Laser tracker calibration procedure at Central Office of Measures

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Abstract. A laser tracker is a portable coordinate measuring system that tracks a moving target reflector and measures the position of the target in spherical coordinates, the establishment of an ASME B89.4.19 laser tracker verification facility at Central Office of Measures, Poland is introduced. The set of laser wavelength calibration, environmental sensors calibration, ranging tests, length measurement system tests and two-face system tests were performed to assess the performance of instruments. For length measurement errors the Brunson Instrument Company KinAiry laser tracker evaluation system was used. Example results from the tests were presented.

1. Introduction
The laser tracker is a portable coordinate measuring system. Laser trackers have become popular measuring tools for users needing to make precision measurements for large volume metrology. Typical applications of laser trackers include the measurement of aerospace assemblies, power plant structures, civil engineering structures and terrestrial transportation vehicles.

Laser tracker is a polar coordinate measuring system. Laser tracker can work with stylus and retroreflector combination (SRC), retroreflector or spherically mounted retroreflector (SMR). The radial distance or range component is typically measured by an interferometer (IFM) or an absolute distance meter (ADM). Azimuth and elevation angles of the target is determined by angle encoders on the mechanism.

Operator can take points by touching the measured surface with SMR or SRC. The laser tracker is automatically follow the movement of the retroreflector. The laser tracker transforms coordinates of measured point from spherical \((r, \theta, \phi)\) to cartesian \((x, y, z)\) coordinate system.

As with any metrology tool, a laser tracker needs to be calibrated and its performance verified. The most commonly used standard for laser tracker performance verification is ASME B89.4.19 [1]. The B89.4.19 Standard describes performance tests for trackers that use a cooperative target such as a retroreflector. The B89.4.19 Standard explicitly ensures metrological traceability of the test results using traceable reference lengths employed in the evaluation procedure.

In this paper, we briefly review the performance tests in facilities at Central Office of Measures, and discuss some results from B89.4.19 tests conducted on our tracker.
2. Laser tracker verification process at Central Office of Measures (GUM)

The Standard proposes a common set of ranging tests, length measurement system tests and two-face system tests, which can be performed by manufacturers and users to assess the performance of their instrument. Tests are sensitive to the different potential error sources, including errors resulting from geometric misalignments within the tracker.

Three test coincides with procedures used for calibrations of laser interferometers. The laser wavelength calibration for trackers that have an IFM is made to determine laser frequency using a frequency comparison against an optical frequency synthesizer shown in Figure 1.

The environmental sensors calibration (temperature, pressure and humidity) are made by comparison against similar sensors which have been previously calibrated by GUM.

The ranging tests assess the distance measuring capability of the tracker along a purely radial direction. Capability of the tracker is tested on 50 m tape bench shown in Figure 2 [2]. The horizontal and vertical rotation axes of the tracker remain stationary during this test in order to isolate the ranging errors of the tracker from other error sources. The SMR is mounted on a carriage moved on rails on a tape bench and the position of the carriage is measured using calibrated interferometer. The carriage is moved to a series of locations.

The refractive index correction to the laser vacuum wavelength is calculated using measurements made by environmental sensors of air temperature, pressure and humidity. The environmental conditions during calibration are recorded. The facility is maintained at 20°C±0.2°C. The pressure, temperature, and relative humidity sensors have expanded (k = 2) uncertainties of 20 Pa, 0.01°C, and 1 % RH (relative humidity) respectively. Temperature sensors are located every 2.5 meters. The expanded (k = 2) uncertainty of reference length \( L \) is \( U/L = 5 \mu m + 0.5 \times 10^{-6}L \). The results from long ranging tests for GUM’s Laser Tracker are summarised in Figure 3 for interferometer and in Figure 4 for ADM measurements respectively. Blue lines are maximum permissible error (MPE) given by the manufacturer.

Volumetric length tests are performed to assess the tracker’s ability to measure different lengths within the work volume. Because these tests exercise the kinematic links in the tracker, they are sensitive to most of the tracker’s geometric misalignments. The ASME B89.4.19 standard requires several tests that rely on measuring a known reference length (artefact) and comparing the observed error (laser tracker measured length minus reference length) with the specified maximum permissible error (MPE) given by the manufacturer.
Figure 3. Interferometer ranging test results. Blue lines are maximum permissible error (MPE) given by the manufacturer.

Figure 4. ADM ranging test results. Blue lines are maximum permissible error (MPE) given by the manufacturer.

Figure 5. Brunson Instrument Company KinAiry laser tracker evaluation system.
The main artefact (or reference length) is specified to be at least 2.3 m long. For length measurement errors the Brunson Instrument Company KinAiry laser tracker evaluation system was used shown in Figure 5. KinAiry is comprised of a carbon-composite, precision length artefact, mounted at heavy duty rotary positioning device. Three nests are fixed on the surface of the tube at beginning, in the centre and nominal separation of 2.31 m. The measurand is the point-to-point separation of the nests. The reference length can be calibrated using the range measurement capability of the laser tracker, with the calibrated value being established as a part of the test procedure. Three measurement runs are performed.

The measurements are partitioned according to the orientation of the reference length: horizontal length measurement system test, vertical length measurement system test, right diagonal length measurement system test, left diagonal length measurement system test. After that the entire tracker is then rotated by 90° about the standing axis and measurements are made again. This process is repeated for the 180° and 270° orientations of the tracker as well. Series of measurements are performed for 1, 3 and 6 m distance from the tracker to the reference length.

There are a number of geometric errors in a tracker that reverse in sign between front face and back face measurements, when measurement is made after a 180-degree rotation about both the horizontal and vertical axes. The front face and back face measurements are performed for each point during volumetric test. The two-face test is performed using only the ADM. Example results for ADM volumetric measurements are shown in Figure 6.

![Figure 6](image)

**Figure 6.** Volumetric length measurement system test results (ADM mode). Blue dash lines are maximum permissible error (MPE) given by the manufacturer.

### 3. Conclusions

An overview of service for laser tracker performance verification at GUM has been described. The descriptions of the different tests were given. Example results from the main volumetric test; the two-face tests and ranging tests were also presented.

### 4. References

[1] ASME B89.4.19-2006: Performance Evaluation of Laser Based Spherical Coordinate Measurement Systems, ASME, November 2006

[2] „Final report on supplementary comparison EURAMET.L-520: Comparison of laser distance measuring instruments“, Mariusz Wiśniewski, et al., Metrologia, Volume 51, Technical Supplement, 2014