DETERMINATION OF COORDINATE MEASURING MACHINES ACCURACY CHANGES MADE BY DIFFERENT NODES DENSITY IN CAA MATRIX

Adam GĄSKA[1], Jerzy SŁADEK[1], Ksenia OSTROWSKA[1], Robert KUPIEC[1], Marcin KRAWCZYK[1],Wiktor HARMATYS [1], Piotr GĄSKA[1], Maciej GRUZA[1], Danuta SZEWCZYK[1], Renata KNAPIK[1], Artur KMITA[2]

1 Laboratory of Coordinate Metrology, Cracow University of Technology, Poland, agaska@mech.pk.edu.pl, sladek@mech.pk.edu.pl, kostrowska@mech.pk.edu.pl, rkupiec@mech.pk.edu.pl, mkrawczyk@mech.pk.edu.pl, wiktorharmatys@gmail.com, pjgaska@gmail.com, gruzam@interia.pl, danutaszewczyk1@wp.pl, re.knapik@gmail.com
2 Renishaw Sp. z o.o., Poland, Artur.Kmita@Renishaw.com

Abstract:

Advances in modern manufacturing techniques implies more efficient production but also new tasks for coordinate metrology and producers of Coordinate Measuring Machines (CMMs). Main aim here is accuracy improvement. The solutions used regarding CMM construction are easy and it is hard to improve it now. So accuracy improvement is done mainly using sophisticated mathematical algorithms that are responsible for correction of relevant errors. Different types of errors could be compensated, including: probe head errors, machine dynamics errors and most of all machines geometrical errors. Almost all coordinate measuring machines produced nowadays are equipped with geometrical errors compensation matrix known as CAA matrix (Computer Aided Accuracy).

CAA matrices are based on grid of reference points (nods) in which certain values of components of geometrical errors are experimentally determined. Values between this nodes are estimated using simple interpolation methods. Theoretically, the more dense is the grid on which CAA matrix is described, the better is the accuracy of the machine on which the matrix was used. On the other side, increased number of nods implies bigger costs of matrix determination connected with greater amount of time and workload.

This work presents experiments aiming in determination of CAA matrix using LaserTracer system done for different densities of matrix nodes. The relations between maximum permissible errors obtained on machine using matrices with different densities of nodes will be shown. Authors would also try to answer the question how to determine the most appropriate nodes density regarding the ratio of time spent for matrix creation and obtained accuracies.

Keywords: geometric compensation, CAA, geometric error, machine mapping, CMM

1. INTRODUCTION

One of the main components that affect the accuracy of the measurement are errors of the kinematic system of machine, on which the measurement were carried out. First models of kinematic errors for coordinate measuring machines (CMMs) were created and implemented in practice at 70' of last century [1], however first attempts of eliminating the machine tools geometric errors were made at the second half of XIX century [2,3]. Nowadays, in the era of costs minimization majority of measuring and machining devices are equipped with geometric errors software correction systems because it is more profitable to produce parts (which built kinematic system of machine) that are more distant from ideal geometry and then compensate geometric errors influenced by this faults than to produce expensive parts with very narrow shape and dimension tolerances.

There are few different models of CMM errors i.e. full rigid body, reduced rigid body which determines geometrical errors described by different number of geometrical components. More often models are supplemented with elastic errors of the machine. The most common model met in the coordinate metrology consists of 21 geometric error components, which includes translation, rotation and squareness errors. All of them were presented at figure 1.

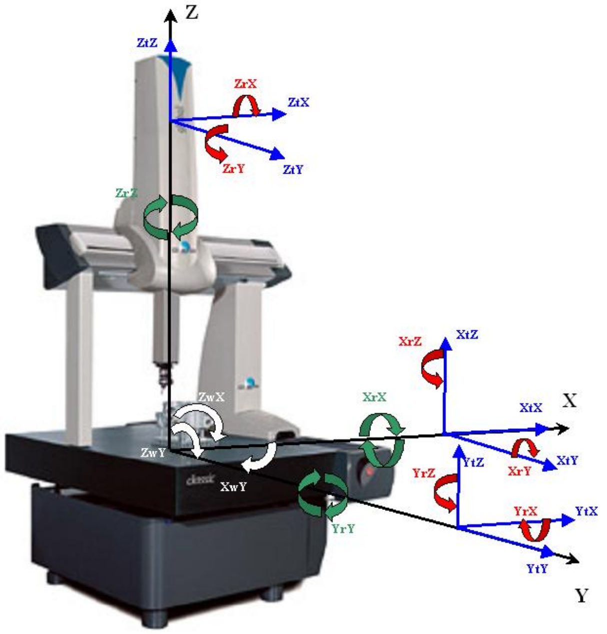

Fig.1: Geometric errors of CMM [4]

Errors presented in Fig. 1 significantly affect the indication error *e* of the measuring machine. Their impact can be written mathematically by well known equation (1) [5,6]:

$$e = k \cdot M \qquad (1)$$

where:

e - indication error of the machine
k - vector containing 21 geometric errors components,
M - weighted matrix which maps the impact of each element of the k vector on the x, y, z components of indication error.

This equation is a base for correction of geometric errors of CMM using CAA (Computer Aided Accuracy) matrix. The matrix is formed by measuring geometric errors in the evenly spaced reference points in measuring area of machine. After the data obtained during the machine tests is being uploaded to the controller, it is possible to correct on-line, particular errors at any point of the measuring volume using equation (1).

As it was mentioned above, machine errors are measured experimentally only in reference points. In order to make it possible to know the values of errors at any point of measuring area, the interpolation methods have to be used. Interpolation is just some kind of estimation of values that are between points in which certain values of function are known. Therefore, one of methods of CMM accuracy improvement is construction of CAA matrix, in which nodes are propagated more densely than in standard CMM (i.e. Fein-CAA used in UPMC machines). In this way it is possible to recognize experimentally values of errors which are usually obtained using interpolation. However, increase of the CAA nodes density causes longer time of CAA determination. Next chapters present changes of accuracy provoked by the different nodes density of CAA matrices and compare the time that was spent for their determination. It also shows differences between determination of CMM errors using different methods.

2. METHODS USED FOR GEOMETRICAL ERROR COMPENSATION

In this paper, geometrical errors were determined using two different methods. First one, classical method using laser interferometer and the second one, determination of errors using LaserTracer system.

2.1 Classical method of CMM geometric error determination (using laser interferometer)

Classical measurement of geometric errors of CMM involves using a laser interferometer. These devices are characterized by very good metrological features. Measurements carried out on these devices are performed at feed rates up to 1 m / s [7] with nanometer resolution. Single-frequency laser accommodates the electronics used for interpolation, increasing stability and counting interference fringes. The laser frequency is calibrated using a reference laser. Additionally due to the influence of environmental factors which affect on the operation of the laser [8], there are systems for compensating the wavelength depending on the conditions under which the tests are carried out, for example, temperature, pressure and humidity. With the use of laser interferometer the following components of CMM geometric errors can be determined: positioning errors of particular machine axes, perpendicularity of axes errors, straightness errors and rotation errors. For determination of each component special optical systems are needed. During researches, reference points are designated in which all measurable geometric error components are determined. Information about them is then sent to the machine controller, for example, in a tabular format. They include information about various errors for each machine axis and also about the applied measurement interval.

Fig. 2: Measurement of rotation errors using laser interferometer

The biggest drawback of this method is that it is impossible to determine all geometric errors using laser interferometer (for example rotation errors xrx, yry, zrz). Combination of following tools is also needed for determination of 21geometric errors: straightness standard, gauge blocks (or other length standards), electronic level, MCG (Machine Checking Gauge) or others.

2.2 Geometric error determination using LaserTracer system

Analyzing the literature from last few years [8,9], it could be noticed that the increasing interest is given to usage of laser tracking systems for determination of the geometric errors. These machines determine the coordinates of measuring point on the basis of distance from the retroreflector to interferometer, taking into account tracking system position angles, red from its angular encoders. The first attempts with tracking devices aiming in identification of geometric errors were made in the 70s of last century, but because of the low accuracy of trackers at the time, the results were not satisfactory. Now when some tracking systems are able to achieve uncertainties of length measurements less than 1 micron, it is possible to successfully determine the geometric errors using this devices. The idea of determination of the geometric errors is based on the Novel method described in [10]. The biggest difference is that instead of centers of reference elements at

2D standard, as a basis to the computation the coordinates of points, at which the retroreflector mounted on the CMM stopped during measuring sequence, are taken.

Application of LaserTracer (LT) for determination and correction of geometric errors of CMM is based on measuring the distance between a retroreflector mounted at the machine probe head (or instead of it) and the LaserTracer. With laser tracking mechanism LT follows the reflector while the machine moves along a predefined grid of points. LaserTracer works together with metrological software Trac-cal developed by Etalon company to facilitate experiment set-up (planning the mapped volume, setting the measuring path, establishing connections between devices) and processing the results. This software allows also to generate a geometric error correction matrix in a format suitable for machines produced by different manufacturers.

Described method needs to use multilateration technique as LaserTracer is able to measure only the distance (from itself to center of reflector) while determination of geometric errors requires knowledge of points coordinates in measuring volume of the machine. Multilateration is the method that uses only distance measurements from several different positions in order to determine the position of the localized object. This method was primarily used in GPS satellite navigation systems. It has also been used for many years in the so-called Internal GPS measurement systems to measure large objects, and more recently also used to correct the accuracy of the measuring machines and to create a coordinate measuring systems with a very large range.

3. PERFORMED MEASUREMENTS

All measurements presented in this paper were performed on Zeiss WMM850S machine which is placed in Laboratory of Coordinate Metrology at Cracow University of Technology (LCM). The measuring volume of this machine is about 1200\800\700 mm. Temperature during measurements was at the level of 19,7 ± 0,4 °C.

In the first phase the CAA matrix was created using classical laser interferometer (Fig. 2), straightness standard, two electronic levels and MCG. The nodes were placed evenly in all axes. The distance between two neighboring nodes measured along the axis was equal to approximately 40 mm. Total time of matrix determination equaled to about 16 hours.

The second phase consisted of CAA matrix determination using LaserTracer working with Trac-Cal software. Nodes were also placed evenly through whole measuring volume of machine. Distance between two neighboring nodes measured along the axis was again equal to approximately 40 mm. Measuring sequence was programmed in Trac-Cal software and repeated 7 times. 4 different positions of LT (Fig. 3) were applied and different offsets of reflector center to ram reference point were used (combination of them gives total amount of 7 repetitions of sequence). Total time of matrix determination equaled to about 8 hours in this case.

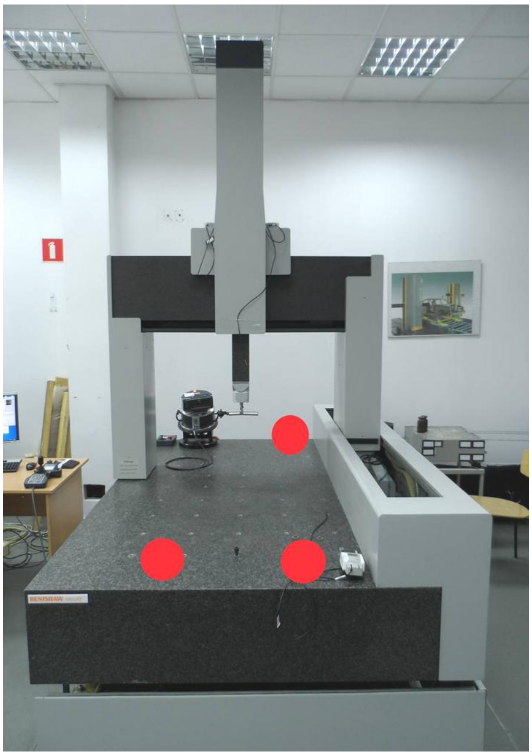

Fig. 3: LaserTracer positions during measuements

The last phase was similar to second one with this difference that the distance between two neighboring nodes was equal to approximately 100 mm. Total time of matrix determination equaled to about 5 hours in this case.

In each case, machine length measurement errors was checked using length standard, according to ISO 10360-2 [11].

Results of presented measurements are given in next clause.

4. COMPARISON OF OBTAINED RESULTS

Table 1 and figure 4 below presents the comparison of length measurement errors resulting from transferring into machine controller each of three mentioned matrices.

Table 1: Comparison of matrix determination time and effect on machine accuracy

Type of matrix	Time spent on determination	MPE of machine using this matrix
XL-80 40 mm	16 hours	2,5 + 3 * L\1000
LaserTracer 40 mm	8 hours	2,5 + 3 * L\1000
LaserTracer 100 mm	5 hours	2,5 + 4 * L\1000

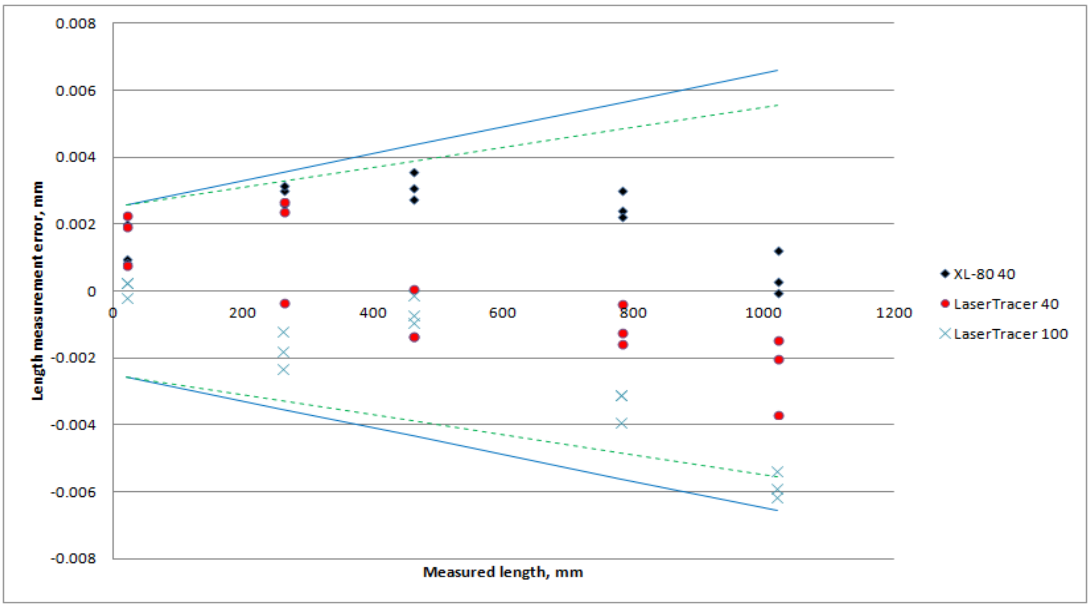

Fig. 4: Comparison of CMM accuracy depending on CAA matrix used, blue solid line indicates MPE_E = 2,5 + 3 * L\1000 while the broken green line indicates MPE_E = 2,5 + 4 * L\1000, where L is measured length given in mm.

5. CONCLUSION

Results presented in this paper shows that there are only little differences (less than 1µm per meter) in machine accuracy resulting from using CAA matrices with 40 mm and 100 mm distance between neighboring reference points. The time of determination of the more dense matrix is almost two times bigger than for the less dense one. So in this case the matrix with nodes distance equal to 100 mm could be preferable. However, this situation will probably not happen for all kind of machines. Zeiss WMM850S is the machine which has high natural accuracy, and solid kinematic construction based on granite. For other machines, the variability of geometric errors could be much bigger and the differences in machine accuracy resulting from different nodes density in CAA matrix also could be bigger.

The tests aiming in determination whether decreasing of distance between neighboring nodes below 40 mm would increase machine accuracy are conducted now at LCM. Authors suppose that it is possible providing stable ambient conditions in laboratory.

The differences between machine accuracies using matrices with 40 mm step but obtained using different methods are insignificant. So the LT advantage over classical method should be noted. In case of LT usage, the time of CAA determination is drastically lower and only one device is used for determination of all machine errors. However, there are still fields in which the standard laser interferometer shows its advantage. This situation happens for example during compensation of high-accuracy machines.

ACKNOWLEDGEMENTS

Reported research were realized within confines of project financed by Polish National Centre for Research and Development No: LIDER/06/117/L-3/11/NCBR/2012.

REFERENCES

[1] Hocken R., Simpson J., Borchardt B., Lazar J., Stein P.: Three dimensional metrology, Annals of the CIRP 26 1977 403-408.
[2] Sartori S., Zhang G.X.: Geometric Error Measurement and Compensation of Machines, Annals of the CIRP 44 (2) 1995.
[3] Evans, C.J.: Precision Engineering: an evolutionary view, Cranfield Press, Cranfield, UK 1989.
[4] Sładek J., Gawlik K.: Accuracy of coordinate measurements. Cracow University of Technology 2011 495 pages.
[5] Jakubiec W., Malinowski J.: Metrologia wielkości geometrycznych, WNT, Warsaw 2004.
[6] Trapet E., Hegelman R., Wäldele F.: Coordinate Metrology. PTB-Bericht F-11, Braunschweig, II 1992.
[7] Gawlik J., Kowalski M., Ryniewicz A.: Analysis of Measurement of Precision Machines Guides. 4th International Conference on Ultraprecision in Manufacturing Engineering. „Progress in Precision Engineering and Nanotechnology", Braunschweig, Germany 1 1997 319-322.
[8] Schwenke H,. Knapp W,. Haitjema H,. Weckenmann A., Schmitt R., Delbressine F. - Geometric error measurement and compensation of machines—An update, , CIRP Annals 57 (2) 2008 660–675.
[9] Balsamo A., Pedone P., Ricci E., Verdi M.: Low-cost interferometric compensation of geometrical errors; CIRP Annals - Manufacturing Technology 58 (1) 2009 459-462.
[10] Trapet E., Franke M., Hartig F., Schwenke H., Wadele F., Cox M., Forbers A., Delbressine F., Schnellkens P., Trenk M., Meyer H., Morltz G., Guth Th., Wanner N.: Traceability of coordinate measuring machines according to the method of the Virtual Measuring Machines.PTB- F-35 , Braunschweig Germany, 1999.
[11] ISO 10360-2:2009 - Geometrical product specifications (GPS) - Acceptance and reverification tests for coordinate measuring machines (CMM) - Part 2: CMMs used for measuring linear dimensions.

Registration via Web site	https://www.conftool.com/ismqc_2013/
Contact Address	kstepien@tu.kielce.pl