



Research project “European Training for Coordinate Metrology”



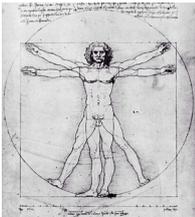
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Abstract

Coordinate metrology currently plays a crucial role within the quality assurance. Therefore, operators must possess a high level of competencies for executing measurement tasks with a coordinate measuring machine. Since a vocational education is missing, the operator has to obtain this knowledge in training lessons. Currently, training is mainly offered by machine manufacturers. In these lessons, only machine-dependent knowledge is focused, metrological competencies are usually unconsidered.

There are occasional activities to eliminate this absence by offering profound and independent training in coordinate metrology. The contents of these training offers are not homogenous and thus their degrees are not comparable. Within the framework of the Leonardo da Vinci-Programme of the European Commission, which predominantly promotes the cooperation of education actors in Europe, the research project “European training for coordinate metrology” pursues the goal of synchronizing these activities European-wide and to raise them to a common, high-quality standard.

Background



A request of the European Union is to promote the cooperation between the member states and all actors are involved in vocational education across national borders. 1995 the European Commission has therefore launched the programme LEONARDO DA VINCI that is currently in the second phase. The programme has three main aims:

- Improvement of skills and competencies,
- Improvement of accessibility and quality of vocational education and of lifelong acquisition of skills and competencies,
- Promotion and encouragement of the contribution of vocational education to the innovation process.

Initial situation

The permanently increasing application fields for coordinate metrology are due to the universality and flexibility of coordinate measuring machines (CMM). Their varied applications require a high degree of

basic and action knowledge from the CMM operator and measurement planner in order to achieve measurement results with the smallest possible measurement uncertainty. Measurement deviations in Coordinate Metrology are caused by the operator, environment, workpiece and measuring machine.

Only very little information is available on the influences of the operator, although this can be the cause of the greatest deviations in results. To achieve measurement results with small deviations that are reliable and largely operator-independent, it is necessary to

place emphasis on the operator’s education. In addition to skills for handling of machines and software the operator has to possess a well-founded knowledge about machine technology and the evaluation process coupled with extensive knowledge of physics and mathematics, metrological experience, and thorough knowledge of engineering design standards. This can only be guaranteed by a comprehensive and profound training.

As yet, training is affected in courses provided by the coordinate machine manufacturers, where the focus is only on machine and software specific details. Impartment

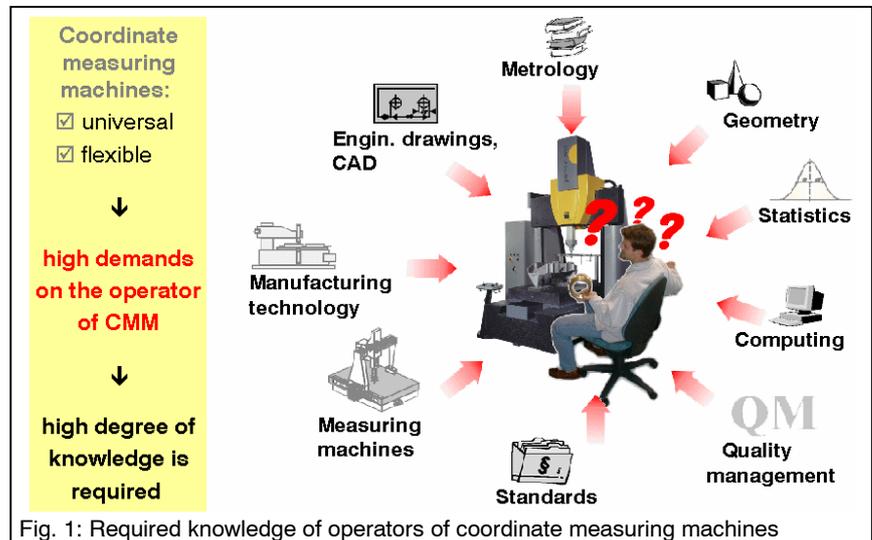


Fig. 1: Required knowledge of operators of coordinate measuring machines

of metrological competencies is unconsidered in these courses.

With the completed research project „Ausbildungskonzept Koordinatenmesstechnik“ the Chair QFM has dealt with these problems in collaboration with a project accompanying committee of industry representatives. The team has developed a German training concept for coordinate metrology.

In Germany, training concerning this concept is promoted by the association „AUKOM – Ausbildungskonzept Koordinatenmesstechnik e.V.“. The association has been founded by the industry representatives, which were members of the project accompanying committee. There are several activities in Europe comparable to AUKOM, which support the education in coordinate metrology, such as in Great Britain and in Italy. However, all these activities exist separately and independently, there is no Europe-wide homogeneous, coordinated action and thus no comparable degrees.

Training concept AUKOM

The research project AUKOM was sponsored by the AiF member organization “Federation for Quality Research and Science” (FQS). An

industrial working team consisting of 8 partners from the industry and research institutes has promoted project progress.

Primary objective of the project was providing a comprehensive training concept for operators of CMM:

- with well-founded and practically proven procedures
- with machine independent basics for analysis of measurement tasks, for planning and execution of measurements as well as for evaluation of measurement results
- with interfaces to manufacturer-specific training on measuring machines and software
- with comparable final exams and generally acknowledged certificates

Starting from the deficit that German-wide a homogeneous and comparable training in this field did not exist at this time, the essential knowledge for professional execution of measurements with a CMM has been evaluated and summarized as training contents. These contents have been afterwards classified into three training levels, level 1: CMM-User, level 2: CMM-Operator and level 3: CMM-Expert.

Expert, on the basis of varying working profiles of CMM operators have been analyzed and with this associated divergent essential standard of knowledge.

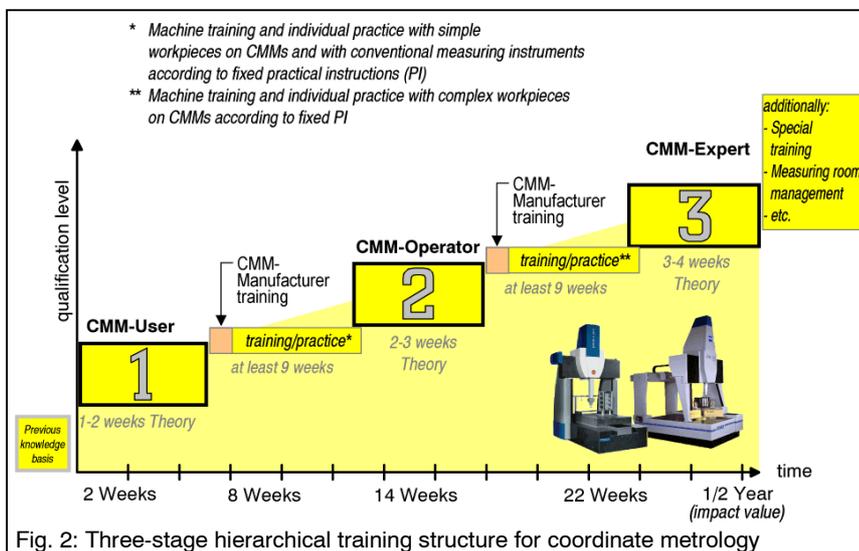
The research project was completed at end of the year 2001 after duration of 3 years. Since then the association AUKOM e.V. pays attention to the realization and further development of the training concept. Thereby the association solely takes on professional responsibility for training sessions and leaves the execution of the training to coaches, which are acknowledged by the association.

Aims

Primary objective of the project EUKOM submitted within the framework of LEONARDO DA VINCI pilot projects is the establishment of a comprehensive European training concept in coordinate metrology that fulfils the aspect of the lifelong learning. This objective includes the following partial intentions:

- Definition of an European-wide comparable and high-class qualitative educational level in coordinate metrology
- Preparation of European-wide homogeneous training materials
- Equalization of metrologists who don't have access to training courses by a European-wide e-Learning offer
- Foundation of a European association, which promotes education in coordinate metrology European-wide

Within the project, an innovative learning arrangement for coordinate metrology will be developed taking the realization of new learning strategies into account. This arrangement will enable a European-wide homogeneous and comparable, high-quality training of



machine operators as well as of lateral hires in coordinate metrology, which finally contributes to a European-wide acknowledgement of acquired skills by issuing a certificate.

Strategy

The project will be conducted in co-operation of 7 European project partners. The curriculum of the training concept, the didactics to be used as well as the form of presentation will be defined together. The work programme contains the following work packages:

- Project- and quality management contains all activities concerning coordination and communication between the project partners. The Chair QFM is contractor and project coordinator.
- Requests of the target group on training in coordinate metrology regarding methodology and content will be determined by means of a European-wide user needs analysis.
- Based on the results of the user needs analysis and the experiences of the project AU-KOM the curriculum of the European training concept will be defined. Following, the methodology of the learning arrangement will be determined in consideration of innovative learning theories and learning forms.
- After the analysis of boundary conditions for a training concept and compilation of objectives in the last work packages, the European training concept will be defined.
- For a subsequent evaluation of the developed concept representative training materials will be realized. Thereby documents for face-to-face lessons will be elaborated as well as multimedia learning material will be implemented into an e-Learning platform.
- In closed relationship with the previous work packages the evaluation of the training concept will be carried out. The formative evaluation allows testing and improving the training concept during the development process. The summative evaluation starts when the development of the concept and representative training material is completed. The evaluation of the project progress and of the results will be

<p>Level 1: CMM-User</p> <p>1-1 Measurands and units in Coordinate Metrology Measurands: Length and angle, examples for measurands, units, declaration of measurements, legal basics, conversion of degree in radian</p> <p>1-2 Location in plane Drawing plane, Cartesian coordinate system and axis, points in coordinate systems, quadrants, polar coordinates</p> <p>1-3 Location in space Cartesian coordinate system in space, projection, cylinder coordinate system and Sphero coordinate system, conversion into Cartesian coordinates, spatial distance, coordinate transformations</p> <p>1-4 Geometric features Standard geometric features, required minimum number of probing points, projections, standards</p> <p>1-5 Geometric links Relations between geometric features (distance/ angle/ intersection/ symmetry)</p> <p>1-6 Fundamentals of metrology Measuring – checking – gauging – Taylor's principle, simple measuring devices, definition of features, Sizes and tolerances, overview form- and position tolerances, Principle of Coordinate Metrology</p> <p>1-7 Construction of CMM Axes, workpiece holder, rotary table, probe systems, Scanning, articulating probe holders, styli, stylus change system, control unit and CMM computer</p> <p>1-8 Types of CMM Cantilever type, moving bridge type, column type, gantry type, differences between CMM types</p> <p>1-9 Preparation of measurements at CMM Influences by environment, standard-compliant temperature, effects of temperature differences, cleaning and fixing of workpieces, starting of CMM, accident prevention</p> <p>1-10 Stylus configuration and qualification Choice of styli, planning stylus change, stylus qualification with reference sphere, compensation of tip diameter and stylus bending, mechanical filter effect, inherited errors of imprecise stylus qualification</p> <p>1-11 Measurements with CMM Machine coordinate system, definition of workpiece coordinate systems, probing strategy (number and distribution), consideration of collision</p> <p>1-12 Evaluation of Measurements and Statistics Evaluation criteria, dispersion, Gaussian distribution, histograms</p> <p>1-13 Accuracy Basic requirements for measurements, production techniques and accuracy, accuracy of CMM, acceptance inspection, influences on measurement result</p> <p>1-14 Basics – Quality management Definition, standards to Quality management, measurement report, quality control charts, cooperation Engineering – Manufacturing – Quality assurance</p> <p>1-15 Learn to learn</p> <p>1-16 Self management</p>	<p>Level 2: CMM-Operator</p> <p>2-1 Overview – complete measuring sequence Analysis of measuring task, definition of measuring strategy, planning of measuring sequence, execution of measurements, analyse and interpretation of measurement results, consideration of measurement uncertainty, documentation</p> <p>2-2 Overview – Geometry Standard geometric features and degrees of freedom, symmetry, normal vector and perpendicular, parallelism, angle in space, projections, distances in space</p> <p>2-3 Tolerances of size Symbols of tolerances, definitions, ISO system of limits and fits, general tolerances for size, impacts on measurements</p> <p>2-4 Tolerances of form and position Symbols of tolerances, definitions, datums, general tolerances for form and position deviations, size general principles, impacts on measurements</p> <p>2-5 Measurement strategy Tasks of inspection plan, Analysis of measuring task, workpiece coordinate systems, datum features, datums sequences, fixing of workpieces, definition of probing sequence, probing strategy, evaluation criteria and linkage of features</p> <p>2-6 Probing strategy Stylus configuration, functional components of styli, stylus qualification, number and distribution of probing points, mechanical filter effect of tips, choice of tip diameter, scanning, single point probing</p> <p>2-7 CNC Programming Kinds of CNC programming, parts of program structure, principles of documented and traceable programming, online documentation of measuring programs, assignment of variables, modular structure of programs, data export, CAD information</p> <p>2-8 Evaluation General sequence of evaluation, evaluation criteria (Gaussian associated ..., Minimum circumscribed reference ..., Maximum inscribed reference ..., Minimum zone reference ...), mechanical and digital filter, linkage, methods of evaluation</p> <p>2-9 Influences on measurement result Influences by CMM, by software, by workpiece and by measurement strategy, by environment, by operator; physical effects, measures for reduction of influences</p> <p>2-10 Documentation Measurement report, kinds of Documentation, reports for different recipients, traceability, graphical evaluation, evaluation of form deviations and form plots</p> <p>2-11 Use of statistical parameters Statistical parameters, kinds of distribution, probability network, samples</p> <p>2-12 Statistic Process Control Feature category, analysis of suitability and ability, process models, quality control charts, influence by measurement uncertainty</p> <p>2-13 Basics – inspection equipment monitoring Inspection equipment monitoring, inspection equipment, calibration chain, traceability, monitoring of CMM</p> <p>2-14 Basics – Quality management Standards of Quality management, tools, certification, audit</p> <p>2-15 Contact less coordinate metrology</p>	<p>Level 3: CMM-Expert</p> <p>3-1 Expert knowledge – Geometry Calculation of angles, centre of gravity, distances, faces</p> <p>3-2 Basics – Manufacturing Production techniques and accuracy, geometrical deviations and reasons, function based and manufacturing oriented engineering</p> <p>3-3 Basics – CAD Generation of technical drawings and CAD drawings, CAD interfaces, dimensioning in CAD drawings, automated CAD data post processing, import of point clouds</p> <p>3-4 Expert knowledge – Datums Setup of functional datums, guidelines for definition of datums, choice of suitable datum features</p> <p>3-5 Expert knowledge – Geometrical tolerances Guidelines for tolerancing of form and position deviations, functional tolerances, Maximum-Material-Condition (MMC), Least-Material-Condition (LMC), projected tolerance zone, free state tolerancing</p> <p>3-6 Optimized measuring sequence Accuracy optimized measuring sequence, time optimized measuring sequence, optimization of proceeding ways, feature based measurements</p> <p>3-7 Expert knowledge – CNC programming Offline programming, fallback positions and fallback levels, program loops / program jumps / program modules, macros, user interfaces, program optimization</p> <p>3-8 Digital filtering and evaluation Software filter, Gaussian filter, high-pass filter, low-pass filter, waviness, roughness, excursion: software gauging, calculated gauging</p> <p>3-9 Stochastic Confidence level, hypotheses, tests, valuers</p> <p>3-10 Evaluation of measurement uncertainty Determination of measurement uncertainty acc. GUM, uncertainty budgets, PUMA method, extended measurement uncertainty, Conformity, ISO 14253-1, Virtual CMM</p> <p>3-11 Quality management Aspects and methods of quality management, communication and collective responsibility, Total Quality Management (TQM), quality circle, CAD software, automated Quality data processing</p> <p>3-12 Monitoring of CMM Maintenance and continuous inspection of CMM, Measurement room monitoring, user qualification and training, control strategies</p> <p>3-13 Quality costs Determined and real incurred costs, decimal rule of nonconformity costs, emergence of nonconformity and removal of nonconformity, cost-conscious tolerancing</p> <p>3-14 Digitizing of freeform surfaces Digitizing of known and unknown surfaces, patches / faces / surfaces / edge lines, scanning, iterative alignment, bend dependent distribution of probing points, generation on CAD data from measuring points, reverse engineering</p> <p>3-15 Good Coordinate Measurement Practice „Culture of good measurements“</p> <p>3-16 Measurement room management</p>

Fig 3: Curriculum of the European training concept EUKOM

utilized with an evaluation tool especially developed for that purpose, which is based on the EFQM model for an assessment of Business Excellence.

- The project results will be published continuously at international conferences, on a current project webpage as well as through articles in international professional journals.
- According to existing associations, which nationally promote education in coordinate metrology, an umbrella organization will be founded, which performs this task in Europe. The foundation preparations are part of final planning for an ongoing use of the project results.

■ Project progress

The present state of the project activities is:

- The European-wide user needs analysis through interviews of the target group members has been finished.
- Based on the training concept AUKOM the Curriculum has been determined.
- As methodology of the learning arrangement a combination of face-to-face session and e-Learning has been defined.
- Ilias has been selected as e-Learning platform and has been configured. Platform handling has been trained in a workshop.
- Learning aims, contents and didactics are presently defined by the project partners and will be elaborated as training

documents and multimedia training materials subsequently.

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■ Publications

- WECKENMANN, A.; GAWANDE, B: *Koordinatenmesstechnik. Flexible Meßstrategien für Maß, Form und Lage*. München, Wien: Carl Hanser Verlag, 1999
- WECKENMANN, A.; ET AL: *Ausbildungskonzept Koordinatenmeßtechnik*. In: *Qualität und Zuverlässigkeit QZ 44* (1999), Nr. 2, S. 164.
- BEETZ, S.; ET AL: *Ausbildungskonzept Koordinatenmesstechnik – AUKOM*. Projektbericht: FQS-DGQ-Band 81-01 (2002), FQS (ed.)
- WECKENMANN, A.; BEETZ, S.: *Training in Coordinate Metrology changes*. In: *Probing* (2003), Nr. 9

■ Project data

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