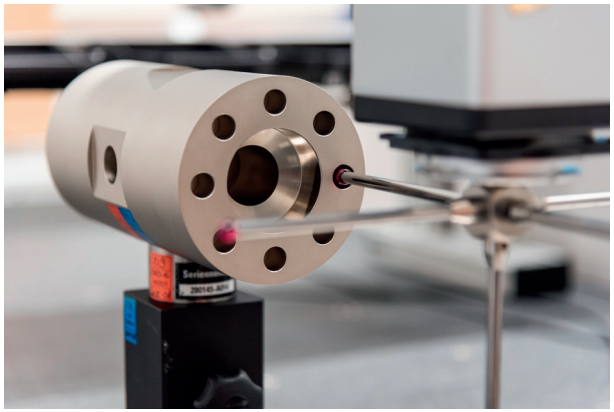
Verification

PTB coordinated and analyzed comparison measurements to verify the VCMM method of determining task-specific measurement uncertainties. The verification measurements were conducted using eight different CMMs from all four project partners involved. Two different reference standards were utilized to determine task-specific measurement uncertainties for a total of 70 features.
The measurements of a steel cylinder calibrated for form and dimensions by PTB allowed for the comparison to independent reference values. Additionally, an aluminum “Multi-Feature Check” reference standard whose properties were similar to real workpieces provided valuable information about the applicability of the VCMM method in industrial environments.



Multi-Feature Check: Reference standard for verification measurements on several coordinate measuring machines.

Reliable measurement uncertainty estimation using the simulations of PTB’s VCMM enables users from science, calibration laboratories and industry to provide task-specific measurement uncertainties under consideration of many influences.

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The Virtual Coordinate Measuring Machine (VCMM)

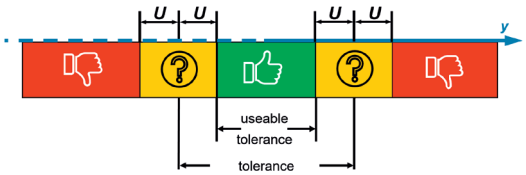
Determination of task-specific measurement uncertainties via numerical simulation

Motivation

$$Y = y \pm U$$

The measurement result Y consists of the best estimated value y and the region between $y - U$ and $y + U$, which is considered to contain a large portion of the distribution of values that can be attributed to Y [GUM, JCGM 100:2008].

The transfer of measurement results consisting of the measured value y and the assigned measurement uncertainty U is essential in industrial quality assurance.

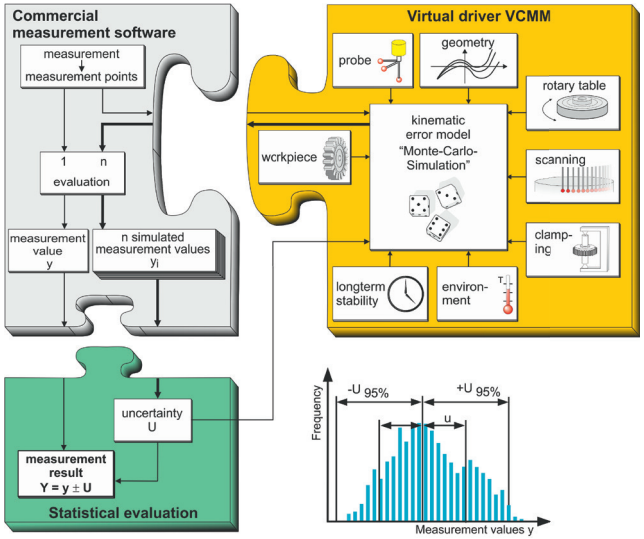


Importance of measurement uncertainty: Reduced usable manufacturing tolerance according to ISO 14253-1

Measurement uncertainties are of the utmost economic importance, since they form the basis for the evaluation of conformance of a part within the specified tolerances. Furthermore, they are an essential element in the exchange of measurement results between machines and allow automatized assessment to take place in digitalized industrial environments. Any error-free and automatic interpretation of data must be reliable and machine-readable – for example, by considering the measurement uncertainty.
Numerical simulations provide an effective and cost-efficient method of determining task-specific measurement uncertainties.
Since the 1990s, PTB, manufacturers, and users of coordinate measuring machines (CMMs) have been developing the so-called "Virtual Coordinate Measuring Machine" (VCMM). In order to account for advancements in technology, the VCMM is constantly being refined and enhanced to include optimized mathematical models and updated procedures.

The VCMM Principle

In the method used in the VCMM, the measured value y of a feature is determined from the captured measurement points by the analysis software of the CMM manufacturer. The estimated measurement uncertainty U is obtained from a large number of repetitive measurements performed by passing the point cloud to the VCMM's kernel and reproducing the measurements in a virtual environment.

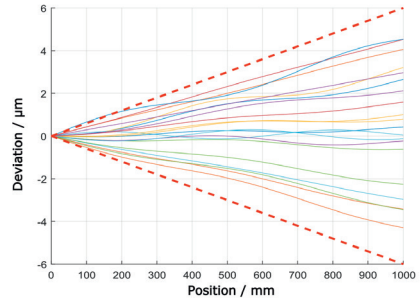


Sketch of the VCMM principle

The VCMM varies the received measurement points according to defined probability distribution functions and input parameters, thus creating a slightly distorted but realistic data set of the feature. It is passed to the CMM's analysis software for the same evaluation as for the initial measurement points. Therefore, an additional realistic measured value can be computed for the feature. The virtual measurements are repeated until the statistical analysis of the simulated results shows only minor variations and can be considered for the determination of the measurement uncertainty U.

Treatment of Uncertainty Contributions

To allow the VCMM to estimate measurement uncertainties, it is necessary to create a digital twin of the CMM based on detailed information about the uncertainty contributions and the influence of the CMM's operational and environmental conditions. To this end, the VCMM is made up of several separate modules that consider these influences using mathematical and physical models. These can be classified according to their sources: influences of the CMM, contributions from the environment and influences exerted by the workpiece under test.
Each of the VCMM's influences is characterized by a set of input parameters containing a value (e. g. mean value) and a probability distribution function with its attributes (e. g. normal distribution with standard deviation); this set is used to generate a virtual point cloud. The input parameters are either individually determined by the user and the manufacturer for each individual CMM or can be obtained from a general classification according to machine classes based, for example, on maximum permissible errors (MPEs). The former method focuses on users who need to achieve the smallest possible measurement uncertainties, whereas the latter method is suitable for users who focus on economic and temporal efficiency. The simulation based on MPE values computes typical deviations within the range of specified MPE values, but does not take into account information about the individual CMM.



Parametrization by CMM class: The curves depict several possible position deviations within the specified MPE values of the CMM class (dashed lines) simulated by the VCMM.