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Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future

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TRAINING CONCEPT FOR COORDINATE MEASUREMENT

A. Weckenmann, R. Roithmeier and M. Knauer

Chair Quality Management and Manufacturing Metrology
University Erlangen-Nuremberg, D-91054 Erlangen, Germany

Abstract: Coordinate measurement must be executed considering objective comprehensive criteria, in order to ensure the comparability of the results of measurement. A profound education of the personnel responsible for the measurement as well as standardized procedures are necessary prerequisites. The aim is to supply an established device neutral training concept for coordinate metrology as well as procedural statements for the support of the analysis, planning and execution of measurements and analyses of the data. Thus the comparability and the correctness of measurement results will be increased.

Keywords: Coordinate measurement, training concept, preventive quality management, metrology, coordinate measuring machines

1   INTRODUCTION

Coordinate measurements can only lead to correct and comparable results if the same general accepted and objective comprehensive rules are the base for the entire measurement (fig. 1). These rules are in particular:

- interpretation of measurement task,
- measurement strategy, including
- sampling of measurement points and
- probe selection, probe calibration etc.,
- conducting measurement,
- analysis and evaluation of measurement data,
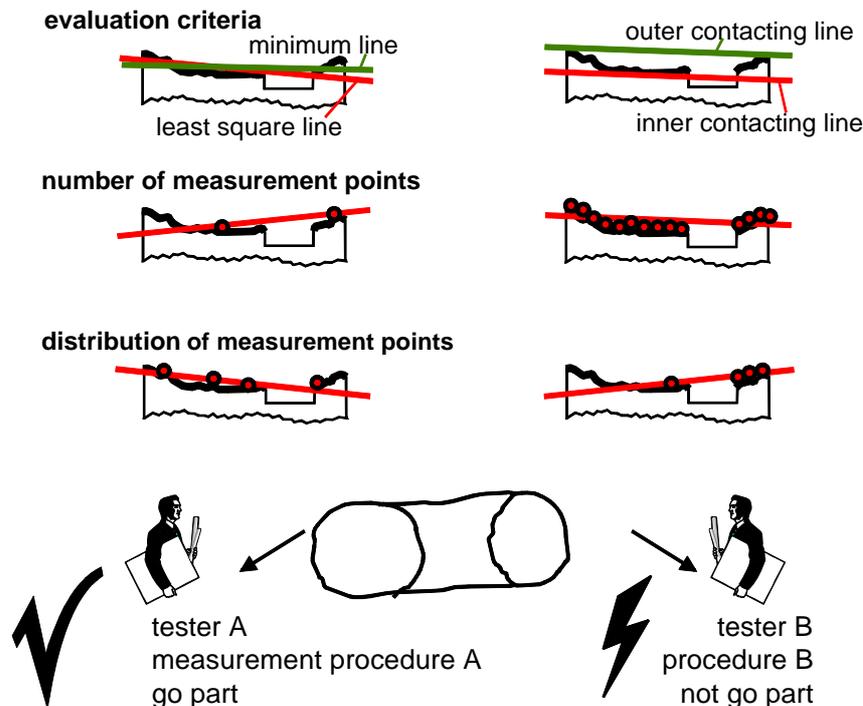- documentation.

Figure 1. Influence of measurement strategy and user decisions on measurement result

Thorough information about coordinate metrology as well as about physical, mathematical and some elementary machine-specific knowledge are indispensable for a CMM (coordinate measuring machine) operator. A profound training of the personnel responsible for the measurement and standardized procedures is necessary. It can support the operator at the time of analysis, planning and execution of the measurement as well as analysis and evaluation of the results.

2   DEFICITS

The factors which influence the result of measurement can be divided into three groups: measuring instrument, environment and workpiece, operator including measurement strategy. The factors wich have influence on the measurement

- instrument
- environment and device
- operator and measurement strategy

cause result deviations in the ratio of approx. 1:10:100 [1] (fig. 2). For the influence factor "operator", which is responsible for the highest result deviations and uncertainties, the least concrete specifications for comparable measurement results are available.
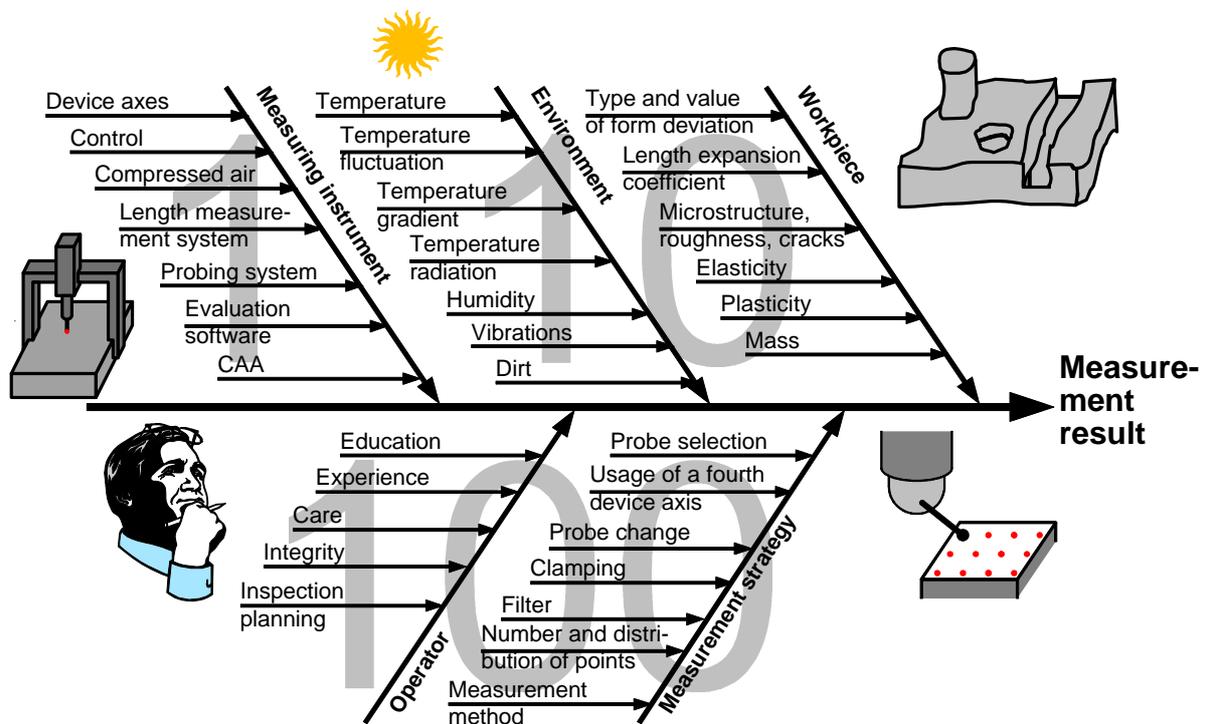

Figure 2. Influences on result value and uncertainty using flexible measuring instruments

The interpretation of the inspection plan and the measurement procedure as well as the evaluation of the result take place according to subjective criteria of the individual operator, which are partly arbitrarily and scientifically not always secured or do not correspond to international standards. Training courses offered by the CMM manufacturers frequently only focus on device-specific technical details, without dealing with the problem definition of the task specific measuring process planning in particular. A standardized vocational description for industrial metrology is missing.

3   AIM OF RESEARCH

The goal of the research is to supply an established device neutral training concept for operators of coordinate measuring machines, limited on the tasks of standard geometrical features and sheet metal measurements. The educational course offers methodologies tested in practice for the development of measurement plans and for the execution and analysis of measurement (*Good Coordinate Measurement Practice*, GCMP).

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The working program to achieve this target is arranged as follows:
− Sampling of a representative collection of typical measurement tasks and requirements derived from industrial practice,
− Preparing a device neutral training concept, based on the determined requirements**,**
− Structuring the course content according to the previous knowledge statuses, the qualification goals as well as the different types of knowledge,
− Compilation of the rules of „*Good Coordinate Measurement Practice*" (GCMP)
− Preparing sample training documents (theoretical base of coordinate metrology, practice-relevant case examples, procedural statements) and testing in workshops with companies,
− Publishing the project results by regularly offered seminars as well as supplying documents in the World Wide Web.

3.1   Training Requirements

To sample a collection of typical measurement tasks and most frequent problems using CMMs there has been extensive questionings with CMM users in industry. As a result of the analysis of these interviews and the relevant literature such as for example [2], [3], or [4] there was build up a complete knowledge base of the step-by-step procedures interpretation of the measurement task till finishing the documentation (fig. 3).
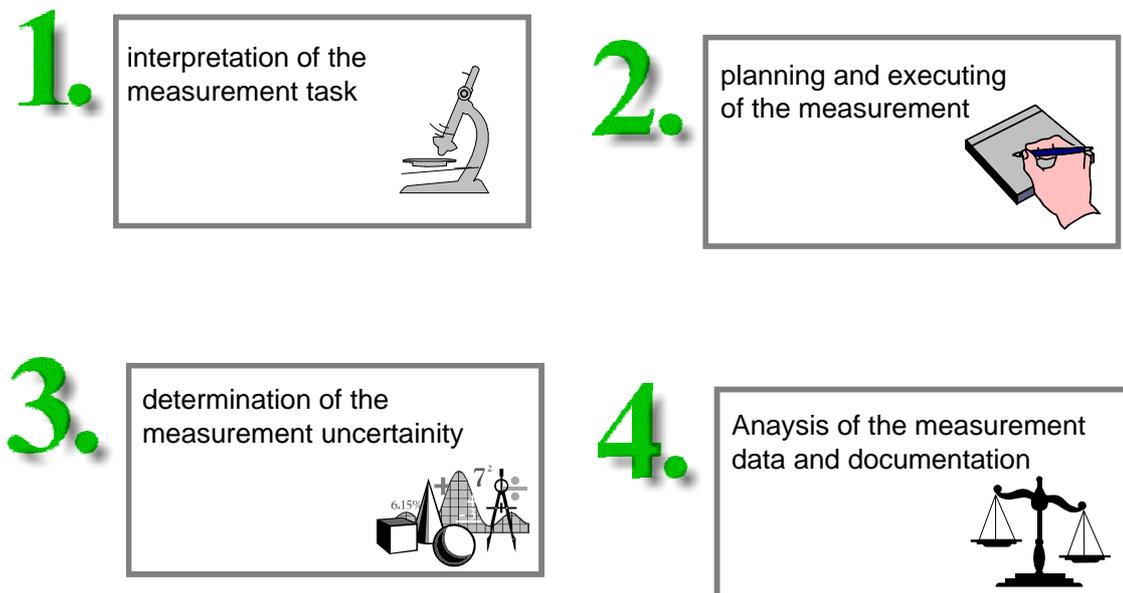

Figure 3. Systematic control with CMM´s

3.2   Structured Training Concept – Previous Knowledge

In the next step the course content was structured according to the previous knowledge statuses, the qualification goals and the different types of knowledge of the trainees. The following three types of previous knowledge statuses have been defined:
− knowledge of a typical engineer
− knowledge of a typical technician
− unskilled (no previous knowledge).

For these three types of statuses the usual previous knowledge of each group was examined. Additionally, a required previous knowledge status („presupposed knowledge") contending basics of mathematics, physics and engineering was determined to reduce the total education time (table 1).

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Table 1. Previous knowledge of the three status types

Type	Previous knowledge
Unskilled Presupposed knowledge	**mathematics:** fundamental rules of arithmetic, calculus of variables, two or more unknowns; functions; dots, straight lines and geometric bodies in 2D and 3D; trigonometry; symmetry, vectors **physics:** kinematics, velocity, force, torque, heat, linear thermal expansion, tension, pressure, gravitation **computers:** handling computers, electronic data processing **material science:** metals, metal alloys, plastics **manufacturing engineering:** fundamental knowledge about manufacturing like milling, drilling, forming, cutting, welding, etc.
Technician	knowledge of an unskilled trainee and additionally **mathematics:** Cartesian coordinates in 2D and 3D, translation and rotation, calculation of angles, planes, distances **engineering drawing:** understanding engineering drawings, dimensioning; CAD drawings **other knowledge:** regulations for prevention of accidents, operational sequences
Engineer	knowledge of a technician and additionally **mathematics:** cuts, solid angles, projected angles **statistic:** straggling, average value, Gaussian distribution, equipartition, classification, probability papers, diagrams and charts **quality management:** principle of documentation, statistical quality control, quality control chart, process monitoring, ISO 9000, audits, ...

3.2   Structured Training Concept - Qualification goals

Based on the knowledge collections shown in table 1 the modular qualification goals
- CMM user
- CMM operator and
- CMM expert as well as the
- manager training CMM (for department heads, chiefs, design engineers etc.)

was developed (fig. 4). The detailed knowledge, which has to be trained in the educational lessons and which is checked in a final test (with a marked certificate) is listed in table 2.
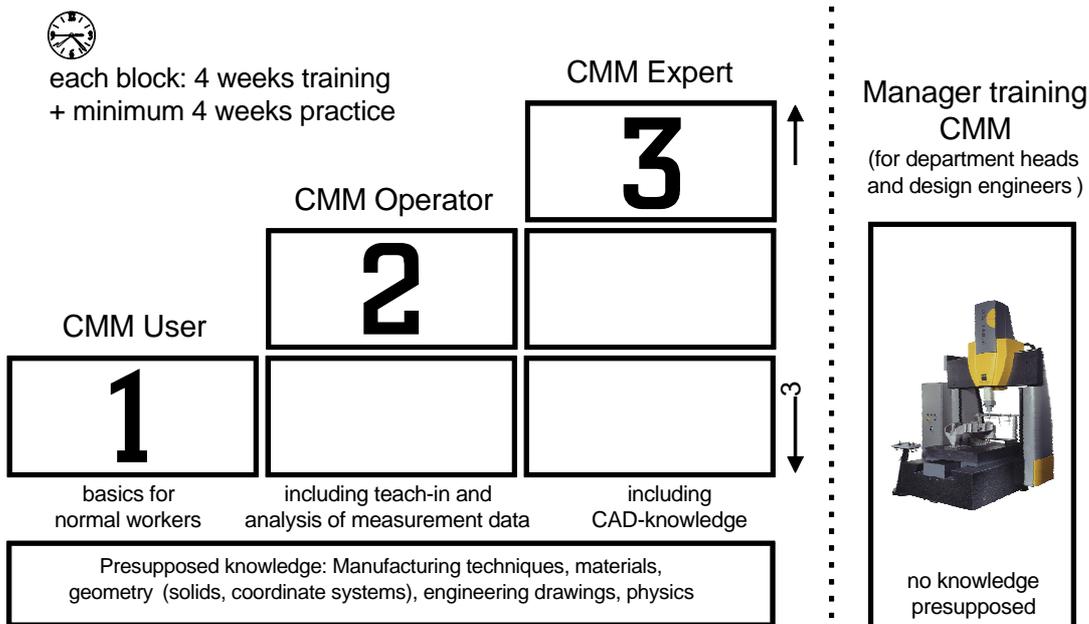

Figure 4. Hierarchized qualifications of the training concept coordinate measurement

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Table 2. Detailed knowledge of the three different qualification goals

Qualification goals	Training content for all statuses (engineers, technicians and unskilled trainees)	Additional knowledge for technicians and unskilled trainees	Additional knowledge for unskilled trainees
CMM user 1	**mathematics:** vectors, planes, normalized vectors, geometrical bodies, polar coordinates **metrology:** standards, manufacturing techniques, probe calibration, work loading and fixture, sampling of measurement points, analysis of measurement, correlation between manufacturing, design and measurement task **CMM:** design of CMMs, maximum measurable workpiece size, probe, CAA correction, precision; rotary table	**mathematics:** cuts, distances, solid angles, projected angles **statistic:** straggling, average value, Gaussian distribution, standard deviation **quality management:** principle of documentation, statistical quality control	**mathematics:** Cartesian coordinates, translation and rotation **engineering drawing:** understanding engineering drawings, dimensioning **other knowledge:** regulations for prevention of accidents, operational sequences
CMM operator 2	**mathematics:** symmetry, normal, error calculus, difference between Gauss and Chebyshev, maximum inscribed circle/cylinder, minimum circumscribed circle/cylinder, etc. **metrology:** geometrical tolerancing, feature based metrology, form, form plots, form errors, scanning, measurement of sheet metal, digitizing, temperature correction, systematic and random errors, duration of measurement, optimizing the measurement time **CMM:** mechanical filter, special probes, CNC programming, principles of programming	**statistic:** sample, entities, straggling, average value, Gaussian distribution, diagrams and charts **quality management:** 2D- and 3D-Plots, diagrams, statistical quality control, quality control chart, ISO 9000, etc.	**mathematics:** calculation of angles, planes, distances
CMM expert 3	**mathematics:** complex geometric solids, calculation of fitting algorithms **statistic:** stochastic, tests, estimation functions, null hypothesis, etc. **metrology:** measurement uncertainty including the calculation of measurement uncertainty, guidelines of dimensional relations and geometrical tolerancing, objective-oriented measurement, digital filters, roughness, waviness, off-line programming, maximum material requirement, etc. **electronic data processing:** automatic data evaluation and statistics **quality management:** QM methods, TQM, quality costs, measurement room monitoring, principles of managing a measurement room **CAD:** interfaces, automated analysis of CAD drawings	**statistic:** equipartition, classification, probability papers **quality management:** process capability, process monitoring, audits, etc.	**CAD:** making of engineering and CAD drawings, dimensioning

The manager training CMM contains the design of CMMs, maximum measurable workpiece size, probes, CAA correction, precision of CMMs, rotary tables, CAD interfaces, basics of measurement

strategy and the correlation between manufacturing, design and measurement task. Furthermore it contains measurement uncertainty, necessary operator knowledge, education duration, standards of metrology and quality management and fundamentals of quality management.

All contents of the educational course are categorized by the different kinds of knowledge
- basic knowledge / structural knowledge
- action knowledge
- additional knowledge
- standards knowledge

In this training concept for every kind of knowledge there will be used a optimal adapted training method. A special focus will be put on the sensitization of CMM operators about measurement uncertainty and uncertainty influences.

4   CONCLUSION AND FUTURE WORKS

In this report, a basic training concept for coordinate measurements was introduced. The following steps have already carried out:
(1) Sampling of a representative collection of typical measurement tasks derived from industrial practice,
(2) Preparing a device neutral training concept, based on the determined requirements,
(3) Structuring the course content according to the previous knowledge statuses, the qualification goals as well as the different types of knowledge.

The future work will be as follows:
(4) Compilation of the rules of *Good Coordinate Measurement Practice* (GCMP)
(5) Preparing sample training documents (theoretical base of coordinate metrology, practice-relevant case examples, procedural statements) and testing in workshops at companies,
(6) Defining a standardized vocational description for industrial metrology
(7) Publishing the project results by regularly offered seminars as well as supplying documents in the World Wide Web.

The execution of training measures will contribute to the motivation of the operators of coordinate measuring machines. In the sense of quality management confidence between business partners and into their results will be established. Using the confidence into the correctly executed inspections of the supplier, own inspection expenditures can be reduced. Finally quality costs can be reduced and also unnecessary discussions about the measurement results will be avoided.

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AUTHORS: Prof. Dr.-Ing. A. Weckenmann, Dipl. math. techn. R. Roithmeier, Dipl.-Inf. M. Knauer, Chair Quality Management and Manufacturing Metrology, University Erlangen-Nuremberg, Naegelsbachstrasse 25, D-91052 Erlangen, Germany, Phone Int +49 9131 85 26521, Fax Int +49 9131 85 26524, E-mail: qfm@qfm.uni-erlangen.de, URL: http://www.qfm.uni-erlangen.de