ACCURACY ASSESSMENT OF A LASER TRACKER SYSTEM

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Abstract:

Choosing the right laser tracker system for large-scale metrology is not easy. Currently on the market there are several manufacturers of laser tracker systems, such as: Leica, Faro, API and Nikon. What is new is the Etalon LaserTracer. They differ in terms of construction, application and also the accuracy of the system. What is more there is no one common international standard for the evaluation of their accuracy. The international standard is currently under preparation. So the accuracy of laser tracker systems are provided in a many different way by manufacturers. Therefore, there is a need to determine as soon as possible a common method for testing laser tracker systems.

One of the possibilities for testing the accuracy of laser trackers is test according to ISO 10360-2:2009 and ISO 10360-5:2010. These standards allow to evaluate the error of indication of calibrated test length and errors of a probing system. Unfortunately, these standards do not fully take into account the characteristics of coordinate measuring systems such as laser trackers. Therefore it is necessary to adapt their to test the performance of laser trackers.

The paper presents the method for testing the performance of laser tracker systems according to ISO 10360-2:2009 and ISO 10360-5:2010 to fully fit laser trackers requirements. For test API laser tracker with two standards (calibrated standard of length and calibrated sphere) was used. The paper shows the measurement method, the results of the measurements and the conclusions of the study.

Keywords: CMM-metrology, laser tracker, calibration, accuracy, large-scale metrology

1. INTRODUCTION

In spite of the laser trackers are well known and widely used for many years there is no one accepted method by all manufacturers of laser trackers for testing their accuracy[1]. Nowadays laser trackers are tested according to ASME B89.4.19, VDI/VDE 2617 sheet 10 or using some other methods. International standard ISO 10360-10 is now in preparation [2,3,4].

Laser tracker can work with stylus and retroreflector combination (SRC), retroreflector or sphericaly mouted retroleflector (SMR). Each of them has a different accuracy of the system, so it is not sufficient to calibrate only the SMR when also the SRC is frequently used. Aware users of laser trackers require calibration of all available tools (cat's-eye retroreflector, SMR 0,5", SMR 1,5" and SRC with different stylus length or diameter probe diameter). This paper describes tests of the laser tracker system used with 2 different configuration: with SMR 1,5" and SRC.

2. LASER TRACKERS

The laser tracker (LT) is a portable coordinate measuring system (CMS). Operator can take points by touching the measured surface with SMR or SRC. The LT is automatically follow the movement of the retroreflector. The center of the retroreflector is determined by measuring a distance (from the LT to the retroreflector center) and two angles (vertical angle and horizontal angle). The LT transforms coordinates of measured point from spherical to Cartesian coordinate system. The final step is radius compensation to calculate point of contact instead of retroreflector center.

LTs are used to measure large spatial objects in aerospace, automotive and other industries fields. There are many examples of the LT application for example: large parts inspection, assembly of wing body, align of accelerator parts, align of robotic lines, calibration of robots, reverse engineering, compare to CAD model and so on.

The measurement uncertainty of the CMS is described in papers [5,6,7] . The uncertainty of measurements taken by laser trackers is determined by a number of uncertainty sources: structure of the laser tracker, environment, work piece, operator, measurement strategy and software.

As describe in paper [5,8,9] the errors of the laser tracker derived from: static errors (geometric and non-geometric errors) and dynamic errors. Static errors are being changed slowly in time and they are related to geometric errors of the LT such as mechanical inaccuracies of the rotational axes misalignment, encoder scale errors, the laser beam offset, SMR errors, etc. Non-geometric errors are related to laser beam wavelength variation and can result in distance measurement errors. Non-geometric errors applies to both the laser interferometer (IFM) and the absolute distance meter (ADM). Dynamic errors include acceleration of the retroreflector in a scanning mode, servo errors from the mirror steering control system and vibrations of the LT. Typically static measurement are more accurate than dynamic measurements because dynamic measurement needs additional corrections.

3. DIFFERENCES AND SIMILARITIES BETWEEN ISO 10360-2 AND DRAFT ISO 10360-10

The ISO 10360-2 and ISO 10360-5 is primarily applicable to the Cartesian CMMs, but others CMS with non-Cartesian axes can be also tested under the condition that both parties (CMS's user and a calibration laboratory or manufacturer) mutually agreed[10,11]. Draft international standard ISO 10360-10 apply to measuring system that use spherical coordinate system and use retroreflector as a probing system. This draft standard also apply to system that use IFM and AFM, or both IFM and AFM measurement mode.

Both standards recommends to executed acceptance test according to the manufacturer's specification and procedures but only the ISO 10360-2 emphasizes that they must be in compliance with the ISO 10360-2 standard.

Both standards are based on the same assumption to test specific errors of the measuring instrument.

A probing performance test for CMMs is a separate part of ISO 10360 standard. It was moved from part ISO 10360-2 to the part ISO 10360-5. The procedure for the form error and the size error for a single stylus probing configuration CMM and for the LT is almost the same. For the CMM it shall be performed only once but for the LT it shall be performed twice. First test for the LT shall be carried out in distance less than 2 m and approximately the same height. The second test for the LT shall be carried out at approximately 10 m from the tracker and more than 1 m above or below the tracker. The more significant difference is in the procedure of the location error. In ISO 10360-10 draft standard it is named as two face test. Two face test also occurs in the ASME B89.4.19 standard and is excellent diagnostics of tracker's health[9]. This test depends on the distance of the test sphere from the LT and also angular orientation of the LT. It gives information about a general condition of the LT and it is recommended to be performed first.

Length performance test is the most important part of both standards. Both standards are similar in the amount of required measurements but there are significant different in orientation of the calibrated test length in the measured volume. The ISO 10360-2 is based on 105 measurements for E_0 tests (the ISO 10360-2 requires also some additional positions but they are irrelevant for the laser tracker calibration). The same situation is in ISO 10360-10, it requires also 105 measurements (41 compulsory plus 64 user-defined measurements positions). As mentioned in [12]: "position 1 and 2 of the draft ISO 10360-10 includes the spirit of the ISO 10360-2 where each axis is tested for at least 66% of its range".

Both standards shows how to properly perform a thermal compensation. It is necessary to achieve proper results of tests. A new synthetic length test was added in the ISO 10360-10 draft standard to test the temperature compensation capability of the LT system.

4. ADAPTATION OF THE ISO 10360-2 AND ISO 10360-5 IN ORDER TO CALIBRATE THE LASER TRACKER

In this method the LT is treated as a black box without attempting to isolate all error sources in different tracker constructions. The aim of this method was to adapt a well-known and widely used parts of ISO 10360-2 and ISO 10360-5 for calibration purpose of the LT.

Calibration the LT system consists of two main parts: testing errors of the probing system and testing errors of indication of the calibrated test length.

Tests of the probing system errors must be completed before tests of length measurement errors. The SMR or the SRC is used as a probing system. This test shall be consisted of measurement of 25 points on a test sphere. All points shall be evenly distributed over the hemisphere of the test sphere and then a least-squares sphere fit shall be calculated. After this, a diameter and a form error of the test sphere shall be calculated.

The calibration procedure should test all errors of the LT and take into account the appropriate orientation of the test lengths. The measurement position and orientation of the Ball Bar is consistent with the specification described in ISO 10360-2. The procedure for length measurement errors of the LT shall be conducted using a ram axis stylus tip offset of zero (E_0) and the SMR. Five different calibrated test lengths shell be measured in each of seven different positions and each length shall be measured three times. Three positions shall be placed along three main directions X, Y, Z and four positions shall be the space diagonals. This procedure should be repeated as many times as required at different distances from the LT by using overlapping method or this procedure shall be repeated in defined distances from the LT. In case of using the SRC instead of the SMR, the procedure shall be the same.

5. CALIBRATOIN OF THE LASER TRACKER

During calibration of the LT system two standards with valid calibration certificate have been used. All results has a direct traceability to the unit of length – the meter. For length measurement errors the three meter long Ball Bar was used (fig. 1).

Fig. 1: The Ball Bar 3 m and the Laser Tracker

For probing errors the test sphere with diameter of 25 mm was used. A equation (1) below shows the Ball Bar uncertainty of calibration with a coverage factor k=2, where L is in mm:

$$U = (1.00 + 0.001 \cdot L)\ \mu m \quad (1)$$

The form error of the calibration sphere was 0.00009 mm and uncertainty of calibration was 0.0001 mm with coverage the factor k=2. The diameter of calibration sphere was 24.99018 mm and the uncertainty of diameter calibration was 0.0002 mm with the coverage factor k=2.

In research API Laser Tracker equipped with a SpatialAnalyzer software was used (fig. 2).

Fig. 2: The Laser Tracker (API)

This Laser Tracker has built-in interferometer (HeNe Laser) and Absolute Distance Meter (IR laser) on-board. It has rugged aluminum design and is one of the lightest laser tracker on the market. It weighed only 9 kg, so it can be easily moved during tests. The sensor head features 360° yaw and 360° roll to measure even the most complex parts.

It has integrated camera and useful software function that allow to focus on the calibration, not the tool. If the beam is broken, the LT will find automatically the SMR or SRC (available only when AFM is enabled). Another valuable useful feature during calibration is a visual information that tells you what mode is used now: IFM mode or both IFM and ADM mode. Worth a look feature is indicating that the temperature gradient exceeded a certain value. This feature allowed us to control the temperature in the laboratory in which we use Radian Laser Tracker. The novelty is equipped the LT with a part temperature sensor, not only an air temperature sensor. It has also self-compensation procedure before starting measurement. This LT has a self-diagnostics feature including excessive vibration, elevated temperature, laser beam deviation, detecting a bad SMR, and laser intensity. Important from the management system point of view is a calibration certification reminder.

During tests the SMR 1,5" and the SRC Intelli Probe 360 (IP360) wireless was used. The build-in retroreflector of IP360 is used to determine the base location of the Intelli Probe 360. This probe uses build-in gyroscope to determine the stylus orientation vector.

6. CALIBRATION RESULTS

Results of the LT calibration using wireless Intelli Probe 360 is presented on fig 3. The IP360 was used in horizontal probe position. It was equipped with 100 mm stylus and probe with a diameter of 6 mm. A maximum permissible error of length measurement for this probe is shown below (Eq. 2):

$$MPE(E0) = 0.078 + 0.005 \cdot L/1000\ mm \quad (2)$$

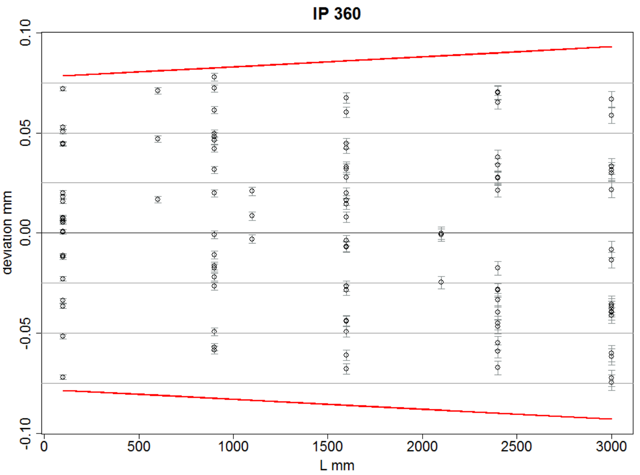

Fig. 3: MPE(E0) for the IP360

Results of the LT calibration using the SMR 1.5" is presented on fig 4. The maximum permissible error of length measurement for the SMR 1.5" is shown below (Eq. 3):

$$MPE(E0) = 0.035 + 0.005 \cdot L/1000\ mm \quad (3)$$

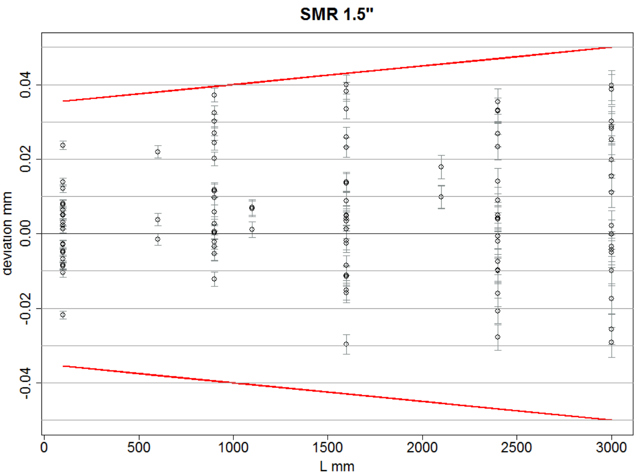

Fig. 4. MPE(E0) for the SMR 1.5"

Results of the LT calibration using the SMR 1.5" in one axis only is presented below (fig. 5). The maximum permissible error of length measurement in one axis only for SMR 1.5" is presented in Eq. 4:

$$MPE(E0X)=0.009+0.005 \cdot L/1000 \text{ mm} \quad (4)$$

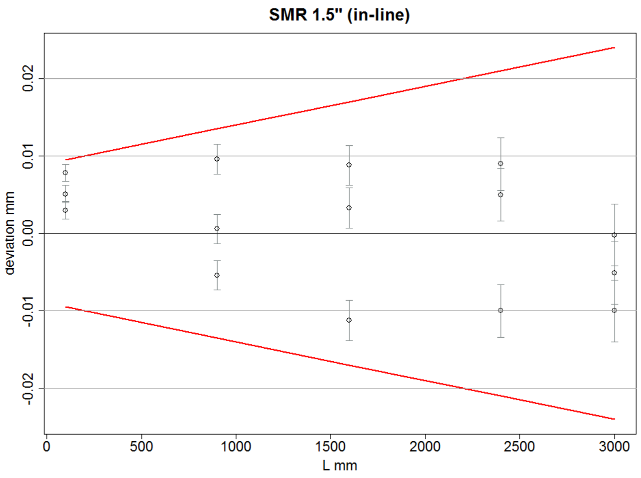

Fig. 5: MPE(E0X) for SMR 1.5” (only in-line measurements)

For all measurements the evaluation of uncertainty was calculated according to ISO TS 23165:2006. More detail about this uncertainty calculation can be found in [13,14]. The standards with an actual certificate of calibration were used to ensure traceability to the SI unit of length.

As indicated above it is possible to calibrate the LT in accordance with ISO 10360-2 and ISO 10360-5.

It is very important for the users whether he is using the SMR or the SRC because they have significantly different values of the MPE (fig. 3 and fig. 4). Wireless IP360 is more than two times less accurate than the reflector 1.5". That is why the calibration should be performed for all possible configuration of the LT. This is important for users who want to use for measurements both the SMR and the SRC.

The LT is more accurate in the in-line position (radial position) than other positions as we can see on fig. 4 and fig. 5. Research for the reflector 1.5" showed that the in-line position is two times more accurate than other positions. That is why it is significant to calculate the MPE also for in-line positions.

7. CONCLUSION

There is no international standard for testing trackers now. This results in the use of different standards and recommendations, which are characterized by different approaches to the accuracy assessment of laser trackers. This leads to variation when comparing trackers tested according to different standards or recommendations. Therefore, this paper attempts to evaluate the accuracy laser tracker according to well-known and widely used international standard ISO 10360-2. Described in this paper research has shown that it is possible to calibrate the laser tracker system based on the standard ISO 10360-2.

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