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Important details of models for analysis of uncertainty of coordinate measurements

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Abstract

The paper gives a proposal for presenting the models used for evaluation of uncertainty of coordinate measurements in accordance with the provisions of the standard ISO 14253-2. The problem is described with use of the model developed by authors basing on the standard ISO 15530-3 and own experiences concerning determining the uncertainty of measurement using of calibrated workpieces. In particular an experimental approach is proposed for estimation of uncertainty component arising from the differences among workpieces and the calibrated workpiece in roughness and form deviations.

Keywords: measurement models, uncertainty evaluation, coordinate measurements.

1. Introduction

Evaluation of measurement uncertainty is not an easy task therefore the standards considering this subject should be of very high quality. An example of the standard in the field of manufacturing metrology is ISO 14253-2 [1]. From the point of view of this publication there are two very valuable aspects included in this standard:

- the standard points out that the uncertainty of a measurement process can be evaluated using different models or different levels of detail, or both; the two extreme cases are the black box method and the transparent box method,
- the example of evaluation of measurement uncertainty of the local (two-point) diameter of a cylinder using an external micrometer shows that the measurement process must be very well known and the measurement model should be documented precisely as possible.

Thus, the uncertainty evaluation should always start with the definition of the measurement model. The starting point for defining the model is well defined geometrical product specification [2].

In view of the widespread use of coordinate metrology in many areas of machine industry, more and more attention is brought to the problems of uncertainty assessment in coordinate measurements. The up-to-date results of the standardization works in this subject are two documents: the ISO 15530-3 [3] standard and the technical specification ISO/TS 15530-4 [4]. The method described in the first document requires carrying out an experiment with use of "calibrated workpiece", and the second document foresees the use of computer software, especially software based on Monte Carlo simulation.

For the first case the significant difficulty is connected with including in the budget uncertainty components which are not covered by the experiment – the standard does not provide guidance good enough in this matter.

On the other hand, the models which enable analytical evaluation of the uncertainty, including simulation models, are very complex and their documentation is not an easy task. Additionally, authors of the uncertainty evaluation software (UES) are not interested in publishing the models due to commercial aspects. Therefore, the verification of the supplied software is very hard, and the requirements in this field, defined in ISO/TS 15530-4 are not precise enough.

This paper gives a proposal for presenting the models accordance with the provisions of the standard ISO 14253-2.

2. Uncertainty budget according to ISO 15530-3

The uncertainty budget presented in the Table 3 of ISO 15530-3 [3] (Table 3 title: *Uncertainty components and their consideration in the uncertainty assessment*) includes 4 uncertainty components which are added with the weight factor (sensitivity coefficient) equal 1.

The first, the most important uncertainty component u_p is assessed based on the results of the experiment and therefore it is a key problem to properly plan and carry out the experiment. Deeper analysis shows that the procedure for estimating uncertainty concerns a particular CMM and assumed measurement strategy, thus the **constant factors** (not changing during the experiment) will be (among the ones listed in the standard): geometrical errors of CMM (under the condition that the workpiece will be measured in the same location in the CMM measuring volume), systematic errors of probing system, errors induced by the measuring strategy and scale resolution of the CMM. The plan of the experiment consists of 20 repeated measurements of the calibrated workpiece distributed over time to include influence of other **factors** threated as **random**: temperature of CMM, drift of CMM, temperature of workpiece, repeatability of the CMM, temperature gradients of the CMM, random errors of the probing system, probe changing uncertainty, errors induced by the procedure (clamping, handling, etc.), errors induced by dirt.

The second uncertainty component is the calibration uncertainty of the calibrated workpiece u_{cal}.

The third uncertainty component u_b covers all the factors contributing to u_p and the thermal environment during the assessment of the calibrated workpiece. It's connected with the requirement of the standard ISO 15530-3 (analysed by the authors [5]) to correct observed systematic error *b* and is not to be discussed here.

The fourth uncertainty component concerns differences among workpieces and the calibrated workpiece in roughness, form deviations, coefficient of thermal expansion and elasticity u_w. The evaluation of this component is the subject of the next chapter.

3. Form deviations and roughness

As the “method of evaluation” for component u_w the “use of type A or B method” is specified in the standard. However, the type B evaluation can only be used in very special case when the measured element is feature of size and the evaluated characteristic is the size (e.g. diameter of shaft or hole). For such case the input data for evaluating the uncertainty component arising from the form deviation can be the measured value of roundness/cylindricity or its tolerance *T*. Assuming the worst case of the form deviation (e.g. oval) the appropriate probability distribution can be chosen. Using the example from ISO 14253-2 [1], the following reasoning can be performed. The effect of the form deviation on the diameter is assumed to be two times the cylindricity deviation:

$$a_W = 2 \cdot T \tag{1}$$

If a rectangular distribution is assumed (*b* = 0,57) than:

$$u_W = b \cdot a_W \tag{2}$$

Unfortunately, more complex characteristics, i.e. distances of features other than features of size, and especially geometric deviations (orientation, location and run-out) the type B method is not possible to use because there are no known models which enable determination of the weight factors for particular component uncertainties in the budget. The example concerned with the temperature error given in the standard can be applied only for the measurement of features of size.

The authors propose to use an experiment (type A evaluation) to assess the component uncertainties arising from the workpiece form deviations. The influence of the form deviations (and other differences) can be assessed by comparing repeatability (expressed by the standard deviation) of the measurement of calibrated workpiece s_2 and the spread of the results of the measurements carried out with randomly changed probing strategies for all features of the workpiece s_1. If s_1 is larger than s_2 the u_w can be calculated as follows (otherwise u_w=0)

$$u_W = \sqrt{s_1^2 - s_2^2} \tag{3}$$

The proper measurement model is depicted on Figure 1.

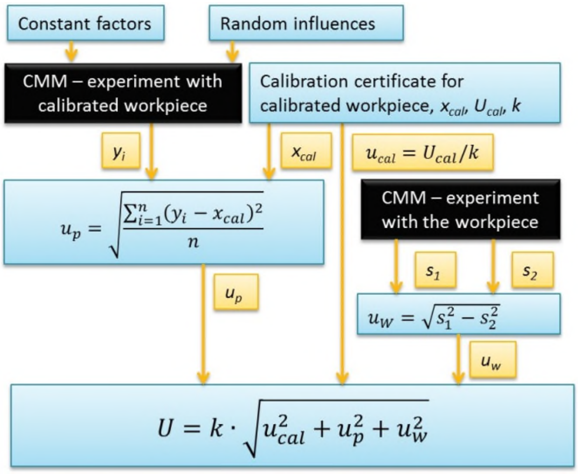

Figure 1. The model for evaluation of coordinate measurement uncertainty with use of calibrated workpiece.

4. Experiment

The procedure of uncertainty evaluation (according to the model from Figure 1) was carried out for one characteristic (position of hole “1” in relation to datum system consisting of bottom plane A, axis of hole B and symmetry plane C) of the workpiece presented on the Figure 2. The plane A was probed in 12 points, the hole B in 8 points (2 sections with 4) and the planes determining the symmetry plane C with 4 points each. The uncertainty component u_w was evaluated by experiment consisting of 10 repeated measurements with the same probing strategy (s_2 = 1,7 µm) and 10 repeated measurements with changing probing strategy for each repetition (s_1 = 6,1 µm). The change in probing strategy was generated by rotating and shifting the probing point patterns.

The final results are presented in the Table 1.

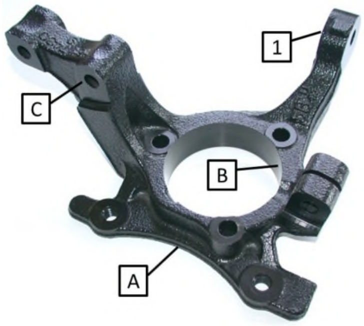

Figure 2. The workpiece.

Table 1. The uncertainty budget for the position of hole in relation to the datum system.

Uncertainty component	Value, µm
u_{cal}	1,2
u_p	2,8
u_w	5,9
U	13

4. Conclusion

Due to wide spread use of the coordinate metrology in the manufacturing it is necessary to intensify the work on the standard ISO 15530. The works must include the provisions of ISO 14253-2 pointing out the necessity of detailed description of the measurement model. Authors point out the necessity of grouping the uncertainty components presented in ISO 15530-3 and investigated in the experiment into “constant factors” and “random factors” as well as problem of including form deviations in the uncertainty evaluation. Other remarks concerning the ISO 15530 series can be found in [6].

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