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# ON-LINE ESTIMATION OF THE COORDINATE MEASUREMENTS ACCURACY IN LABORATORY AND INDUSTRIAL CONDITIONS

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**Abstract:** According to technological requirements, measurements are useful only when they are stated with their accuracy. Due to this fact, the importance is given to the possibility of determining the accuracy of measurement. Currently used methods for the measurements accuracy estimation are difficult to implement and time consuming, and because of it, the issue of accuracy estimation is often underestimated, especially in industrial conditions. Method presented in this paper is an on-line accuracy estimation method based on virtual CMM idea. The prevalence of this method can help to improve this situation, and thus reduce the amount of erroneous assessments of compliance of the products with their geometrical specification.

**Keywords:** virtual CMM, measurement accuracy, uncertainty.

## 1. INTRODUCTION

Assessing of dimensional compliance with geometrical product specification (GPS) is becoming crucial task for the production engineering. The risk of wrong decisions carry consequences that are observed as a wave of product complaints in main branches of industry. Due to this fact, it is important to have a possibility of precise determination of the accuracy of measurement, because results of measurements are useful only when they are given with their accuracy. In the case of coordinate measuring techniques (CMT) the task of accuracy estimation is particularly difficult and not always straightforward [1,2,3]. Therefore, users of this technique, as well as manufacturers of these measuring systems often overlook the problem of measurement accuracy giving in exchange the accuracy of measuring devices. This accuracy, is given then, as the maximum permissible error (MPE). Thus defined, it is significantly different from the accuracy of the real measuring task, and may lead to bad decisions in the determination of compliance with the specifications of the product [2,4-9]. What is more, considering each measuring task as a measurement of distance (this happens when the MPE is used instead of real task-specific accuracy) is not consistent with the coordinate measuring technique nature, which is the measurement of values of coordinates of measuring point.

It is therefore essential, to implement new, correct and metrologically validated methods. Currently used, are difficult, require knowledge and experience in the field of measurement and are hugely time consuming [10,11]. It cause, that they are used only in the best laboratories. In recent years, the new methods called simulative methods were presented [10,12-21]. In practice, these methods require development of so-called virtual measuring machines used to assess on-line accuracy of measurement. These methods are as far the most accurate as they are based on reproducibility of measuring point idea and because of it, they are consistent with coordinate measuring technique nature. Two main concepts could be pointed out here: identification of sources of CMM errors (including kinematic errors) and errors of the probe head (as example of this methods PTB Novel method can be taken [22,23]) and the second one – so called Matrix Method (MM), created at Cracow University of Technology and based on identification of errors at selected reference points in machine measuring area and construction of CMM model using different interpolation methods (for example artificial neural networks [20]). Both concepts are continually developed. MM is also implemented on large scale machines, here, a possibility of usage of LaserTracer (LT) and LaserTracker for the construction of reference points grid was noticed. The experiments with using laser tracking systems and numerical Monte Carlo method (MCM) has lead to development of new accuracy estimation system [24]. It can be used both in laboratory and industrial conditions. The main assumptions of created model were presented in next clause.

## 2. ASSUMPTIONS OF CREATED MODEL

At first, it is important that nowadays, in the typical measuring machines the systematic errors are compensated for the kinematic system of CMM through use of CAA (Computer Aided Accuracy) correction matrix, for probe head - an example of dynamic error correction matrix could be given, as well as for components originating from the environmental influences exemplified by the temperature correction (e.g. ACTIV). Therefore, authors decided to transfer the problem of modeling of accuracy of the CMM to the field of residual errors that remain uncompensated.

Given the above facts, it is assumed that the presented simulative model is developed for modern metrological systems, equipped with a full, active error compensation (so it is designed for about 90 % of total amount of CMMs).

The described model of CMM consists of two basic modules:

- module that simulates the residual and random errors dependent on kinematic system of CMM,
- module that simulates the workings of the probe head.

The first module of CMM model is built by describing each point on the grid of reference points with the probability distribution (*t* distribution in case of this model) with which it is reproduced on a machine. Currently, only LaserTracer (LT) meets the requirements concerning the accuracy that allows to do so. This is why it was used (combined with the multilateration technique) for experimental determination of distribution of errors in reference points (fig. 1).

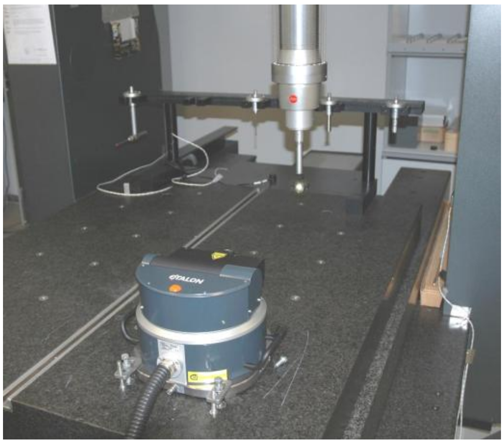

Fig. 1. Cooperation between CMM and LaserTracer aiming in description of CMM volume by reference points grid

The second module forming part of the described measuring virtual machine is a module responsible for the simulation of probe head of CMM. To describe this system Probe Errors Function (PEF) described in [20] has been used. The module gets the values of the individual errors of the PEF through Monte Carlo simulations.

Data used to build this module was collected by multiple measurement of spherical standard (fig. 2). Standard was measured each time in 163 points that create the reference grid for values of PEF. Proper operation of the model is provided by using a spherical standard of suitably small form errors (its diameter should be smaller than 30 mm).

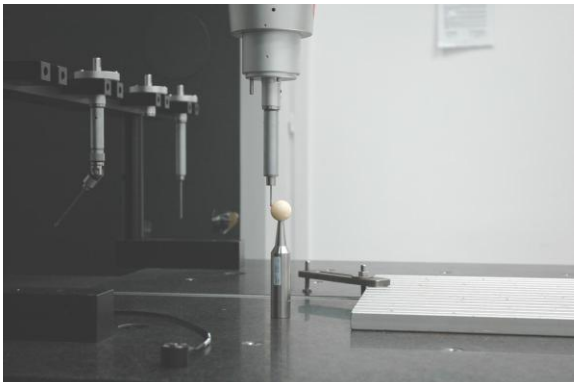

Fig. 2. Measurements of spherical standard performed on Leitz PMM 12106 machine equipped with Leitz measuring probe head

In both modules there is a problem of interpolating values of errors between nods of reference grid. It is obvious that in real measurements majority of measuring points would lay between nods of reference grid. In order to get the variability of errors in this points, authors used different interpolation methods. In case of kinematic system errors the b-spline and “nearest-neighbor” interpolation methods were used, while in case of probe head errors interpolation, the bilinear interpolation was used. More detailed description of presented model can be found in [24,25]

Correctness of described model was proved in Laboratory of Coordinate Metrology in laboratory conditions, where all requirements of its correct use concerning the temperature stability and the proper operation of the geometric and temperature compensation systems were met. It is commonly known that in industrial conditions there is also the aspiration to meet all these requirements, however, due to interference caused by manufacturing or assembly processes it is not always fully possible. This is why, there is a need to check the correctness of described model in industrial conditions, where it is intended to be used. The considerations concerning industrial implementation of this model were also presented in this paper.

## 3. INNOVATION OF DESCRIBED ON-LINE ACCURACY ESTIMATION SYSTEM

Modern CAA systems allow a comprehensive accuracy correction and calibration of the CMM, this is why it was important to undertake research on the modeling of residual and random error, because they primarily affect the accuracy of the measurements carried out on modern coordinate systems. Virtual measuring machines models previously used focused on modeling both systematic and random errors, and because of it, their application requires usage of expensive standards and additional software. In addition, the implementation of such a model is much longer than of that described in this paper. So creation of presented here accuracy estimation system is not only the original solution but also a solution designating new area of research in metrology.

To implement the described method, an unique measuring system called LaserTracer is needed. Described model is the first simulative accuracy estimation model that use the innovative achievement of laser technology - the LaserTracer. Thanks to its application, process of implementation of virtual machine model, both in industrial and laboratory conditions, becomes extremely fast and convenient. Besides, the developed method, meets the expectations of industry, which needs an effective method of on-line accuracy estimation of performed measurement.

Additionally, despite the numerous advantages of method described in the previous chapters and its comfortable use, such solutions are practically unknown in the industry (they are usually used in leading calibration laboratories, mainly in Germany). Blocking factor of the implementation of virtual models proposed by a few companies could be a high price of this service. The model proposed in this paper requires far less labor, so the price of its implementation will be much lower. The above factors may affect the prevalence of the model in industry, making the issue of reporting of measurement results with the corresponding uncertainties (which, as shown in the first chapter, is a key issue not only in metrology but also in the whole production engineering) can finally be properly solved.

## 4. RESULTS OF VALIDATION MEASUREMENTS PERFORMED IN LABORATORY CONDITIONS

Verification of the model consisted of two stages. In the first one, developed model was tested according to VDI/VDE guidelines [12]. The second stage consisted of performing the common metrological tasks such as measurements of: the point-to-point distance, the plane-to-plane distance, the diameter of the sphere, the form error of the sphere and the distance between the centers of two spheres. Then, for each measurement the standard uncertainty was determined according to the methodology used in the classical methods of determining the accuracy of measurements. The uncertainty determined in the classical way was compared with the uncertainty obtained by the developed simulative model.

All tests were performed in Laboratory of Coordinate Metrology at Cracow University of Technology, which is a laboratory accredited according to ISO 17025 standard. Measurements were done at Leitz PMM 12106 measuring machine. All of performed tests proved correct functioning of presented model. As an example, the results of measurements of diameter of sphere (fig. 3) were presented in Table 1.

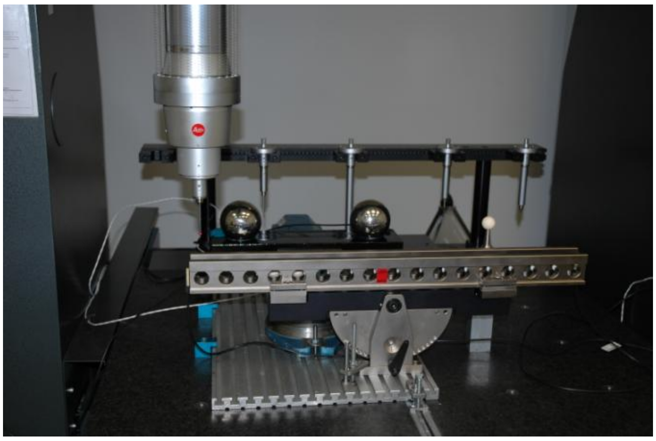

Fig. 3. Measurements of sphere diameter

Table 1. Results of measurements of sphere diameter.

| | Diameter, mm | Standard uncertainty, mm |
|---|---|---|
| Multiple measurement/ uncertainty according to multiple measurement method | 79.9989 | 0.0008 |
| Single measurement/ uncertainty using created model | 79.9985 | 0.0006 |

Results of all performed verification tests can be found in [25].

## 5. PLAN OF INDUSTRIAL IMPLEMENTATION

The main stages of adaptation of created model in industrial conditions includes:

- development of test procedure concerning the implementation of the simulation model for accuracy estimation for machine working in industrial conditions.
  The main challenge is to create a research methodology for different temperature ranges in which the machine is used. The model presented in earlier chapters assumes correction of systematic errors of the kinematic system of machine. This correction is performed on coordinate measuring machines by using of CAA correction matrix. These matrices work well in some temperature range. When the temperature changes, only some of geometrical errors (i.e. position) are corrected considering this thermal influence. This is why, with the change of temperature, the residual errors of the measuring machine could also change. Therefore, a possible option for providing correct functioning of the model in industrial conditions is to determine the field of variation of residual errors for few intervals of the temperature range in which machine operates.
- research on determining the distribution of residual errors made with use of CMM and validation of developed test procedure.
  It is planned to carry out the test cycle mainly for variable temperature, which affects the coordinate measurement in large scale. It is planned to verify the correctness of the model in the temperature range from 18 to 22 ° C. Larger deviations from the reference temperature of 20 ° C are rather unusual in industrial laboratories.
- development of an uniform methodology for the description of the CMM measuring volume for all types of machines and the analysis and determination of dependence of the number of reference points in CMM volume on the accuracy of the measuring machine and the size of it, and the analysis and determination of dependence of the number of pairs of angles of probe pin deflection on the probe head type.
  In these stages it is planned to determine the optimal number of points on which the measuring volume of the machine will be described and the number of pairs of angles of deflection of the probe pin, on which the probe head errors will be described, in this way that the faithfulness of representation of the accuracy of the measurements is kept while the process of collecting the required data is the shortest one. Number of points will depend on the accuracy of the measuring machine and the size of the measuring volume. Number of pairs of angles of deflection of the probe pin will depend on the type of probe head used on the machine and its accuracy.
- development of the software that supports presented virtual model.

As a part of this phase the following tasks will be completed: development of the concept of software that supports the simulative accuracy estimation model, development of a graphical user interface for this software, development of the communication interface between the software and the machine controller, development of a software module responsible for the selection of the matrix of residual error distribution depending on the temperature, and adjusting the software to work with CMM.

– verification tests on CMM in Cracow University of Technology (CUT).

After development of a complete methodology of implementation of presented model and creation of software that supports it, verification tests will be performed on the measuring machine that is commonly used in industrial purposes and will be mounted for tests in CUT. This tests are designed to demonstrate the correctness of the earlier findings and helping to prepare for the commercialization of the system and the software.

– installation and verification of the system of accuracy estimation on at least one measuring machine used in industrial conditions.
– popularization of created method.

## 6. CONCLUSION

The model presented in this work is less labor-intensive than models based on the modeling of individual components of the systematic errors of measuring equipment. Thanks to this, it can be easily implemented in industrial or laboratory use.

The data necessary to build the described model, thanks to LaserTracer and combined with effective working plan can be collected even in a single day. That rapid process of a model creation for certain machine can contribute to the increase of popularity of developed method, which models measurements in the manner most similar to the nature of coordinate measurements.

Virtual model of CMM based on the modeling of residual errors with the use of LaserTracer system and multilateration methods allows for the construction of an on-line virtual machine, which combined with a typical metrological software enables determination of the uncertainty of modeled measurement in the quasi-real time. This is the most effective method from known methods of uncertainty estimation.

As a potential recipients of presented model, all industrial plants using coordinate systems should be treated. The issue of reporting of the measurement results with the corresponding uncertainty, as already demonstrated in the first chapter, is a fundamental issue in the field of metrology and widely understood quality control. This case, until now, due to the complex methodology of determination of uncertainty and its huge time-consuming rate, is underestimated in most companies. The prevalence of the described method can help to improve this situation, and thus minimize the amount of erroneous assessments of compliance of the products with their geometrical specification.

It should be also noticed, that there is a possibility of system implementation in a single day. It is the only model of a virtual measuring machine, which can be implemented in such a short time. This feature also predisposes it to be used on a large scale in the industry.

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