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# AN APPROACH FOR EFFICIENT IMPLEMENTATION OF UNCERTAINTY ANALYSIS IN PRODUCTION-RELATED MEASUREMENT PROCESSES

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**Abstract** – The statement of measurement uncertainty with a given measurement result provides valuable information about its quality and reliability. In the ISO/BIPM Guideline to the Expression of Uncertainty in Measurements (GUM), a commonly accepted procedure to evaluate the uncertainty is described. Yet for measurement results in manufacturing metrology, measurement uncertainty is only rarely evaluated and stated, because the procedure based on GUM is considered as too complicated. To solve this problem, an assistance system is developed to support the analysis of measurement uncertainty in companies as well as enhance a workflow optimized procedure for the evaluation. As a prerequisite for the implementation of such an assistance system, generic processes have been defined, splitting up the steps of uncertainty evaluation and implementing them in typical processes of production metrology. These generic processes open up the possibility to implement the GUM steps into any existing processes among companies and allow a comprehensive and coordinated determination and evaluation of the measurement uncertainty based on the GUM. This implementation of processes for measurement uncertainty evaluation contributes towards providing the required accuracy for the production processes as well as the customers' demands to quality.

**Keywords:** Uncertainty analysis, manufacturing metrology, knowledge management

## 1. INTRODUCTION

The statement of measurement uncertainty with a given measurement result provides valuable information about its quality and reliability. Therefore, to take decisions about the quality of a product, e.g. regarding the conformity of a manufactured product with given specifications in customer-supplier relationships, it is necessary to consider the uncertainty of the measurement result [1]. In the ISO/BIPM Guideline to the Expression of Uncertainty in Measurements (GUM), a commonly accepted procedure to evaluate the uncertainty is described [2]. Yet for measurement results in manufacturing metrology, measurement uncertainty is only rarely evaluated and stated. It suffers from the problem that the expression of uncertainty is difficult to implement on the basis of the GUM procedure. The guideline states abstract procedures that have to be made applicable for each company. Due to this additional required effort, the possible users often totally neglect a norm conform performance of measurement uncertainty analysis.

Additionally, the steps required for the determination of measurement uncertainty usually cannot be performed by the employees actually executing the measurement, as they lack knowledge in mathematical and statistical basics required for the modelling of the measurement process. On the other hand, specifically trained experts in manufacturing metrology usually are not informed about the situation in actual production respectively the performance of measurements there. Thus, it is difficult for them to comprehensively gather relevant information about the measurement process.

To solve this problem, an assistance system is developed to support the analysis of measurement uncertainty in companies as well as enhance a workflow optimized procedure for the evaluation. As a perquisite for the implementation of such an assistance system, generic processes have to be defined, splitting up the steps of uncertainty evaluation and implementing them in typical processes of production metrology. These generic processes open up the possibility to implement the GUM steps into any existing processes among companies and allow a comprehensive and coordinated determination and evaluation of the measurement uncertainty based on the GUM.

## 2. SUPPORT FOR UNCERTAINTY ANALYSIS BASED ON GENERIC PROCESSES

The analysis of generic steps is based on common practice in production metrology and typical employee groups that take part in the processes. To determine the generic processes, a model of usual workflow and processes in production metrology has to be defined. This model contains all steps from the entry of the measurement task till the documentation of the results with all the additional information and experience gathered among the process steps as shown in Table 1.

TABLE I. Generic Process Steps

| Step name | Basic steps |
|---|---|
| Measurement task | Entry of the measurement task<br>Check if measurement is required<br>Appoint responsibles<br>Release tasks for employees |
| Measurement planning | Specifications<br>Measurement criterias<br>Prepare documentation |
| Preparation | Setup<br>Approval<br>Instruction of workers/employees |
| Data Gathering | Taking samples<br>Measurement<br>Save data |
| Result evaluation | Import results<br>Algorithm setup<br>Calculation<br>Measurement uncertainty determined<br>Complete result stated |
| Reaction | Reaction mechanism ready<br>Import data<br>Export result<br>Take action if required |
| Documentation | Document all relevant information<br>Give access to needed information |

These process steps contain the basic requirements given in norms.

In addition to the core processes, support processes have to be considered, taking part in multiple steps. These are combined under the concept of a measurement management system according to ISO 10012 [3]. They consist of measurement device planning, measurement device surveillance, measurement device administration as well as a consistent improvement management. These functions interact at several points with the core processes and can therefore not be implemented in such. The tasks of a measurement management system are shown in Table 2.

Based on the core and support processes, possibilities and problems concerning the evaluation of measurement uncertainty are gathered.

The results of the analysis show, that there are several important points for implementing an assistance system. Several steps stated in the GUM can be found in the existing steps. These have to be used for implementing a full measurement uncertainty analysis. Based on the existing steps, the new and changed steps have to be implemented under the premise to provide a comprehensive result of measurement uncertainty until the measurement results are evaluated. To achieve this, the GUM steps have to be separated from each other and moved to each measurement process step.

TABLE II. Measurement management system tasks

| Task | Description |
|---|---|
| Calibration | Manage all calibration demands |
| Procurement | Plan and procure all needed measurement devices for the company |
| Evaluation of Measurement Uncertainty | Expression and evaluation of the measurement uncertainty as well as the validation of the measurement process |
| Measurement surveillance | Surveillance of the consistency of the measurement process |
| Training | Develop and perform training concepts for the employees |
| Improvement | Consistent and permanent improvement |

The two critical steps are the modeling and the determination of the input factors for the standard uncertainties. These steps require the most knowledge and experience, hence the help of an assistance system would relieve the workload of the user.

Due to these changes, the involved departments and employees have to be informed and trained for the new steps. Additionally, documentations for the input in the measurement analysis must be provided.

To further improve the assistance system, modules for the estimation and the optimization must be included. An early estimation of the measurement uncertainty based on past experience of similar measurements can be used to distinguish the effort for a certain analysis. A module for optimization has the advantage of finding the “best” procedure and input values for a target measurement uncertainty. This procedure can be used based on the PUMA procedure, which uses iterations to optimize measurement uncertainty [4].

The next step of the analysis is which personal groups are taking part in the generic measurement steps. Therefore a basic outline of each group competences, tasks and possible weaknesses related to measurement uncertainty evaluation was achieved. There are six different personal groups taking part in the workflow, which show a more or less significant influence on the measurement uncertainty evaluation and the framework required for this. First of all, the two most important groups are the quality- and measurement employees, as well as the shop floor workers. These two groups are directly involved in the process. Metrologists plan measurement setups and execute complex measurements. They also are responsible for the calibration and conformity checks as well as the determination and evaluation of the measurement uncertainty. The problem is the lack of information directly from the shop floor. This information is needed to model the measurement process as well as determine the uncertainty input factors. The shop floor workers on the other hand have to produce and assemble the parts that are evaluated. Therefore they have to perform simple measurement tasks and check control cards. Because of their proximity to the production process, they can provide valuable information for the measurement uncertainty.

The Problem is that shop floor workers don't have the background knowledge and the motivation to provide this information in the way it is required. They should be trained in order to solve this issue. Training concepts may vary because of different company backgrounds.

The other four groups are involved whether in the preparation and administration of the measurement processes or are handling the results. These are construction employees, the business administration, in and outbound logistics as well as contact persons. Depending on the function, the employees have a certain impact on the measurement uncertainty. Constructionists e.g. determine the tolerances for the product which result in certain measurement procedures and their corresponding measurement uncertainty. The business administration creates the basic guidelines for quality and measurement. They are also the decision instance for all major changes in the company. Therefore they have to be involved in the process of implementing an assistance system. A steady stream of information and ratios has to be provided in order to maintain and direct the usage of the assistance system. Contact persons as well as employees in in and outbound logistics must have the knowledge about their relevant parts of measurement uncertainty. Logistic employees have to judge inbound deliveries whether they are conform to the conformity agreements. Contact persons must be capable of communicating quality issues to external sites like institutes, public administration as well as customers and suppliers. Other groups are unlikely in generic measurement processes but there may be exceptions like human resources employees who are responsible for personal planning and need to know which skills are required for a task.

The main issue in these tasks is the communication between shop floor workers and metrology and quality management employees. Due to different educational backgrounds, there is a mismatch in the communication. The information needed by the quality management is rarely known among the shop floor workers, therefore these workers have to be trained which information is needed and why. Due to these insights in the overall process is strengthened. This may result in various positive effects on the workers and the general workflow.

Another problem is the large amount of information and knowledge as well as experience that is required to set up a suitable model of the measurement process and determine the standard uncertainties to be inserted to quantify the influence factors.

Therefore, a system has to be implemented to support the determination of standard uncertainties based on experience and reasonable procedures, as well as a database to collect characteristic uncertainty influences. This would greatly reduce the effort to train the employees. A standardised procedure for each input factor makes it possible to allow steps for a measurement uncertainty determination to be performed by non-metrologists with the proper training.

Considering these requirements, an optimised procedure in the generic processes has been created. It includes tasks related to the evaluation of measurement uncertainty directly into the according phases of the measurement processes, where the required information is specified. The following part outlines all new or changed steps that have to be added to the generic process steps. Where they should be added depends on the company that is considered.

These improved process steps begin with the sum up of all information about the measurement and the input values. Beginning with the analysis of the measurement task, an interdisciplinary team has to check the own capacities as well as possible options for the analysis. Afterward they have to determine the factors for standard uncertainty as well as a way determine them. This can be achieved by the standard procedures in conjunction with experience from past measurements from the database. The next step is the modelling. This is a critical step because the modelling requires the most experience from the employees. Based on the mathematical and physical conditions of the measurement process, the model for the measurement has to be created by using a function graph. This can be supported by the assistance system. Based on that model a process equation can be determined and afterward inverted to the model equation based on the GUM procedure.

The other critical step is the determination of the input values. First step is the measurement as well as the documentation of all relevant environmental conditions. Afterward the series of measurement have to be prepared for the evaluation. Then, the standard uncertainties after GUM Type A can be calculated. Type B uncertainties must be gathered depending on their source, like calibration certificates, norms, etc. to complete all input factors. Afterwards, all gathered standard uncertainties have to be discussed and verified. The subsequent calculation is based on the GUM procedure [5]. In addition to the complete measurement result, a measurement uncertainty budget has to be set up. It has to contain all values and procedures, how they were gathered. They are the basis for measurement uncertainty evaluation and optimization; therefore they have to be judged by an interdisciplinary team, which can be the conclusion to the beginning meeting of this team.

Additionally, a documentation system is implemented that enhances the use of information of former measurements and their related uncertainty to improve future measurement tasks. Therefore a simple system has to be implemented, that allows the workers and employees to document new information and experience based on checklists or free text in their regular workflow. This provides a steady stream of information which can be used for measurement uncertainty determination, evaluation and optimization. To achieve this, the format of input has to be adjusted to the specific user groups, ranging from checklists or tags for shop floor workers to notes and comments on measurements for metrologists.

## 3. FOLLOWING STEPS

The implementation of an assistance system can be detained by several issues. Before implementing, a plan/actual analysis has to be made regarding the process structure of the company. Possible risks and problems must be identified before the implementation starts. Possible cost due to high complexity problem can grow exponential and therefore reduce the use of the assistance system. If problems are identified, external help may be required.

Employees may decline the new processes. The old processes practiced for years are the reason that several employees may not want to change their working behaviours. To solve this problem, these people have to be identified by surveys and working trials. Afterwards they can be informed about the positive effects of the assistance system on their workflow.

An assistance system may not be the best solution for every company. The use must be executable with little to none additional effort. Also, investment calculations have to be made whether the usage of this system has a positive impact on the capital and cash flow of the company.

## 4. CONCLUSION

To achieve GUM conformity, the metrologist has to be supplied with all relevant information for the evaluation. This includes information for modelling and input factors as well as boundary conditions. The user has to be supported by a tool to standardise the procedure. An interdisciplinary platform must be established to gather input and knowledge of the evaluation as well as provide use to all participating partners in form of better process understanding. The new processes will provide the measurement uncertainty until the end of the result evaluation. The users and participating employees have to be trained for proper use and contribution to the new process structure. Within their tasks, they have to be supported by handbooks and context sensitive help as well as reference persons responsible for each step if any problems occur. The unique potentials of each employee group have to be taken into account for the new processes. Shop floor workers can provide useful information about the production and the boundary conditions. Metrology employees got a vast knowledge about measurement instruments and norms.

In order to implement a comprehensive measurement uncertainty evaluation in companies, the employees have to participate in this project. The leaders must make sure that all relevant persons are involved in this change and motivates their employees. If the evaluation of the measurement uncertainty is implemented in the business processes, many benefits can be achieved. Based on the norm conform uncertainty, the company can compare and interpret their results with their suppliers and customers as well as prove their products conformity with the requirements. In order to produce high tech products, very precise production and reliable inspection are required. An implemented measurement uncertainty evaluation will be a huge contribution towards providing the required accuracy for the production processes as well as the customers' demands to quality.

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