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MODELING AND ASSESSMENT OF LARGE CMMs' ACCURACY

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Abstract: In this paper presented is the research on developing of a model of CMM based on application of artificial neural networks. The work focused on developing a conception of large CMMs' errors. Described here is the large CMMs' error identification method that utilises standard plate and laser interferometer, and presented are the possibilities of its application for development of measurement machine model. So developed method enables to carry out assessment of large CMMs' accuracy, while related to it a CMM model is being utilised for the realised measurements' accuracy assessment.
Keywords: Large CMM, artificial neural network, virtual CMM, accuracy

1. INTRODUCTION

In spite of the long-time research, in cases of application of the coordinate measurement machines (CMMs), assessment of the realised measurement tasks' accuracy remains still the key problem. With this topic connected is also the necessity to identify accuracy of CMM itself. The existing conception of the CMM's' accuracy assessment, that is a fundament of the standards and guidelines being published, has been derived from the testing procedure based on length measuring. But one should point out that realisation of length measuring is only one out of the tasks executed with CMM, and not particularly representative to this technique. Also while analysing - from a theoretical aspect - the process of measurement realisation with CMM, one should point out that the most primary task is to determine a coordinate of the measuring point. This is the only task being exercised as direct measurement, while the other tasks are the indirect measurements, in the metrological aspect. Therefore a conception of definition and assessment of accuracy of the machine itself - as a measuring tool, and as further implication, the accuracy of so realised measurement, should be based on a method of the accuracy assessment of a point determination within the CMM measurement space. Taking the above assumption as the basis, in the Cracow University of Technology [2, 3] developed was the original conception of CMM's accuracy identification as error matrix determination for the defined network of reference points contained within the test area, with taking into consideration the errors of contact head. From the metrological aspect, such matrix may characterise the tested CMM much better and more precise than a definition being presently in use, grounded on determination of boundary values of error for length measuring. It also becomes a good basis for developing the CMM-measurement accuracy assessment system. Such system has been realised for the machines of small and medium measurement range, with utilisation of a standard ball plate. The paper presents continuation of the research with respect to large machines. The importance of this task is therefore the greater, because issues of large CMMs accuracy assessment have not been ultimately resolved so far [1].

2. VECTORIAL CHARACTER OF THE MACHINE ERROR

Generally, there are two possible approaches to the issue of coordinate machine's error determination.
The analytical one shall be to determine all possible components that participate in the machine error, while the other approach is synthetic, where an error is treated as a whole. The latter approach was applied to describe vectorial character of the coordinate machine's error. Such error is being described with a vector of difference between an actual radius-vector $\bar{P}_a$ (actual) and a given $\bar{P}_n$ (nominal). Vector $\bar{P}_e$ from a metrological point of view shall characterise the CMM's accuracy at a particular point.

$$\bar{P}_e = \bar{P}_a - \bar{P}_n \tag{1}$$

In this $\bar{P}_e$ vector possible is to distinct two components: one dependant of its position and the other independent. Thus, the $\bar{P}_e$ vector equation can be expressed in the following form:

$$\bar{P}_e = \bar{P}_m + \bar{P}_h \tag{2}$$

where: $\bar{P}_m$ is a component dependent of the machine's position, while $\bar{P}_h$ is an independent one. In case of a coordinate measurement machine, responsible for the dependent error $\bar{P}_m$ are components connected with the machine's geometry and kinematics (21 errors) as well as with the configuration of dislocations. The error independent of the machine's position $\bar{P}_h$ is a result of impact which has a measurement head, with the particular probe, on this measurement.
The idea of an error's vectorial character is presented in Figure 1

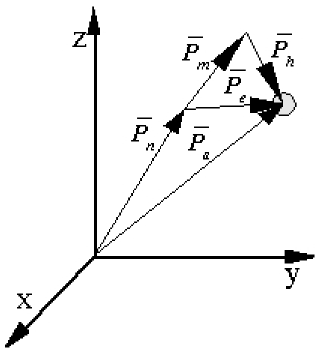

Fig. 1. Vectorial character of the error

3. MATRIX METHOD OF THE CMM ACCURACY IDENTIFICATION

The matrix method of a CMM accuracy identification described in [3-5] has been developed on a basis of the above-presented error model. This method enables to determine a CMM uncertainty as the maximum difference between the assumed point and the measured one.

Errors dependent of the machine's position and the independent ones (various configurations of the head) are determined separately in this case and only set out together in the conclusion that enables to determine a single coefficient for the assessment.

The machine error is being determined with a standard. The role of assumed points is here played by coordinates of the standard's reference elements (sphere, inner spherical cap). Those elements should create a kind of reference net that enable to obtain the relevant information regarding the tested machine. Since the 3-dimensional models cannot meet such requirement, for the purpose of testing applied was a plate standard. With its help created was a net obtained by metering of a standard in several positions parallel to the main plane of the CMM measuring space – XY, YZ, XZ (**Fig.2.a, b, c**).

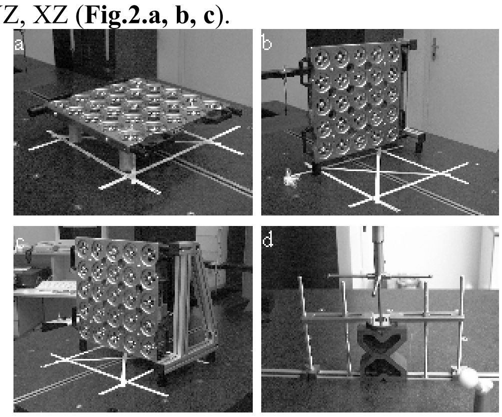

Fig. 2. Sequence of a plate positions assumed for determination of the reference grid: situation a) XY, b) YZ c) YZ in the consecutive position d) determination of FBG for the head.

Thus, in case of position parallel to plane XY, there is a possibility to transform relationship (1) into the following one:

$$[P_{eXY}(i)] = [P_{aXY}(i)] - [P_{nXY}(i)] \quad (3)$$

where: $[P_{eXY}(i)]$ is a matrix of deviation vectors between the matrix of results obtained from measurements of plate $[P_{nXY}]$ and the matrix of points the calibrated standard $[P_{nXY}(i)]$.centre. Parameter (i) means the consecutive positions of a plate parallel to plane XY.

By setting out the maximum values from measurement done in planes XY, YZ, ZX one can eventually obtain the uncertainty $U_m = \max Up_{pl}$ where the reference pl means one of the main planes.

As has been mentioned earlier, the uncertainty component independent of the machine position is understood as uncertainty of a head. This uncertainty is being determined with the help of two-dimensional standard i.e. in this event – a standard ring (**Fig. 2d**).

The head error function formulated in this case is being described in polar system and determined separately for each particular probe. And similarly in this case as the assessment of this component considered is a maximum deviation between the measured point vector and a radius of the determined circle. This uncertainty should be determined for each probe participating in measurements.

Finally, the uncertainty equation assumed the following form:

$$U_{MM} = U_h + U_m$$

and is presented eventually as:

$$M = A + B(l) \quad (4)$$

where parameter (l) means only information on the size of created reference grid, and for this particular case it is a face of cubicle described upon the reference grid built of reference elements. One can understand this uncertainty as the maximum allowed deviation between the measured point and nominal point in the metered measurement space.

4. WIRTUAL STANDARD BASED ON THE MATRIX METHOD

One of the methods being applied for the purpose of CMM measurement uncertainty with regard to the specific tasks is a method based on the virtual model of uncertainty [4-8,10]. This solution proved to be the more and more frequently approach in the industry circumstances, thanks to its low time consumption and simplicity of application. The relevant modules one can find in the most advanced metrological software controlling CMM.

The principle of the above method shall be creation of an appropriate mathematical model of a machine; such model may then serve a purpose of computer simulation of the machine behaviour, in the events of specific measurement tasks. In the nineties of the last century in PTB was developed one of the earliest programs of this kind [6,7]. Also at the same time a similar model was created in the Cracow University of Technology, described in [5]. Both models base on the previously determined CMM errors.

The measurement uncertainties were in those cases values estimated separately for each out of 21 errors. This method requires form its user the extensive knowledge on the specific impact of a particular machine error on measurement, which in the industrial circumstances is practically hardly ever possible to achieve.

In a matrix method the mathematical model was based on reference grid of points created of three mutually perpendicular positions of a plate, described in a chapter above. Instead of algebraic transforms applied here were artificial neural networks, and a virtual model of the machine was based on three types of network:

- network modelling the machine error,
- network responsible for systematic errors of the head,
- network simulating standard deviations for the incidental (random) part of measurement .

The teaching set for machine errors is being described with the nominal points coordinates – the error vector in a point, for systematic errors of the head – approach angle – the error value, and for the incidental (random) errors of the head approach angle – value of standard deviation.

The operation principle of this model is based on the direct simulation of the machine's nominal points. Points of measurement path are exported to a program and then performed is simulation of measurement demonstrated in Figure 3.

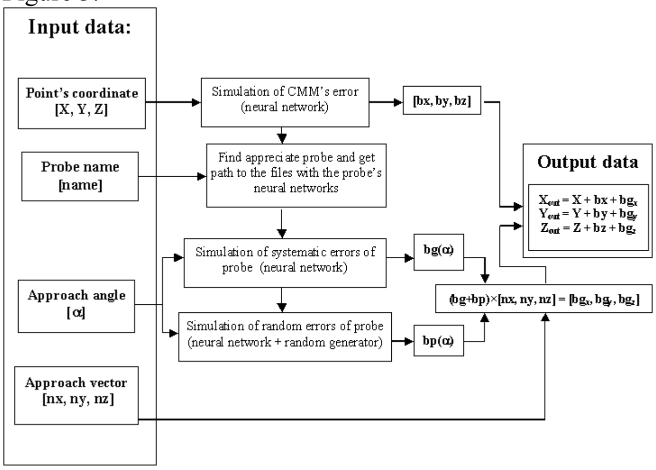

Fig. 3. Scheme of a virtual model based on neural networks [5]

Coordinates XYZ of a point are given as input values for the network that simulates kinematical errors of the machine, while data concerning the approach angle and selected measurement probe are utilised by networks simulating the measuring head with a given measuring probe, as a result obtained are coordinates' errors *(bx, by, bz),* respectively, and systematic error of the head *bg* as well as random (incidental) error *bp*. errors *bg* and *bp* are then processed by the approach vector, being distributed into the particular coordinates. As a result we get the point with coordinates of a nominal point, with consideration of simulated errors.

After performed simulation the points are imported back to the measurement program where activated are its own calculation procedures. Thanks to this approach a virtual machine simulates only and exclusively the CMM tasks as a machine and not a system. However, the software to which connected is VCMM must provide a possibility to export and import of measurement points. The detailed description of structure and operation of simulating program is presented in works [3-5].

5. ANALISYS OF APPLICATION OF A MATRIX METHOD FOR LCMM

Large machines are presently more frequently used in the industry, and therefore numerous European research institutions undertake work aimed at adaptation or developing specific methods that would enable to verify the LCMMs [1,8,9].

Following the earlier research works [3-5] where developed and verified were small- and medium-sized models of measuring machine (as regards their measurement ranges), there were attempts to adopt the matrix method also for testing the large machines. Those attempts faced a number of problems, and one of them was the lack of available standard that might be base for creation of spatial grid of reference.

The standards described in [1,8,9], created especially for testing the LCMMs accuracy, cannot be used for this purpose since the number of their reference elements is insufficient. Therefore there were attempts to apply for this purpose a plate and laser interferometer. With the use of a plate created are the reference point networks in sub-areas of the measurement space of LCMM. With the help of a laser identified are relationships between sub-areas that in this way represent one area for which determined are – with a matrix method - the machine errors. .

This relationship is determined by metering of (a sphere) elements of reference situated on the laser's reflector. A reflector with the element is located on the same clamping with a plate and is being moved to the new sub-area together with this plate. For each new position of the plate determined is a relationship for the purpose of determination of errors occurring between the determined sub-areas.

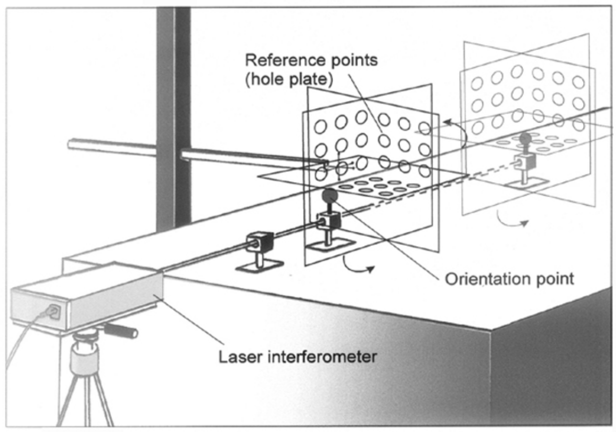

Fig. 4. The concept of transposing a matrix method for large machines

Having analysed the available models of geometrical errors of LCMMs, one can observe that participation of the particular errors of the machine is uneven. Having analysed measurement in the XY plane, one can observe that for a rigid model [7] the maximum values are obtained for the position errors (xtx, yty, ztz), and then from translations (xty, xtz, ytx, ytz, ztx, zty). Rotation errors depend on the reference probe position and a vector situated between the reference probe and used probe [7] (for metering of a plate for the matrix method used is only a reference probe). In case of measurement in XY plane the major participation shall be of errors occurring in X and Y axes, and in particular position errors. Moving the plate to a new along the machine axis forced upon us the necessity to find a relationship between its previous and present systems. This relationship one can find by way of determination of changes that occur between its previous and present coordinates systems. Having assumed the insignificant impact of rotation (the plate is transported along the appropriate slide), one has to determine translation errors. For this reason that the movement takes place only along one axis of the coordinate system, the most significant impact shall have the errors pertaining to this axis. For this purpose a reflector is shifted together with a plate, together with a fixed element of reference. By way of measuring of this element before and after shifting, possible is to determine the distance between them and then taking this into consideration at the moment of creating the area of reference points out of sub-areas. Created in this way a reference grid should comprise in the first place out of those sub-areas where the measurement is performed most frequently, and in such sub-areas the grid should be concentrated, in order to represent the LCMM errors in most detailed way. The same grid shall serve to develop a CMM model based on application of the neural networks. Verification of so developed model is based on a comparison of the real measurements results (performed on the modelled CMM) and virtual measurements for its model for the selected tasks and measuring strategies. The performed research verification of the developed neural model [3-5] and similarly for a LCMM confirmed that such model can be constructed for any chosen CMM.

6. CONCLUSIONS

In this paper presented was a method, called a matrix method, for the CMM assessment - based on vectorial description of the coordinate machine error. Also described was the developed virtual model of a machine, for which applied were artificial neural networks used for re-creation of the machine behaviour. Together with them presented were the possibilities of the matrix method application in relation to the large machines. Proposed was also a solution of the problem of creation of reference grid that enable to determine the relevant components of errors for this matrix method, and also serving as a teaching set for the networks that model kinematical behaviour of a coordinate machine.
The approach to the machine errors description presented in this paper enable to apply the same virtual model of a machine for various types of CMMs.

LITERATURE:

[1] L. Arriba, E. Trapet, M. Barstcher, M. Franke, A. Balsamo, G. Costelli, S.G. Torre, F. Kitzstaeiner, F. San Martin "Methods and Artefacts to Calibrate Large CMMs" PTB 1999

[2] H. Schwenke, E. Trapet, F. Waeldele "Calibration of coordinate measuring machines to identify and improve the measurement uncertainty" III International Scientific Conference "Coordinate Measuring Technique" Scientific Bulletin of the University in Bielsko Biała No. 44, Bielsko Biała 1998, p. 213-232

[3] Sładek J. "Errors Identification and Measurement Accuracy Assessment of Coordinate Measuring Machines (CMM)" Advances in Technology of Machines and Equipment. Postępy Technologii Maszyn i Urządzeń, PAN quarterly Vol. 23 No. 4 1999, p. 113-136.

[4] Sładek J. "A Neural Network Model of CMM Applied for Measurement Accuracy Assessment Proceedings" IMECO World Congress, 2000 Vienna Sept 23-26, vol. 11 p. 281-286

[5] Sładek J. "Modelling and Assessment of Accuracy of the Coordinate Machines and Measurements "- Monograph, 87, Cracow University of Technology, 2002, Kraków

[6] E. Trapet, F. Waeldele "The Virtual CMM Concept" In Ciarini P., Cox M.G., Pavese F., Richter D. (editors) Advanced Mechanical Tools in Metrology, 2nd World Scientific, Singapore, 1996 J.R. Taylor "An Introduction to error analysis" University Science Books, Sausalito CA, 1997

[7] Trapet E., Franke M., Haetrig H, Schwenke H. Waeldele F. Cox M., Forbers A., Delbressine F., Schellekens P., Trenk M., Meyer H., Moritz G., Guth Th., Wanner E. "Traceability of Coordinate Measurements According to the Method of Virtual Measuring Machine" PTB F-35 Braunschweig 1999

[8] Trapet E. "Large Coordinate Measuring Machines- State Art and Future for Geometry Error Correction, Performance Verification and Calibration" - Proceedings of 1st International Workshop Calibration on Coordinate Measuring Machines, Prague June 1-2, 1999

[9] Zeleny V. "Calibration of Coordinate Measuring Machines with respect to standards" 5th International Scientific Conference "Coordinate Measuring Technique" Scientific Bulletin of University of Bielsko Biala No. 3, Bielsko Biala 2002, p. 330-339