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Modularized Modeling of Measurement Processes in Micro- and Nanometrology for Measurement Uncertainty Evaluation

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Abstract: Measurement uncertainty characterizes the quality of a measurement result. It is determined according GUM by modeling the measurement process with all effective influences. Compared to conventional measurement processes detailed models in micro- and nanometrology are not yet sufficiently published due to ongoing research on influences and correlations. In the paper the modeling background according GUM [1] is shown and research results and a demo application in modularization of measurement processes in micro and nanotechnology will be presented.

Keywords: metrology, uncertainty, modeling

1 INTRODUCTION

Product and process development is not possible without improved measurement techniques. The advancements in this fields are closely linked and decision making for product- and process-configuration or -changes based on measurement results, which must be of high quality, consequently. This quality is described by the characteristic ‘measurement uncertainty’ (MU), to be determined according GUM. Measurement uncertainty evaluation considers influences from the item under test, the measuring procedure, the measuring instrument, from calibration, environment and the operator. To improve devices and procedures the single contributions to the resulting uncertainty budget have to be modeled and examined.

For the classical tasks of manufacturing metrology modeling for the determination of measurement uncertainty is presently ongoing. Influences are mostly known. Many open problems and obstacles (Fig. 1) exist however in the field of micro- and nanometrology, since measurement process development is often still part of research activities. Problematic is the limited resolution and discrete structure of material in the form of atoms and molecules, chemical interactions and effects between particles and due to this stronger anisotropies of materials. Many physical characteristics presuppose also a larger number of atoms, in order to get realistic function oriented results (e.g. topography, texture, roughness). Further difficulties result from quantum-mechanical effects leading to an uncertainty in the observation of a test specimen. Furthermore unintentional interactions of sensor and sample take place and an the exact definition of the point of contact becomes difficult. Calibration standards for micro and nano range are not yet available in general. But for traceable results calibration of the instruments by applying calibrated standards is inevitable. At present a lack of texture and form-standards for the Micro technology causes a gap in the calibration chain [2]. (Fig. 1.)

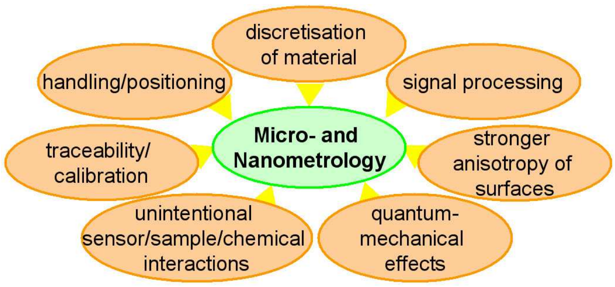

Fig. 1. Specific problems in micro- and nanometrology

2 EVALUATION OF MEASUREMENT UNCERTAINTY

According GUM standardized procedures (Fig. 2.) exist on how to determine the measurement uncertainty. Steps:

- definition of the measurement task, gathering all available knowledge
- **modeling the measuring process**
- evaluating and quantifying influences (value, type A/B)
- calculating and evaluating the uncertainty budget

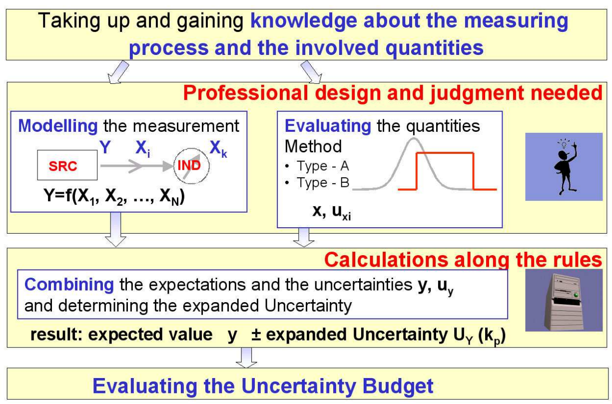

Fig. 2. Fundamental procedure for measurement uncertainty evaluation according GUM [acc: Sommer, LMET, Ilmenau, Germany]

3 APPLICATION ON MODULARIZED MODELING OF MEASUREMENT PROCESSES IN MICRO- AND NANOMETROLOGY

As the modeling is the most difficult part in determining the measurement uncertainty a research program in the field of micro- and nanometrology on this topic has been funded in Germany.

Aim of the project is the measuring process oriented systematized user support for the determination of measurement uncertainty in micro technology. Result will be a supporting system consisting of operator guidance, computation program and a basis for a library of measuring process modules for the simplified graphical modeling of specific micro technological measuring processes. The results can be used for computer-aided user support for the evaluation of measuring results in micro technology.

First results, partly based on former research [4], are:

- a industrial survey on measurement processes where a investigation on measurement process modeling has to be carried out
- a systematic for influencing factors for typical micro- and nano-metrological processes. The following influences and measurement processes have been identified so far and their consideration in the models are under investigation:
  - general influences: temperature, vibration, operator, probing mode (single point, scanning), …
  - micro- and nano-specific: aspect/ration and intrinsic material properties, ratio of roughness to measured length, …
  - opto-tactile probing: ball and shaft diameter, surface properties, measuring mode, aspect ration or penetration depth, …
  - AFM: tip radius, Eigen-frequency of the cantilever, noise, drift or Hysterese, …
  - optical sensor: noise of focusing systems, nonlinearities of lenses, drift, boundary effects, beam characteristic and shape, aspect ratio, …
- a modeling procedure on how to consider influencing factors (Fig. 3.). Modules are influencing parameters, they can be combined to represent complex models.

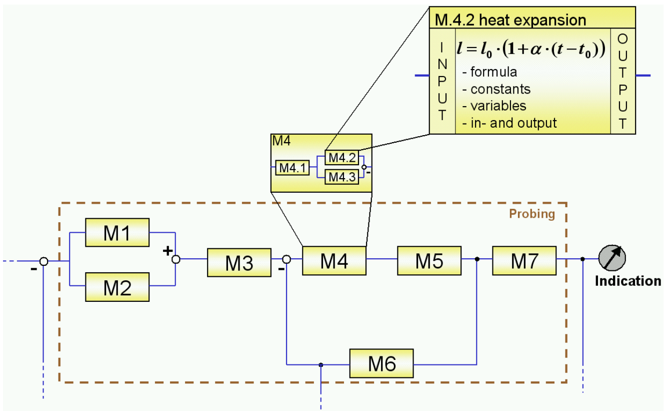

Fig. 3. structuring considered influencing factors

- a easy to use application (Fig. 4.) to demonstrate the modeling procedure. Results are new approaches on how to model, define templates or consider correlations.

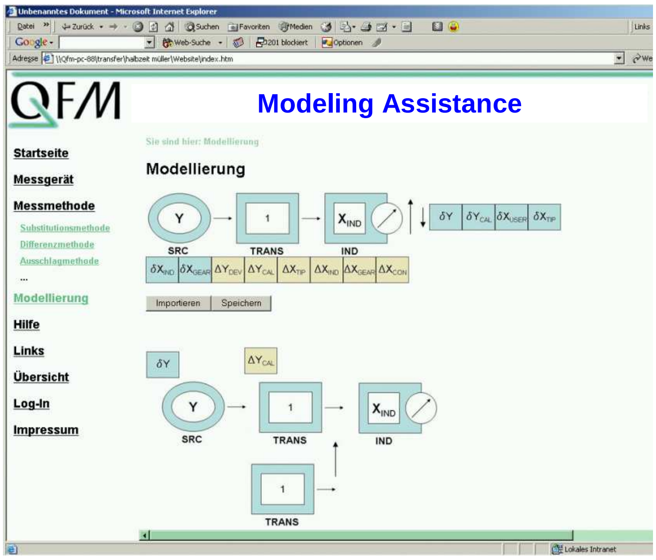

Fig. 4. demonstration of the modularization concept

4 Considering Influences and effects on specific micro- and nano-technological measurement processes

Three measurement processes (opto-tactile, AFM, chromatic aberation) are to be modeled exemplarily within the project and new methods for considering influences in the model will be developed. First approaches on how to model in micro- and nanotechnology are demonstrated below on opto-tactile measurement processes where the position and movement of an illuminated ball tip is observed (Fig. 5).

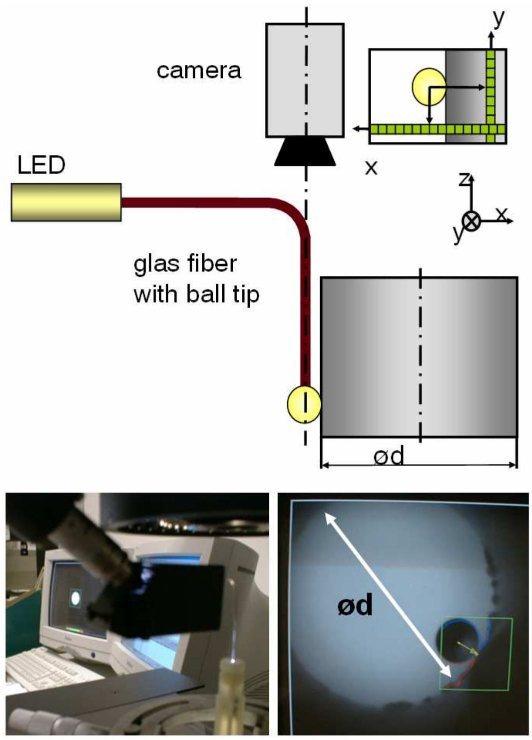

Fig. 5. opto-tactile measurement process; principle, application and analysis

In order to set up accepted models for measurement uncertainty evaluation standardized, accepted procedures on how to model and consider influences and correlations are needed. The classical procedure according GUM (Fig. 6) has to be adapted and developed.

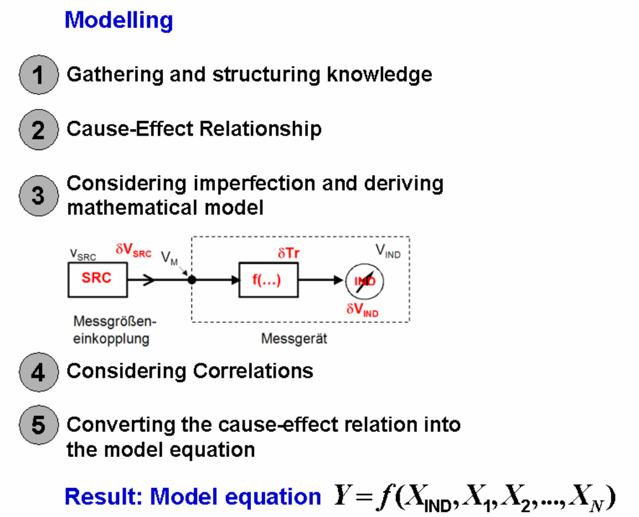

Fig. 6. steps in modeling measurement processes for measurement uncertainty evaluation

In detail the following steps have to be accomplished for an modularized modeling of measurment processes in micro- and nanotechnology to avoid specific problems (exemplarily mentioned for opto-tactile measurements).

- Gathering and structuring available knowledge (e. g. on physical interactions ball tip-surface; optical system; evaluation mode, conditions, etc.)
- Cause-Effect-Relation based on measuring method (difference, substitution, compensation, deflection)
- Consideration of imperfections
  - Modularization of the measurement chain based on (Dominant) Influencing Factors (e. g. Temperature, Vibration, Resolution, etc.)
  - Consideration of Dynamic behavior (e. g. stick-slip while scanning)
  - Consideration of nonlinearities (e. g. nonlinearities in the optical path)
- Determination of correlations (e.g. visibility of the ball tip and depth of penetration)
- Combination of measurement results obtained with measurement devices based on different measuring principles (e. g. optical or tactile) with different resolution and specific measurement uncertainty regime by segmentation in standardized shape elements
- Converting the Cause-Effect-Relation into the model equation or Monte-Carlo Simulation
- Check for plausibility („golden rules“, estimation of undetected error)

4 CONCLUSION

In general it can be stated, that with smaller dimensions to be measured nano and micro-specific influences increase. At the moment there is a lack in models and procedures on how to set up a model in micro- and nanometrology. Additionally the effects and correlations of influences are however to a large extent still insufficiently published or researched. This leads presently to unacceptable high uncertainty ranges. The uncertainty in setting up the model of the measurement process can be reduced by use of standardizes, accepted procedures on how to model and consider influences and correlations. The strong nonlinearities and dynamic behavior in micro- and nanotechnology requires the consideration of simulation results (e .g. Monte-Carlo-Simulation).

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