

The “Virtual CMM” a software tool for uncertainty evaluation – practical application in an accredited calibration lab

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Abstract

As a practicable method to evaluate measurement uncertainties for almost any measurement task on CMM PTB has developed the “VIRTUAL CMM” concept (VCMM). This method is based on Monte-Carlo simulations of the error behavior of a real CMM. Meanwhile the VCMM concept has been integrated in the software of two German CMM manufacturers and within the German Calibration Service (DKD) four laboratories are accredited to calibrate workpieces using this technique. FEINMESS as one of the accredited labs is presenting its practical experiences in this paper.

Introduction

A complete measurement result should consist of the measured value and its uncertainty. The statement of a reliable task specific uncertainty in coordinate metrology is very challenging. This is due to the characteristic of a CMM as a multi-purpose measuring instrument, the large number of uncertainty contributors and their complex kind of propagation. Measurement tasks that include a number of different geometrical features and datums can generally not be described by classical uncertainty budgets.

A way to solve this problem is to use Monte-Carlo based simulation tools to calculate task specific uncertainties as described in [3] or [5]. Together with project partners from academia and industry PTB has integrated the simulation method in commercial software: The “Virtual CMM”. Today, accredited calibration labs in Germany use this technique to perform calibrations of prismatic parts as a essential link in the traceability chain down to the shop floor.

The role of the *Virtual CMM* in the traceability chain

One of the main tasks of PTB as the National Metrology Institute of Germany is to ensure the comparability and reliability of measurement results by making measurements traceable to the SI units. In the field of 3D metrology for prismatic parts, the traceability can be achieved by a calibration chain as outlined in Fig. 1. Starting from the meter definition and its realization by wavelength standards, it propagates traceability to industrial measurements through a chain set up by 2D-artifacts, calibrated CMMs and calibrated workpieces. The most complex chain link is the CMM, which has to take the step from simple 2D artifacts to complex workpieces, which can incorporate a number of complex features with all their task specific contributors. The Virtual CMM simulation software can generate valid uncertainties for all of the measured or derived features and therefore the process of measurement and simulation can be regarded as a traceable calibration. After calibration, these workpieces can be used for experimental uncertainty determination according to ISO 15530 [1]. In order to supply industry with calibrated workpieces PTB established a calibration service under the aegis of the DKD (German Calibration Service) in cooperation with competent calibration laboratories. These laboratories are now accredited according to ISO 17025 to calibrate arbitrary prismatic parts as reference workpieces, traceable in the strict sense. As a result, industry now can be supplied with calibrated workpieces in order to establish traceability of measuring equipment on the shop floor level.

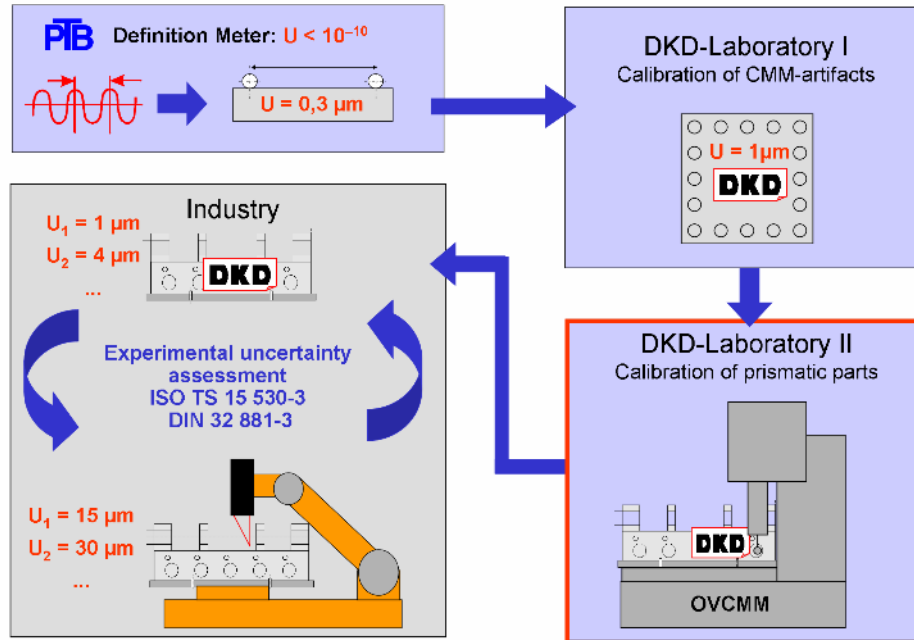


Fig. 1: Calibration chain for CMM

Basic principle of the Virtual CMM (VCMM)

Basis of the VCMM method is the emulation of the measuring process by statistic simulation. These techniques are well established in many domains of nature and engineering sciences. The model of the measuring process and the uncertainty sources affecting it are, analogous to the classical uncertainty budget, the base of the uncertainty evaluation. However the problem is not solved analytically, but by means of a "virtual experiment". The CMM simulator is now integrated in two German CMM software packages (CALYPSO by Zeiss and QUINDOS by Messtechnik Wetzlar). Fig. 2 illustrates the operation of the VCMM. The real CMM probes the workpiece at specified points and records a set of point coordinates. The evaluation software of the CMM calculates the actual result from the set of coordinates recorded. From the recorded set of points further sets are generated by the VCMM by generating systematic and random deviations which are added to the nominal coordinates.

The evaluation software of the CMM calculates results for these additional sets (typically around 100-200) of coordinates and obtains a representative sample of potential measurement results. From these samples, a simple statistical routine is calculating an interval that includes approximately 95% of all results for each measurand. This interval is interpreted as the extended measurement uncertainty U ($k=2$) with a coverage of 95%. The actual measured value and the related uncertainty are stated together in the measurement report of the CMM software.

Essential for the performance of the VCMM is the provision of input parameters to describe all relevant contributions to the error behavior of the CMM. Currently the following contributors are considered:

CMM / Environment	Probing process	Workpiece
<ul style="list-style-type: none"> • systematic deviations of the slideways • uncertainties due to calibration • thermal deformation of the slideways • thermal expansion of the scales • drift effects 	<ul style="list-style-type: none"> • direction-dependent behavior • uncertainties of the stylus calibration • uncertainties when using a probing system with several styli 	<ul style="list-style-type: none"> • thermal expansion of the workpiece • roughness of workpiece surfaces

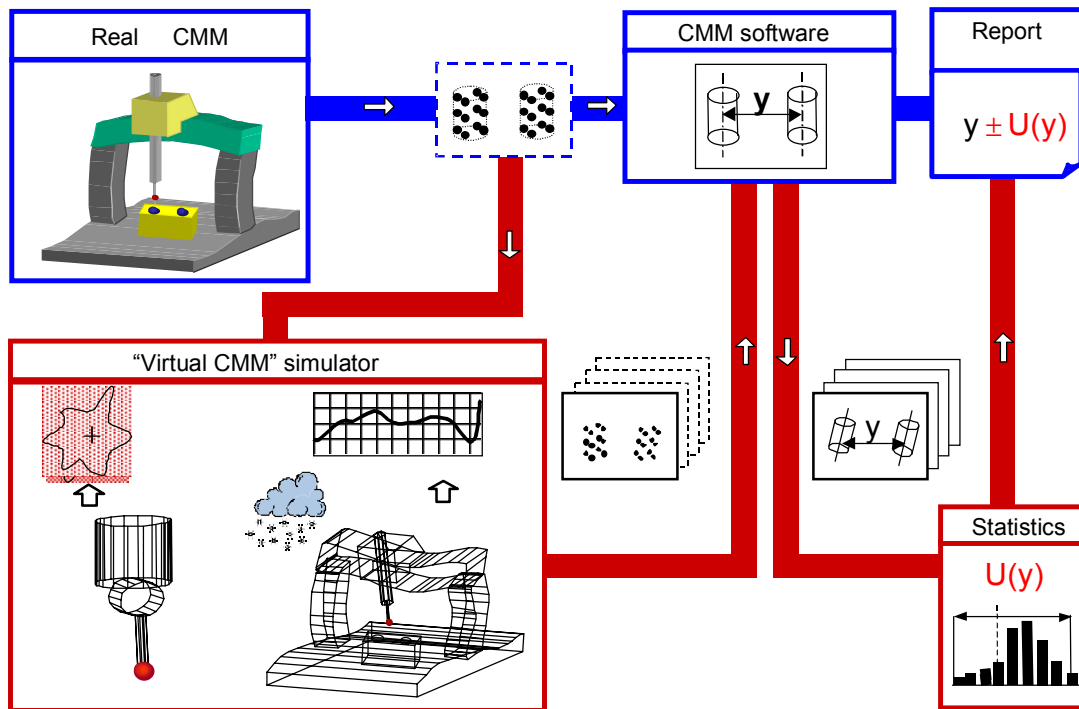


Fig. 2: Data flow of the integrated VCMM (simplified)

Determining input parameters

The input parameters for the simulation software must be determined in advance by specially designed calibration procedures and long term observations. In the following the basic input parameters and the operations for their determination are briefly described. To support the creation of input parameter files PTB has developed the software VCMTool. It can be understood as the user's interface for the parameterization of the error model of the VCMM. VCMTool serves e.g. for entering geometrical parameters of the CMM, temperatures and gradients, material constants and additional constraints. It is also possible to check visually how certain parametric errors are modeled, e.g. changing straightness due to thermal gradients.

To assess the systematic parametric error functions a method based on measurements of calibrated ball or hole plates is used [2]. For this purpose, PTB provides the analysis software called KALKOM. For a full error map it is necessary to measure the plate in at least six positions in the CMM's volume. An upcoming alternative method is the application of high accuracy tracing interferometers (developed by PTB and NPL). This new procedure is less time consuming and also suitable for large scale CMM [7].

To determine error contributions caused by changes of the ambient conditions a long term monitoring of temperature and gradient is essential. This is done using multi-channel temperature logging systems with at least four sensors in the surrounding of the CMM.

After the qualification of a stylus with the standard routine in the CMM control software, there usually still are residual systematic and random deviations which have an effect on the measurement uncertainty. The relating model actually used in the VCMM is developed for mechanically contacting (tactile) probing systems. It describes the behavior in a general form by harmonic functions. This general model has to be individually scaled for each employed stylus. The appropriate parameters are assessed by an additional measurement on the calibration sphere. For this purpose, QUINDOS provides a procedure for probing points according to a specified pattern and transmitting results for storage in the VCMM database.

Concept verification

For proving the proper installation, parameterization and application of VCMM by the calibration labs user comparative measurements on calibrated artifacts have been performed as one prerequisite for becoming accredited. Mainly test cylinders have been used because they can embody a set of different measurement tasks (diameters, length, squareness, coaxiality of different areas of the cylinder, see Fig. 3) and all this geometrical features can be calibrated with sufficient accuracy on CMM using reversal techniques [8].

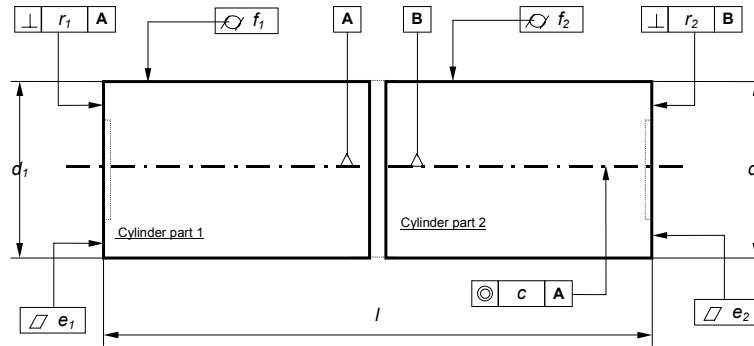


Fig. 3 : Various measurement tasks embodied on a cylinder

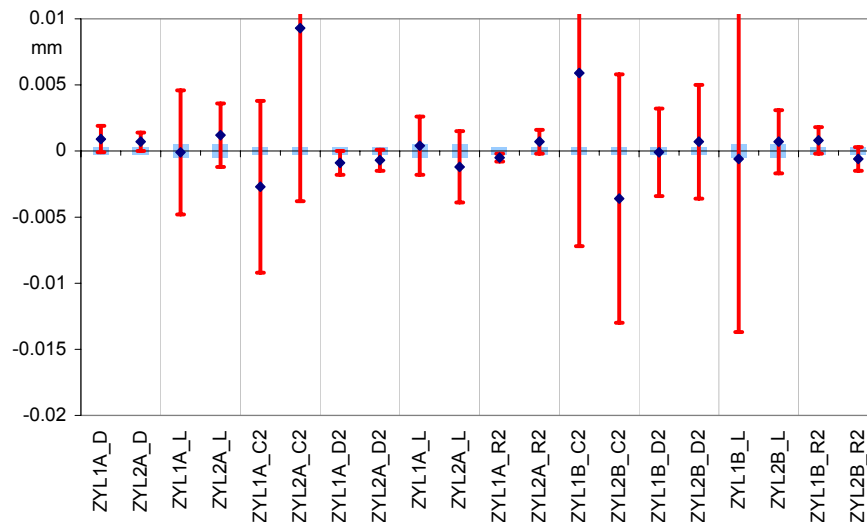


Fig. 4: Deviations of measurement results from calibrated values (both with uncertainties)

To increase the variety of the measuring tasks additionally, also position and orientation of the test cylinder in the measuring volume, the number and distribution of measuring points and stylus configuration have been varied for the test. In

Fig. 4 measurement results are displayed as deviations from the calibration values as well as the uncertainties determined by simulation (error bars) and the uncertainties of the calibration values (boxes) exemplarily for one of the participating laboratories.

Altogether the results show that the uncertainty ranges of all measured values under inclusion of the calibration values overlap. A measure for the compliance can be the E_N value [9], which sets measuring deviations and the uncertainties into relationship. Consistence can be assumed if the condition $|E_N| \leq 1$ is true. For the accreditation this has to be the case for at least 95% of all measured features.

Interim check and re-verification

For the application in a calibration lab it has to be guaranteed that the assumptions, made for creating the VCMM input parameters still correspond to the actual conditions. This is realized by regular monitoring measurements of calibrated artifacts, in order to verify the entire system as “black box”. The measurement task has to be quick and simple but at the same time sensitive to all important uncertainty influences, such as changes of scale factor due to temperature, changes of squareness due to changing temperature gradients or collisions, de-adjustment of the probing system. Two procedures, complying these requirements, are the measurement of ball plates in two crossed positions (according VDI 2617 sheets 5) and the measurement of the so-called ball cube. The decision, whether the VCMM still calculates the "correct" uncertainties, can be determined by comparing the values and uncertainties of the actual test with the calibrated values. If there is are no contradictions the input parameters can be assumed still as valid.

In a research project with CMM manufacturers, metrology service providers and users the PTB develops at present an internet-based system, which makes a "remote controlled" monitoring possible by accredited labs and so in particular release small and medium enterprises of this task [6].

Practical examples of calibration tasks

Within its the first year as a DKD accredited laboratory FEINMESS performed about 25 calibrations of prismatic parts for customers with uncertainties calculated by “Virtual CMM”. Fig. 5 shows some examples to illustrate the variety of calibration tasks. Beside the DKD calibrations, VCMM at FEINMESS is also used regularly for optimizing part programs regarding probing strategy and datum setting.

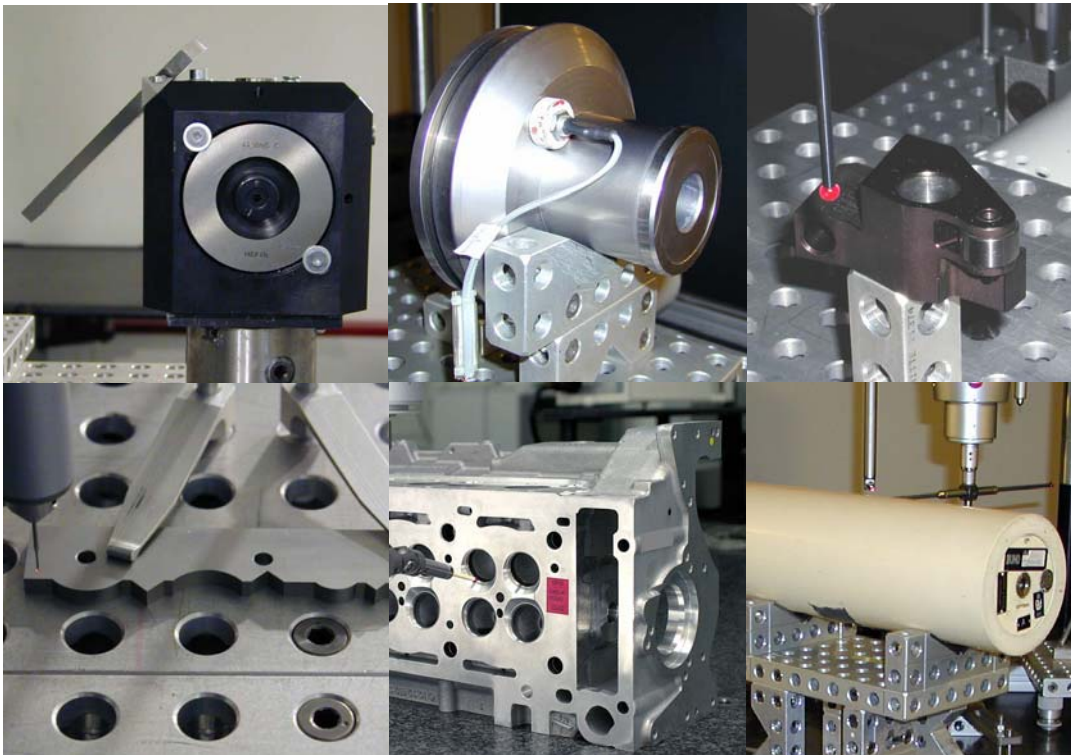


Fig. 5: Examples for calibration tasks

Conclusion and outlook

The „Virtual CMM“ concept is a milestone on the way to achieve traceability in the field of coordinate metrology. This tool is meanwhile integrated and commercially available in two CMM software packages and there is a growing interest from other vendors. Further development targets the extension of the functionality, e.g. integration of models for scanning and rotary tables and also the transfer of the method to other types of measuring devices such as contour tracers. Another important issue is the simplification of the procedures, in particular for defining the input parameters, in order to attract a wider range of users beside the calibration labs.

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