11th International Symposium on Measurement and Quality Control 2013, September 11-13, 2013, Cracow-Kielce, Poland

ACCURACY ASSESSMENT OF COORDINATE MEASURING ARMS USING LASERTRACER SYSTEM

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Abstract:

Along with fast development of industry and manufacturing techniques, also the coordinate metrology, which is closely linked with requirements of modern manufacturing systems, is developing. The increase in products quality requirements provides a new tasks for manufacturers of measuring instruments. Time of measurement, as well as requirements for its accuracy generate development of the new solutions in coordinate metrology systems, as well as the continuous improvement of existing ones. Undoubtedly, one of the newest and fastest growing solutions are Coordinate Measuring Arms.

The paper presents a new conceptual approach for a calibration of Coordinate Measuring Arms. The novelty of the method is usage of the LaserTracer System as a standard of length according to ISO 10360-2:2009 and elimination of operator influence on measurement result by replacing him by an Industrial Robot. In this method, the robot is programed to repeatedly move the coordinate measuring arm. The stylus of coordinate measuring arm is replaced by reflector, which works with a LaserTracer system. The LaserTracer system is tracking the reflector and measuring the distance to it. The precise LaserTracer system is used here as a standard of length and gives a base for arm accuracy assessment.

Keywords: Coordinate Measuring Arm, LaserTracer, calibration, Industrial Robot

1. INTRODUCTION

Coordinate measuring systems are now the base for quality assurance systems in industry. Its constant development predispose them to be used in precise technologies, also in micro and nano scale. The main problem of their usage is development and implementation of modern calibration methods so that all measurements done on different devices were traceable.

Coordinate measuring technique is still experiencing rapid development, which is provoked by improvements in manufacturing technologies. Coordinate Measuring Machines (CMM), thanks to its multitask character and constantly improving accuracy, are superseding the conventional measuring tools such as calipers, micrometers or even microscopes [1].

Coordinate Measuring Arms (CMAs) are undoubtedly one of the newest and fastest growing measuring devices. They are popular mainly because of their mobility and relatively good accuracy [2-3]. Thanks to systems like SpaceLock or GridLock their measuring volume could be extended even to 60 m.

Unfortunately in Europe there has been no normative documents concerning measuring arms accuracy assessment (approved by European Committee for Standardization) developed so far [4]. The producers of CMA usually express their accuracy according to their own procedures or American ASME 89.4.22 series of standards. In Europe, only German guidelines VDIVDE 2617-9 were developed basing on ISO 10360-2 standard. This standard, however changed strongly in 2009. It allows usage of laser standards, whose accuracy predispose them to be used instead of material standards of length [5-7].

In this paper, the developed procedure of CMAs calibration using LaserTracer (LT) system was presented. It is possible to use LaserTracer as a standard of length, as relation between standard and calibrated device accuracies is fulfilled.

Programmed robot, in repeatable manner moves the CMAs stylus and is used here as a mounting and carrying tool for it. In the place of measuring ball of CMA a 0,5" reflector was mounted. The reflector distance form LT center is determined by LaserTracer which is following the movements of reflector (so also the movements of CMA). Consequently, in presented method, the CMA accuracy is assessed using measurement of length standard which is reproduced by LaserTracer.

2. COORDINATE MEASURING ARMS ACCURACY ASSESSMENT

Few normative standards are now available for CMAs accuraccy assessment. In United States the ASME B89.4.22:2004 [5] standard were developed. It is being commonly used by CMAs manufacturers, however sometimes they overuse it in order to get the best calibration results and invite users to buy their products. In Europe, there are two main methods dominating, which are: method based on ISO 10360-2 [6] or method described in VDIVDE 2617-9 [7]. All of them presents different approaches both for determination of probing system errors and positions of standards in CMAs measuring volume during calibration.

2.1 Comparison of CMA accuracy assessment methods according to ISO 10360-2:2009, ASME B89.4.22:2004 and VDI/VDE 2617-9

- The equivalent of C test (measurement of spatial length standard) from ASME standard is *E* test (test of length measurement error). Both tests aims in determining what is the linear accuracy of machine in its measuring volume.
  The difference between those tests lays in standards recommended by different normative documents. ASME standard recommends a plate with three tapered holes arranged in a line. The wholes creates two lengths, which should be calibrated (the shorter length should lay between 50 ÷ 75% of arm length; while the longer one between 120 ÷ 150%). The ISO and VDI/VDE recommends step-gauges or block gauges. According to these standards it should be possible to measure 5 different lengths on used standards.
  The next difference is the way in which the standards are placed in measuring volume of machine and number of measured lengths. ASME standard describes 20 positions in which standard should be placed in arm volume (four vertical positions, six horizontal and ten inclined in 45°).
  ISO standard and VDI/VDE guidelines recommend to repeat three times measurement of 5 lengths of standard in 7 positions, which gives total number of 105 distances measured in arm volume. Additionally, according to VDI/VDE guidelines the measurements of standard positioned parallelly to *z* axis was replaced by measurements of inclined standard.
- As the equivalent of A test the determination of parameters like MPE_{PS} – size error, MPE_{PL} location error, MPE_{PF} form error could be taken. Exactly, the MPE_{PS} parameter express deviation of measured diameter from its real value so the value defined in ASME standard.
- The B test is not present in ISO nor VDI/VDE, however tests described in VDI/VDE have some similar features as B test from ASME standard. They are for example, measurement of sphere in three different locations in relation to CMA mounting or different orientations of stylus and CMA components when measuring the sphere.

3. CMA ACCURACY ASSESMENT USING LASER TRACER SYSTEM, ACCORDING TO ISO 10360-2:2009

The industrial robot was used for moving Coordinate Measuring Arm stylus. It was done in order to move retroreflector, which was mounted instead of CMA stylus in repeatable way, and also it is necessary here that the reflector is moving along the measuring axis which begins in reference (center) point of LaserTracer (Fig. 1).

Table 1: Comparison of CMA accuracy assessment methods

What kind of test	**Acc. ASME**	**Acc. ISO 10360-2**	**Acc. VDI/VDE**
Test A/ Test on standard sphere	9 points measured on the standard sphere	This part was transfered to part 5, but VDI/VDE is based on ISO DIN 10360-5, so if errors are checked using part 5, they will be expressed similarly to VDI/VDE	3 measurements of sphere (in different positions in CMA volume) in 25 points. 3 parameters are estimated: MPE_{PS} – size error, MPE_{PL} location error, MPE_{PF} form error.
Test B/ Point reproduction error	Repeatability measured on standard cone. Cone is placed in 3 different lengths in relation to CMA mounting	No such test	No such test (similarity with this test could be noticed in measuring standard sphere from different 5 orientations and 3 different positions in relation to CMA mounting)
Test C/ Length standard measurements	Measurement of length standard – 2 distances 20 positions: - 4 vertical - 6 horizontal - 10 inclined in 45^0	MPE_E Measurement of length standard – 5 distances measured 3 times in 7 different positions	MPE_E Measurement of length standard – 5 distances measured 3 times in 7 different positions

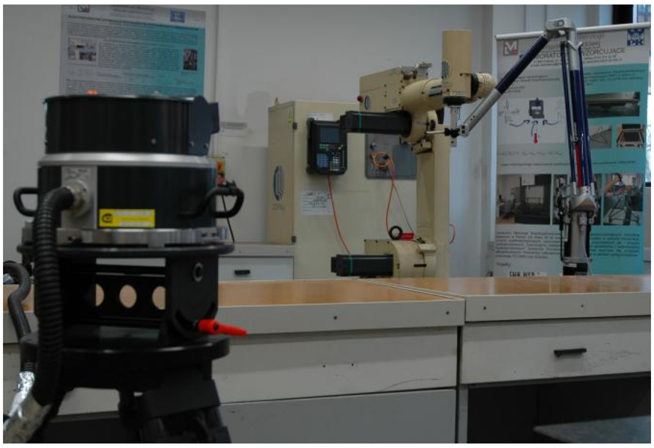

Fig. 1: LaserTracer is following the reflector mounted in CMA which is moved by industrial robot

LaserTracer is accurate device whose uncertainty of measurement can be expressed by equation U = 0,0002 + 0,0003*L /1000 mm, and this is why it can be used for CMA calibration and also calibration of majority of different coordinate measuring systems that are being produced nowadays [8].

At the end of CMA instead of stylus, the reflector should be mounted and defined (calibrated as a new tool) in measuring software of arm. So created system would give as the result of CMA measurement the coordinates of reflector center and the LaserTracer would measure the distance to reflector. By programming the robot in order that it moves through lines that are starting in LT reference point (position of this point could be easily determined using LT software), the measured lengths (nominal) would be given by subtracting the LT indications in different positions of robot, and the lengths measured by arm (actual) would be expressed as point to point distance using X,Y,Z coordinates indicated in each points by CMA.

The [6] standard, as mentioned previously is used for checking three main parameters:

1) length measurement error, when ram axis stylus tip offset is equal to 0 mm (E_0);
2) length measurement error, when ram axis stylus tip offset is equal to about 150 mm (E_{150});
3) repeatability range of length measurement error (R_0).

When using LT to check above mentioned parameters there is no need of having different length standards that should be adjusted to measuring volume of CMA (in accordance with ISO standard). The only limitations in this case are ranges of industrial robot and CMA.

The E_{150} test, described directly like in ISO 10360-2, has no technical sense for arms as stylus orientation can be easily and limitlessly changed thanks to rotary axes of arm. However, there could be a difference in results of calibration for shorter and longer stylus. So E_{150} test could be treated here as test for arm equipped with stylus which length is equal to about 150 mm. The authors of this paper has omitted this test as exemplary CMA which was calibrated according to presented method uses styluses which length does not exceed 80 mm.

In order to determine the CMA length measurement errors for E_0, the positions of LT and directions of measuring lines were set according to ISO 10360-2.

The measurements were done in 7 different measuring lines, three times for each of 5 recommended lengths. It gives total amount of 105 measured lengths. The resulting E_0 values for all distances were obtained as a difference between value measured by calibrated device and translation toward measuring line, measured by LaserTracer. All 105 measured length errors should be smaller than maximum permissible errors $E_{0,MPE}$.

From each 3 repetitions of measured lengths, the repeatability range of length measurement error (R_0) is calculated as difference between maximum and minimum values from obtained results, and checked if it is smaller than maximum permissible errors $R_{0,MPE}$.

The same procedure should be repeated for E_{150} (if apply), with that difference, that there should be 2 measuring lines chosen out of 4 recommended in [6] and the stylus should be longer than in previous case.

4. CALIBRATION OF CMA ACCORDING TO DESCRIBED PROCEDURE

Before the measurements can be performed, the reflector needs to be mounted on CMA instead of its stylus (Fig. 2.), the mounting should eliminate possibility of reflector unintentional movements.

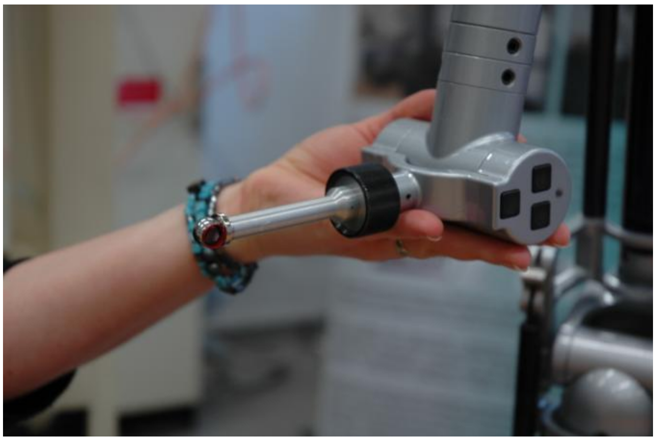

Fig. 2: Reflector mounted on measuring arm

Controlling of the system was done in coordinate system of the robot. The LaserTracer position was then determined using LT software, also in robot coordinate system. The measuring lines were then generated and programmed in the same coordinate system.

Then all required lengths were measured according to methodology described in clause 3. For all measured lengths the E_0 parameter was determined. The results of calibration were presented at figure 3.

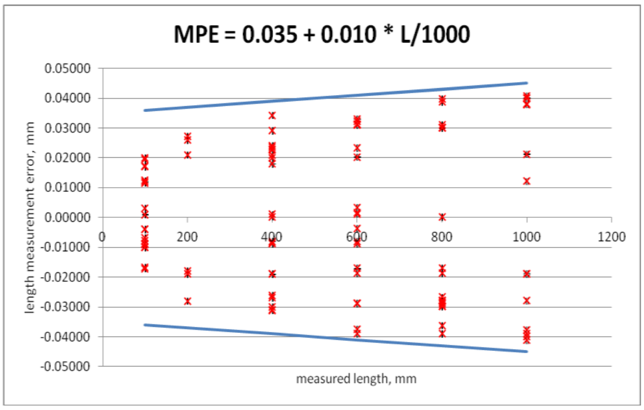

Fig. 3. Results of CMA calibration using methodology presented in this paper

5. CONCLUSION

Romer Omega CMA was calibrated by the producer six months before performing the works described in this paper. The maximum permissible errors given by the producer (determined by measuring gauge block which length was 500 mm) were stated as MPE = 0,042 mm. The MPE equation determined using presented methodology equaled MPE = 0,035 + 0,010*L/1000 mm, where L is measured length given in mm. So comparing the results of measurements done for length 500 mm the difference between producer results and presented method are equal to 0,002 mm. This proves correctness of presented method.

This method has its advantages and disadvantages. The biggest advantage is that it is not necessary to use long and uncomfortable in handling material standards, which can be difficult in use especially if their lengths are bigger than 1 m. The only length standard which might be used is standard, which length does not exceed 30 mm, and which is used to simulate the situation of bidirectional contact measurement (this test wasn't performed within this paper as presented experiments were done just to answer the question whether LT might be adapted to calibrate CMAs). Once developed algorithm of CMA calibration using LT can be used for almost all kinds and sizes of arms.

The biggest drawback of this method is necessity of using rare and expensive LaserTracer system combined with industrial robot. However, CMAs are mobile devices and they can be transported to the place in which they are calibrated. Laboratory of Coordinate Metrology at Cracow University of Technology, in which all presented measurements were done, is equipped with all necessary devices and can use presented method for CMAs calibration. The next tests will be performed and if they pass successfully the method can be used as a calibration procedure in accredited Laboratory of Coordinate Metrology.

ACKNOWLEDGEMENTS

Reported research were realized within confines of project financed by Polish National Centre for Research and Development No: 0869/R/T022010/10.

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