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New reconfigurable ball-bar standard for verification of portable metrology systems accuracy

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Abstract

The new reconfigurable ball-bar standard with spherical nests is presented in this paper. The magnetic field generated by a neodymium magnet installed at the bottom of each spherical nest provides a solid and reproducible mounting of the test ball. Thanks to this design, it is possible to easily replace the test balls, depending on the users' needs. This paper describes also the calibration procedure of the developed standard. Calibration results are compared to results of calibration of a typical ball-bar standard with ceramic balls permanently attached to a carbon fiber bar. Results of this comparison show that there is no significant uncertainty increase caused by usage of spherical nests with a neodymium magnet instead of typical mounting of the balls on the bar. The second stage of experiments included a test of reproducibility of lengths represented by the newly developed standard. In the last experimental phase accuracy of a chosen articulated arm coordinate measuring machine was checked utilizing methodology based on ISO 10360-12 with use of presented standard and a typical ball-bar standard. Results obtained using both standards are statistically consistent. The most important conclusion coming out of performed experiments is that the new reconfigurable ball-bar standard with spherical nests can be used (giving metrologically correct results) for the accuracy verification of portable metrology systems like articulated arm coordinate measuring machines or laser tracker systems.

verification, ball-bar, accuracy, AACMM, Laser Tracker

1. Introduction

Industry 4.0 places special emphasis on increasing the efficiency of the production process. It can be done by integrating individual stages of the process, but also by increasing the efficiency of each stage separately. This trend is clearly visible in the coordinate metrology especially in terms of shortening the time needed for inspection as well as a cost reduction of whole quality control process. The issue that is directly connected with this subject is a traceabilty assurance which is obtained mainly by calibration of measuring instruments. In case of a coordinate measuring system most often calibration is done using material standards, which reproduce reference values. A large number of different solutions can be found in the literature [1,2] for determination of the length measurement error for coordinate measuring systems. The reference value can be determined by measuring various geometric elements depending on the type of artifact, the most common shapes include: planes, spheres, cylinders or cones. A solution often found in the calibration practice is the ball-bar standard in which the reference lengths are represented by distances between centers of the spheres fixed on the frame made of material characterized by low coefficient of linear thermal expansion. In a typical ball-bar standard, the balls are mounted rigidly, and their positions are determined in the calibration process of the standard which is repeated cyclically throughout its lifetime. The limitations of such solution include the inability to change the position of the spheres and their size. Therefore, the new concept of reconfigurable ball-bar standard was developed which would allow to minimize mentioned drawbacks. The following sections describe the artifact construction, discuss the calibration process, and compare the results obtained during calibration of the selected coordinate system using the developed standard as well as the typical ball-bar standard.

2. Methodology and results

The standard for determining the length measurement errors with spherical nests (schematically presented in Fig. 1) consists of a carbon tube on which ball nests are placed, in the number selected by the user. According to information provided by a carbon tube manufacturer, main properties of the material are: Young's modulus - 93 GPa, density - 1,58 g/cm^3, CTE – 1,7*10^{-6} K^{-1}, maximum operating temperature – 120 °C. Each nest consist of a base with three balls constituting support for a reference ball and a clamp which is used to set the position of the nest on the tube.

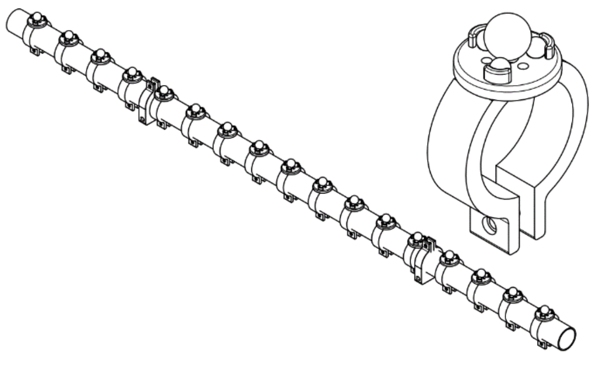

Figure 1. Reconfigurable ball-bar standard with ball nests

Additionally, in the lower part of the base of each nest, a neodymium magnet is mounted in a cylindrical hole. It pulls on the reference ball, thereby causing it to contact at one point with each of the three supporting balls. In such a manner the ball has enough stability to be utilized as a reference element used to reproduce the reference length value. It should be noted that only balls made of ferromagnetic material may be used.

In order to use the standard with ball nests to determine length measurement errors, the lengths represented by the standard should be calibrated, the distances between the centers of individual balls must be determined. Calibration was carried out with a coordinate measuring machine characterized by a reference accuracy that is a part of the equipment of the Laboratory of Coordinate Metrology. It was perfromed in accordance with the assumptions of the calibrated workpiece method presented in [3].

A 1000 mm long ball-bar standard was used as the reference object. The calibration procedure was repeated three times in the assumed time intervals to check whether there is a drift of the distances reproduced by the reconfigurable ball-bar. The reproducibility of the calibrated length measurements was assessed using standard deviation. It was determined for each calibrated length on the basis of measurement results from three repeated calibrations (at different periods). On the basis of obtained results, it can be stated that the tested lengths are highly reproducible. The mean of obtained standard deviations was 0.0004 mm. After the calibration procedure, the uncertainty of determination of each tested distance was estimated. It allows comparision of the uncertainties obtained for the reconfigurable ball-bar as well as for the ball-bar with permanently attached balls. The maximum measurement uncertainty value obtained for both ball-bars equalled 0.0019 mm.

The last phase of the experiment involved calibration of the selected portable coordinate measuring system using a newly developed artifact and a typical ball-bar. In such a way, it is possible to compare the accuracy equations obtained from both procedures, and thus to assess the possibility to use a newly developed standard for checking accuracy of coordinate measuring systems.

The tested system is the six-axis Romer Articulated Arm Coordinate Measuring Machine (AACMM), with a maximum range of about 1.2 m. The arm is equipped with a probing system that enables the tactlie measurements with ruby ball of 5 mm. In both calibration procedures, the measurements were made in accordance with the guidelines of ISO 10360-12 [4]. According to the guidelines the five selected lengths reproduced by the ball-bar should be measured in 7 positions located in the measuring volume of the system (Fig. 2).

Figure 2. Calibrated AACMM with reconfigurable ball-bar in chosen position during calibration procedure

The accuracy of AACMM determined using the reconfigurable ball-bar as well as the ball-bar with fixed balls can be described by the same equation (1):

$$E_{Bi,\,MPE} = 20 + 45 * L/1000\ \mu m \qquad (1)$$

where: L – measured length given in mm.

The calibration results for one of the selected ball-bars position are presented in the figure below (Fig. 3).

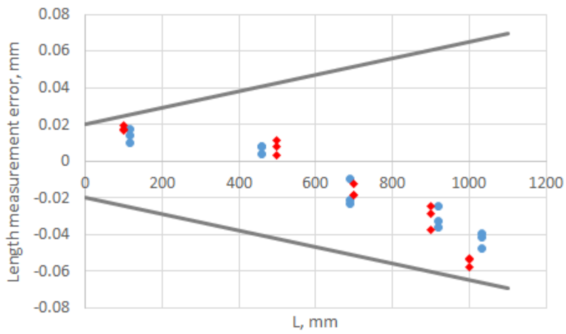

Figure 3. Calibration results for one chosen position according to [4]. The results for the ball-bar with fixed balls are showed using red markers while for reconfigurable ball-bar using blue markers. Grey lines indicate $E_{Bi,\,MPE}$

When both calibration procedures were finished, statistical consistency of results was checked in accordance with the method described in [5]. The results obtained for both ball-bars were found to be consistent.

3. Conclusion

Based on the results of conducted experiments, it can be concluded that the newly proposed reconfigurable standard can be used for checking the accuracy of coordinate measuring systems. Comparison of results of the AACMM calibration carried out with the use of the reconfigurable standard did not show significant differences from the results obtained with the usage of typical ball-bar. As a result of the research, a negligible drift of the lengths represented by the standard was also found. The advantage of the reconfigurable ball-bar over the typical ones is the possibility of personalized selection of the lengths represented by the artifact and a low production cost. An additional advantage of the reconfigurable standard is the possibility of using different sizes of spheres, which may be of significant importance during calibration of optical systems or laser trackers. However, the full analysis of the influence of sphere size on the metrological properties of the newly developed ball-bar is a subject for further research.

Acknowledgments

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References

[1] Cuesta E., González-Madruga D., Alvarez B.-J. and Barreiro J. 2014 *Meas. Sci. Technol*. **25**

[2] Santolaria, J., Yague, J.-A., Jimenez, R. and Aguilar, J.-J. 2009 *Precis. Eng.*, **33** 476-485

[3] ISO 15530-3:2011 – Geometrical product specifications (GPS) – Part 3: use of calibrated workpieces or measurement standards

[4] ISO 10360-12:2016: Geometrical product specifications (GPS) - Part 12: Articulated arm coordinate measurement machines (CMM)

[5] Gromczak K, Gąska A., Ostrowska K., Sładek J., Harmatys W., Gąska P., Gruza M. and Kowalski M. 2016 *Precis. Eng.* **45** 414-422