

DETERMINATION OF TEMPERATURE IMPACT ON CMM RESIDUAL KINEMATIC ERRORS DISTRIBUTION

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ABSTRACT

In case of coordinate machines that use CAA correction matrix, the issue of kinematic errors analysis may be based on the determination of residual error distribution. Temperature changes have an impact on CMM kinematic structure, which may cause the differences in the map of residual errors. As for today, the residual errors were analysed only for the reference temperature. No research was undertaken on the residual errors changes depending on the temperature variations. This paper presents the experiment aimed at residual errors analysis and resulting errors distributions for different temperatures.

Keywords: residual errors, CMM correction.

INTRODUCTION

Today, in the era of continuous development of technology and industry, it becomes even more important to ensure adequate quality of manufactured products. This task is entrusted to Coordinate Metrology which is an essential tool for quality control in modern companies. The biggest advantage of Coordinate Measuring Technique (CMT) is probably its versatility. Since information about the measured object geometrical features are obtained by determining coordinates of points on the object's surface, one device can be used for many measurement tasks. The main tool of CMT is Coordinate Measuring Machine (CMM). In the CMMs the kinematic pairs can shift in mutually perpendicular directions, which determine the Cartesian axes x , y , z and defining the machine basic coordinate system. Thanks to utilization of different types of probing systems, measurements with CMMs may be automated. The unquestionable advantage of CMMs is their high accuracy and repeatability. The most precise machines offer accuracy up to tenths of a micron, and the works on machines that would be capable of measuring in nanometres are in progress.

However, the problem of CMMs accuracy is still important, especially evaluation of measurement uncertainty. Existing methods of uncertainty estimation recommended for CMMs are costly, especially due to necessity of multiple repetitions of measurements and the cost of required standards. Moreover, these methods require the personnel with certain knowledge and skills of percipient analysis of the results. Simulation methods of uncertainty estimation are different approach to the problem. Their functioning is most often connected with the development of the so-called virtual machines, which are responsible for multiple simulation of measuring task. Simulation methods have proved to be an interesting solution, but they are used almost exclusively in the laboratories of the best metrological research centres [1, 2]. This fact is caused by a number of factors, however, the most important ones are: duration of the tests which proceed the preparation of virtual machine for a specific CMM model, and the variability of the conditions in which the machine is working. The models developed so far assume machine functioning at reference conditions (temperature of 20°C). Deviations from this temperature may cause changes in the geometric parameters, espe-

cially those expressing the length which in turn leads to the variability of the CMM kinematic errors. Currently, at the Laboratory of Coordinate Metrology (LCM) the research are undertaken on the virtual machine which would take into consideration both of mentioned arguments. Developed at LCM virtual machine consists of two main modules: one responsible for machines kinematics modelling and one devoted to probing systems functioning. Distribution of residual errors is a basis for module responsible for kinematic errors modelling, it can be also used in determination of the optimal position of measured object in the machine measuring volume [3]. The paper describes the experiment that involved determination of residual errors distribution in different temperatures, in order to check the influence of temperature variability on kinematic errors. The obtained results as well as conclusions are also presented in the paper.

THE ERRORS RELATED TO CMM KINEMATICS

Machine's kinematic errors are one of the main factors affecting the accuracy of any CMM. CMM kinematic errors were the subject of a number of studies [4, 5] which resulted in the development of models of machine errors, for example full rigid body or reduced rigid body models. The most commonly used description of CMM geometrical errors include 21 components:

- positioning errors for each machine axis – xtx , yty , ztz ;
- errors of mutual perpendicularity – xwy , xwz , ywz ;
- translation errors – xty , xtz , ytx , ytz , ztx , zty ;
- rotation errors – xry , xrz , yrx , yrz , zrx , zry , xrx , yry , zrz .

The geometrical errors defined in such a manner are a basis for operation of CAA (Computed Aided Accuracy) Matrix. The matrix itself as well as the methods of its determination are further described in [6]. The usage of this matrix has become a common practice, because it allows to correct most of the errors components associated with the machine kinematic. The Figure 1 shows the values of individual components before (red bars) and after (green bars) the CAA matrix was used.

As it can be seen, some errors were almost completely corrected. The remaining errors include both random errors and systematic errors that cannot be corrected or their correction would be unviable, namely residual errors. Since most of the currently used machines, utilize CAA correction system, the issue of CMM kinematic error analysis can be transferred to the analysis of residual errors. However, because the residual errors take into account the random errors components, they should be expressed rather by the probability distribution than certain values of error.

The residual errors distribution can be expressed by assigning the standard deviations of points coordinate reproduction to chosen reference points in measuring volume of machine. The standard deviations represent the probability of reference point reproduction. The exemplary distribution of residual points is presented in Figure 2. The red arrows represent the standard deviation in scale 100000:1. All values are given in [mm].

EXPERIMENT AND RESULTS

The distribution of residual errors is a basis for operation of one of the modules of virtual machine which is responsible for the kinematic errors modelling. Special methodology for residual errors determination was prepared at LCM for

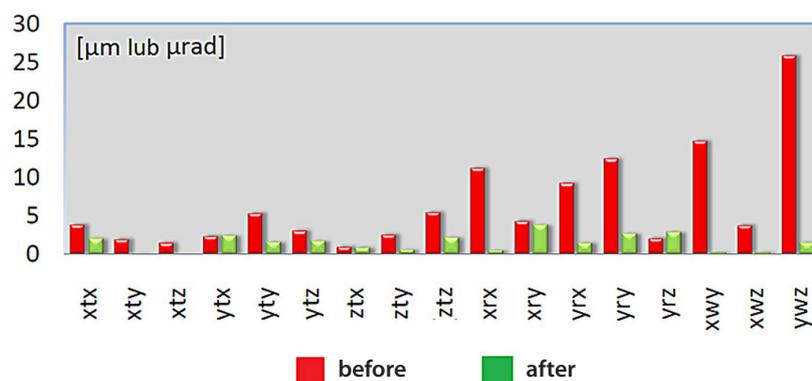


Fig. 1. The geometrical errors before and after applying the CAA correction

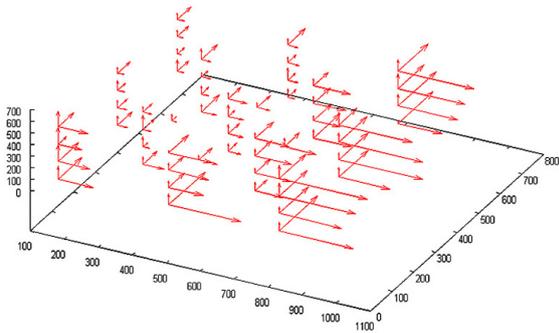


Fig. 2. The example of distribution of residual errors distribution

the purpose of the developed virtual machine [7]. Residual errors are determined in chosen points which defines the reference grid. The required measurements are taken using LaserTracer system which uncertainty for spatial measurements can be expressed by the following equation: $U = 0,2 \pm 0,3 \cdot L/1000 \mu\text{m}$. LaserTracer is a part of laser tracking devices family. It measures the distance to the target (retroreflector) whose movements it follows. During measurements retroreflector is mounted on the machine in the place of probe head. LaserTracer as a more accurate device is used in order to check if machine indicate a correct coordinates of a reference point. The machine is programmed in such a way that retroreflector approach to each node of reference grid from several directions (14 approach direction for each point) and then moves to the another grid

node. As the LaserTracer is able to measure only length, the multilateration method need to be used to determine the coordinate values. That means that the whole measuring sequence should be repeated at least four times, each time placing the Laser Tracer in different position in CMM measuring volume. During all required measurements the CAA matrix installed on the machine have to be active. The described methodology was used to determine the residual errors distribution in different temperatures.

Measurements described in this paper were performed on the Zeiss WMM850S machine, located in the LCM at the Cracow University of Technology. This machine has a moving bridge, and it is characterized by measuring volume of 800\1200\700 mm. It is placed in the air-conditioned room, which allows temperature control. The three following temperatures for residual errors determination were chosen: $20 \pm 0,2 \text{ }^\circ\text{C}$; $21 \pm 0,2 \text{ }^\circ\text{C}$ and $22 \pm 0,2 \text{ }^\circ\text{C}$. The ambient conditions during all measurements were monitored using temperature sensors which were mounted in measuring volume of the machine and close to the scales corresponding to each axis. The readings from sensors indicate that the temperature during the test was within the specified range. The residual errors were determined in 36 reference points distributed evenly in measuring volume of the machine. The grid nodes nominal coordinates are presented in Table 1.

Table 1. The grid of reference points

Point number	x [mm]	y [mm]	z [mm]	Point number	x [mm]	y [mm]	z [mm]
1	180	242	64	19	180	242	338
2	180	627	64	20	180	627	338
3	180	1012	64	21	180	1012	338
4	440	242	64	22	440	242	338
5	440	627	64	23	440	627	338
6	440	1012	64	24	440	1012	338
7	700	242	64	25	700	242	338
8	700	627	64	26	700	627	338
9	700	1012	64	27	700	1012	338
10	180	242	201	28	180	242	475
11	180	627	201	29	180	627	475
12	180	1012	201	30	180	1012	475
13	440	242	201	31	440	242	475
14	440	627	201	32	440	627	475
15	440	1012	201	33	440	1012	475
16	700	242	201	34	700	242	475
17	700	627	201	35	700	627	475
18	700	1012	201	36	700	1012	475

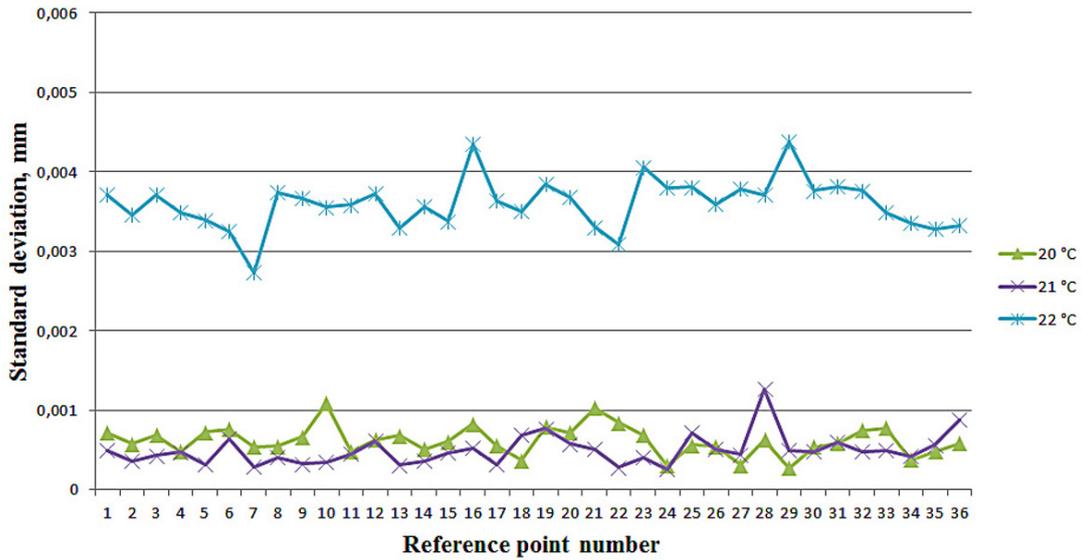


Fig. 3. Standard deviation of point reproduction in x-axis, for different temperatures

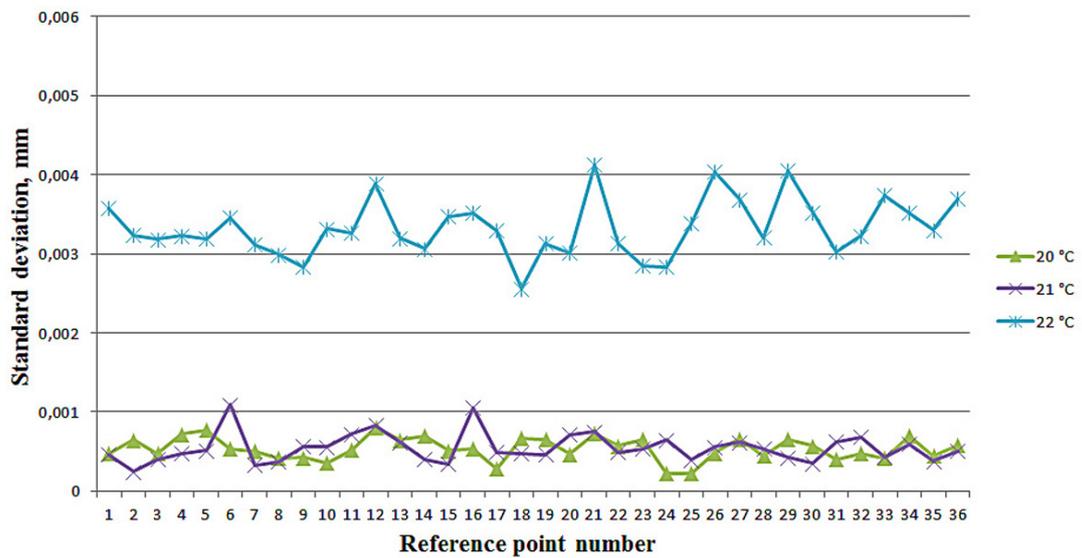


Fig. 4. Standard deviation of point reproduction in y-axis, for different temperatures

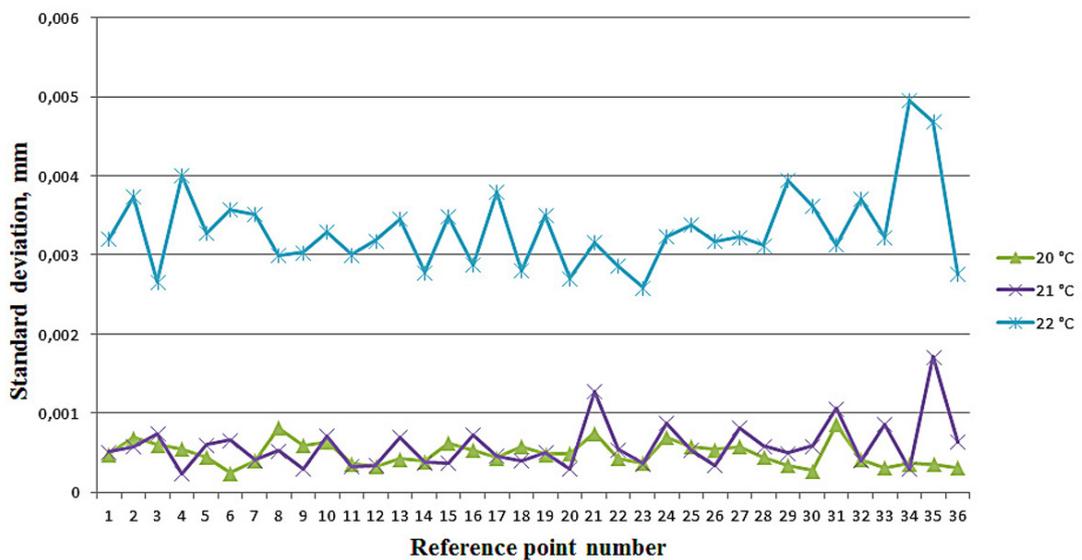


Fig. 5. Standard deviation of point reproduction in z-axis, for different temperatures

The obtained results are presented in Figures 3–5 which show the standard deviation of each point reproduction respectively in x , y and z axis for all three examined temperatures. Point numbers correspond to the numeration from Table 1.

CONCLUSIONS

The obtained results indicate that changes in the temperature noticeably affects the residual errors derived from machine kinematics. The results obtained for the $22 \pm 0,2$ °C are characterized by not only the biggest values, but also the highest variability, which reaches two micrometers. Also the results obtained for $21 \pm 0,2$ °C, show the considerable volatility. The temperatures bigger than 22 °C are rarely met in measuring rooms even in industrial conditions so studies at higher temperatures are unnecessary. The further research need to be undertaken in order to verify if the similar results would be obtained also for the temperatures lower than reference temperature of 20 °C, what appears to be likely. If these suppositions are confirmed, it will mean that Virtual machines that could be successfully implemented in the industry should take into consideration thermal influences. In case of virtual machine developed at LCM that means that residual errors distribution (which is a base for a module that simulates the CMM kinematic errors) should be determined for different temperatures. The number of temperatures in which tests ought to be performed should be chosen on the basis of experience of measuring personnel which work with a specified CMM model.

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