurements² (LECOCQ & FUSS, 2000) are compared to an interferometer bench for distances of up to 32 m. Together both tests provide a better understanding of the instrument and how it should be operated. The observations also provide a reasonable estimate of covariance information of the measurements according to their actual performance for network adjustments.

2 Error Sources and Calibration

Most of today's laser trackers are capable of making at least four distinct measurement types (WILKINS, RULAND, 1998). The four primary observables are angles (both horizontal and vertical), relative distances, absolute distances, and tilt measurements. In addition, there are a series of support measurements, such as barometric pressure and dry bulb temperatures, whose information is required in order to make corrections to the primary observables. The accuracy of the measurements is related to the manufacturing tolerances of various individual components, the resolutions of measurement systems, the overall precision of the assembly, and how well imperfections can be modeled (i.e. calibrated).

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² The testing of absolute laser tracker distance measurements is analogous to the testing of total station distance measurements. This subject is well understood and will not be discussed in this paper

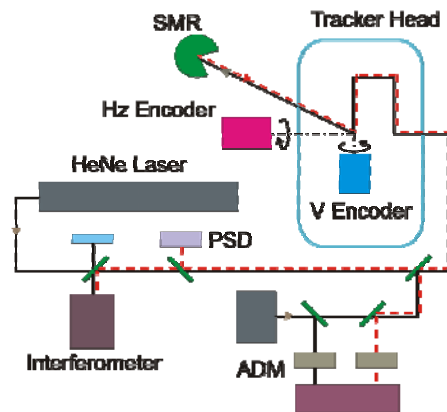
2.1 Angular Measurements

The angular measurements are simply defined as the spatial orientation of the emitted laser beam with respect to the tracker's local coordinate system. This is given by the orientation of the rotating head that emits the beam, hence, anything that affects the head position or its spatial determination will have a negative impact on the measured angles. The main mechanical contributors to this error are the encoders, coupling between the encoders and the rotation shaft, mechanical alignment, and bearing wobble (RULAND, 1993).

The error contribution from the angular encoders themselves can be minimized by using high resolution encoders with a calibration table. The error caused by the coupling of the encoders and the rotation shaft is more difficult to eliminate. The rotation shaft is a precisely machined component that has the encoder attached, but also serves as a carrier for the optics. Any variation in the assembly will manifest itself as a deviation in the encoder reading from the desired "true" value.

An ideal mechanical configuration would have the laser path and the rotational axes of the beam steering assembly one and the same. However, if the beam and the axis are not parallel, the effect is analogous to the collimation error found in a theodolite. As the beam (or telescope) is rotated through 360 degrees, it will trace out a cone. In the case of the tracker, two collimation type errors exist due to the beam path (line of sight), at different locations along its path, having to be parallel to two rotational axes. In addition, if an offset exists between the laser beam and the rotational axis an eccentric error will also exist. As with a theodolite, it should be possible to remove the effects of these errors by measuring targets in both direct and reverse positions and computing the mean to get the result.

The measuring head may be influenced by bearing wobble if the bearings and shaft are not sufficiently aligned or if bearings are substandard or worn. One can understand that if any of these conditions exist, it would have a detrimental impact on the results that would be somewhat inconsistent through the working range of the instrument. This would make it very difficult to model and correct for this effect and makes it imperative that great care be initially taken in the selection and assembly of the shafts and bearings.



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Fig. 1: Laser tracker schematic