euspen's 18th International Conference & Exhibition, Venice, IT, June 2018

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Procedure for integration of measuring systems into manufacturing

Karoly Szipka[1], Andreas Archenti[1]

[1] *KTH Royal Institute of Technology, Department of Production Engineering, Manufacturing and Metrology Systems division Brinellvägen 68, 10044 Stockholm, Sweden*

szipka@kth.se

Abstract

Modern production processes require shorter quality control loops and advanced adaptation to variations in production conditions. Thus, the demand to integrate and optimize measuring systems into production and raise the awareness in the management of uncertainty increases significantly. In the competitive edge of production, uncertainty is not solely object of evaluation but the result of a systematic optimization procedure, in which the selection of proper measuring system with suitable measurement uncertainty plays an inevitable role. This importance and highly developed analysis methods in the state of art make measurement uncertainty an effective basis for decision making related to the different aspects of integration. In this paper an iterative procedure is presented for systematic integration of measuring systems into production. The basis of decisions in the procedure is the "cost of uncertainty", which is estimated after technological assessment. The goal is to select an adequate measurement system for a given measurement task with appropriate metrological properties and set up an uncertainty budget, with components on an optimal level of elaboration. In a case study one possible application is shortly presented.

Measuring systems, Measurement uncertainty, Procedure for Uncertainty Management

1. Introduction

Digitalization is transforming manufacturing industry towards smart factories [1], which advancement will have a significant impact on the future of metrology. Traditionally measurement instruments have been designed and applied to yield the lowest possible measurement uncertainty. However, fastness and flexibility gain more important place in the development of metrology [2]. Fulfilling requirements related to flexibility and fastness significantly supports the reduction of costs and increase the extraction of knowledge related to measurements. These changes directly enhance the spreading and integration of measuring systems into production. With higher integration higher level of control and determinism can be achieved in production processes. Thus, one of the biggest future challenges in metrology is to find reliable connections between the cost of measurements and the measurement result and uncertainty. Furthermore, there is a lack of procedures in state of art which would support the utilization of flexibility in measurements to optimize measuring methods.

In this research a procedure is introduced aiming to optimize measurement procedures for given measurement systems by utilizing their flexibility. Flexibility in this work is understood as the possible application range of different measurement parameters. The optimization is implemented through the systematic description of the effect of changed measurement parameters on the overall measurement uncertainty. In such assessment highly detailed standards and international directives are available [3] [4]. These measurement parameters at the same time are related to cost factors. Factors, which for instance can be related with the measurement time influencing the downtime of production equipment. In the end this leads to the connection between cost factors and uncertainty ("cost of uncertainty") through technological assessment.

An implementation of the proposed procedure is presented in a case study on the inertial sensor-based method [5] applied for the diagnostics of geometric performance in machine tool linear axis.

2. Procedure for integration of measuring systems into production

The procedure introduced in this research is applicable for given measurement tasks and measurement requirements. However, the real boundary conditions for the selected measuring system with the final measurement procedure are defined according to the given manufacturing task, resources, capabilities and the target tolerances (figure 1).

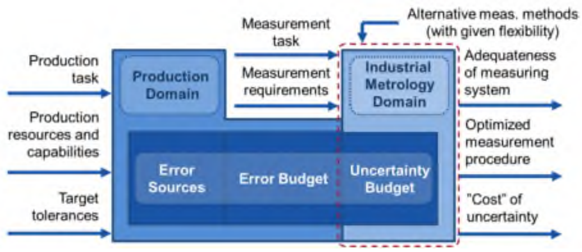

Figure 1. Context, main inputs and outputs of the procedure

A standardized solution for the design and development of adequate measurement processes is the PUMA (Procedure for Uncertainty Management, also referred to as the iterative GUM method) [6]. A drawback of PUMA is that the final outcome may not be optimal only adequate, furthermore it can be insufficient from an economical point. Therefore its application in measuring system integration is limited as the only aspect in decision is measurement uncertainty.

2.1. Main steps of the procedure

The procedure (see Figure 2) includes the following steps: (the iterative implementation starts from step VI):

I. Definition of measurement task and requirements (target uncertainty U_T and C_T cost).

II. Selection of a measurement method which possibly can fulfil these criteria.

III. Collect an extensive list of measurement parameters (P_i, marks the i^{th} parameter), describe constrains of measurement process and develop ranges in which P_i can vary.

IV. Develop cost factors (C_f, e.g. measurement time) from target cost and express their relationship with P_i.

V. Implement initial sensitivity analysis to identify major measurement parameter contributors related to C_f. Often only few P_i dominate the total cost of the measurement, which has to be in the focus of the investigation.

VI. Make the first iteration starting from upper boundaries of P_i, meaning relatively high total cost C_{SUM} and possibly low U_T.

VII. Set up an uncertainty budget focusing on the detailedness of the estimation where relevant P_i has a contribution. Meanwhile the rest of the budget can contain rough estimates. The budget composed according to [2] results in an expanded uncertainty (U_E).

VIII. Compare $C_{SUM}$and U_E with target values. The iterations process continues until the targets are met. In which case the adequate and optimal measurement procedure is found.

IX. Collect consequences connecting C_f and U_E, describing correlations on which basis the change of the next P_i can be implemented.

X. Implement further iterations in which the relevant P_i are adjusted to reach lower C_{SUM}in every round.

XI. In many cases a few uncertainty components dominate the combined standard uncertainty [5]. If $U_E > U_T$ and the relevant P_i is not considered, higher level of estimation is needed for these components in the uncertainty budget.

XII. After all possibilities have been used and systematic reduction of C_{SUM} is not possible, either the more accurate estimation of uncertainty components, then the measurement method is not feasible for the measurement task. Other method needs to be selected or the target values have to be revised.

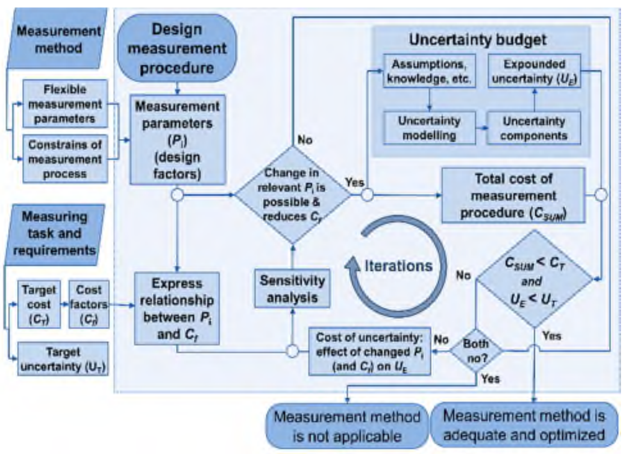

Figure 2. Flowchart of the proposed procedure

3. Implementation: a case study

The introduced procedure is used to optimize the capabilities of the inertial sensor-based method [5] and utilize the flexibility of this approach. The implemented procedure and the results for two different applications (machine tool calibration and degradation identification of three linear axes) can be seen on figure 3. Experiments are implemented on a purpose build test environment, which provides possibility to easily change measurement conditions.

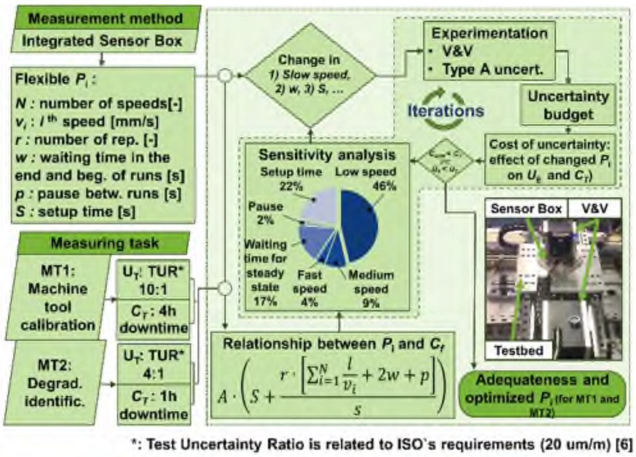

Figure 3. Flowchart of the implemented procedure in a case study on an inertial sensor-based method for the diagnostics of geometric performance in machine tool linear axis

4. Conclusions

The introduced procedure offers a systematic description of a reliable connection between the cost of measurements and the measurement result and uncertainty. As it was demonstrated via a case study the approach supports the utilization of flexibility in measurements and the optimization of measurement parameters, which enable the integration of measuring systems into specific cases in manufacturing. The procedure also supports the comparison of different measurement systems for different measurement tasks and can be applied for the design and development of such systems.

One of the limitations of the approach is that changing parameters one by one makes difficult to explore correlation effects between two or more measurement parameters. Also, the detailed expression of economic costs can be challenging [7]. Furthermore, describing the effect of a changed measurement parameter on type B uncertainty is not always straight forward, and can require time consuming experiments with traceable verification.

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