Under Scrutiny

Coordinate Measuring Machines: From Calibration to Measurement Process Capability

PRACTICAL TIP Discussions of the accuracy of a coordinate measuring machine often fall apart when it comes to definitions of different terms. The machines are calibrated at the manufacturer's facility and the defined specifications are checked during acceptance testing. In order to determine measurement process capability, however, the measurement uncertainty must be estimated for the measurement task at hand.

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MANUFACTURERS define specifications to characterize the accuracy that a coordinate measuring machine can achieve, and to provide a means for comparison between machines. These indicate the maximum permissible measurement deviations for standardized measurements of calibration standards under defined conditions. Measurements of real workpieces will typically have greater measurement deviations, because workpieces differ from the calibrated standards and the boundary conditions defined for the specification will not necessarily be met. The measurement uncertainty can be estimated using various methods that address the workpiece properties. Measurement uncertainty and tolerances are then compared to determine the measurement process capability.

Calibration

Once a coordinate measuring machine has been built, systematic measurement deviations must be largely eliminated. To do so, the deviations in terms of pitch, linearity, straightness, and perpendicularity of the axes are determined using various standards, such as glass scales and ball plates. The machine software then applies the deviations determined during this calibration automatically to correct subsequent measurements of real workpieces. The manufacturer is responsible for the calibration procedure. In order for subsequent measurement tasks to have the smallest possible measurement deviations, precisely calibrated standards are used.

Figure 1. Combination of a 3D fiber probe sensor with low probing error and a multisensor coordinate measuring machine with low length measurement error (© Werth)

Specification

The most important characteristics of a coordinate measuring machine are maximum permissible error of length measurement (MPE E) and the maximum permissible probing error (MPE P).

The length measurement error describes the behavior of the machine throughout the entire measuring volume and incorporates the influences of the machine geometry, the measurement axes, the temperature, and the sensor. The probing error indicates the behavior of the machine in a small measuring volume and is largely determined by the behavior of the sensor being used. Geometric deviations in the machine axes have only a slight effect, while reproducibility in positioning has a much stronger influence.

Both characteristics apply only under defined conditions, such as within a certain temperature range. For modern coordinate measuring machines with temperature compensation, larger temperature ranges are permissible. The machine manufacturer can apply additional limitations. For example, the length measurement error for a measurement can be indicated for one or two axes, such as for 2D image processing machines

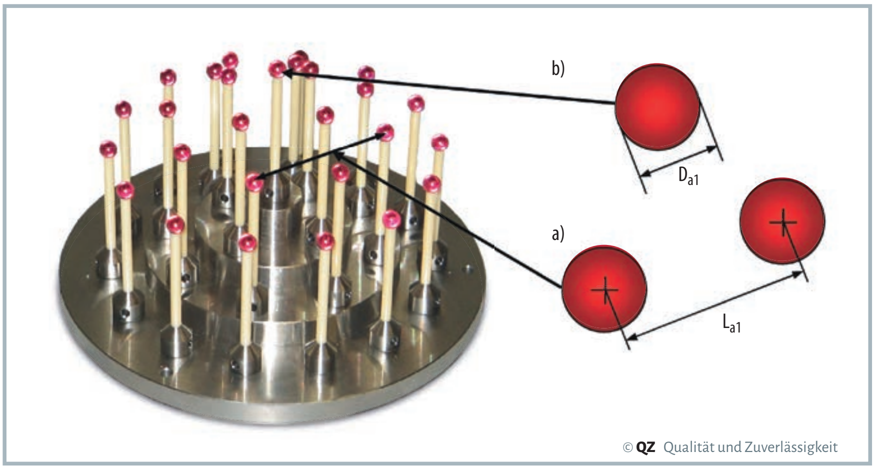

Figure 2. When length measurement error is determined from sphere center spacing, many systematic measurement errors are suppressed (a), so the error of a two-point diameter in the corresponding measurement direction between the sphere centers is added (b) (© Werth)

such as the Werth FlatScope or QuickInspect, or may be valid only in the plane of the measuring table.

A prerequisite for a good length measurement error is the use of a sensor with similar or better probing error. Conversely, in order to achieve a minimal probing error, machines that meet appropriate prerequisites are required. For example, the highly accurate Werth Fiber Probe WFP sensor (probing error up to 0.25 µm) is often combined with the machines of the VideoCheck series, particularly the Werth VideoCheck UA (length measurement error up to (0.15 + L/900) µm (Fig. 1).

Testing and Calibration

When a coordinate measuring machine is tested as part of the customer acceptance test or due to machine maintenance, the deviations from the calibration value of standards are determined. If the length measurement error and probing error are within the maximum value range defined by the manufacturer, then conformity to the specification has been demonstrated and the acceptance test is a success. The procedures are described in the standard DIN EN ISO 10360 and the guideline VDI/VDE 2617.

The measurement uncertainty must be provided for a calibration. In order to be sure that the test is performed in accordance with the standard, the manufacturer or the calibration lab should be in possession of a certificate from a national accreditation service (DAkkS for Germany).

The length measurement error should be checked using bidirectional measurements; that is, the standard should be probed from opposite directions. This procedure is strongly recommended for all types of sensors, because it corresponds to typical, actual measurement tasks such as determining a slot width or a diameter.

Measurements that are merely unidirectional always probe the standard from the same direction. In such cases the deviations from the calibrated value are much lower, because systemic effects such as hysteresis have little to no effect on the results.

Particularly for computed tomography, multi-sphere standards are often used to check the length measurement error. The distances to be checked should not be determined solely by the distance between sphere centers, because the sphere centers are computed from several measurement points from various directions and any systematic measurement deviations that occur due to incorrect threshold value, for example, will be suppressed (Fig. 2).

Measurement Uncertainty and Measurement Process Capability

When determining measurement uncertainty, the entire measurement process must be considered, including not only the machine but also the workpiece and the ambient conditions. A process is described in DIN EN ISO 15530 for determining the measurement uncertainty by measuring calibrated workpieces that also takes different workpiece properties into consideration. This process is expressly recommended for machines with computed tomography, where the radiographic penetration of the workpiece means that its influence is especially important.

Many companies perform measurement system analyses (MSA) or machine capability studies (MCS) using a similar procedure that differs from the ISO standard. The measurement process capability determined from these measurements is described by characteristics such as C_p and C_{pk}, which incorporate the reproducibility of the measurements and the reproducibility and deviation from the calibrated value, respectively.

Alternative methods exist, such as simulation of the behavior of tactile measuring machines or mathematical superposition of various influencing factors. Multisensor coordinate measuring machines enable sensor-specific measurement deviations to be determined by measuring the same workpiece with a second, highly accurate sensor.

In order to ensure measurement process capability, the measurement uncertainty must be significantly lower than the tolerance. A factor of ten is typical. For very tight tolerances, it may happen that this ratio cannot be achieved and the "golden rule of metrology" is not followed. This must be compensated for with appropriately tight manufacturing tolerances. ■

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