ARTIFACT CORRECTION IN COMPUTED TOMOGRAPHY

Flexible and Precise Measurement

The principle of computed tomography causes various artifacts to appear during measurements. Several methods are available to correct the resulting measurement deviations. The most suitable method can be selected for the measurement task at hand.

Figure 1. Coordinate measuring machine with computer tomography for complete and precise measurements, even for workpieces that are difficult to penetrate radiographically.

The integration of computed tomography (CT) in coordinate measuring machines (CMM) has expanded the scope of application of X-ray technology from testing and inspection tasks to high precision measurement tasks. It can be used on various workpieces made of different materials such as plastic or metal (Figure 1). For about ten years now, computed tomography has found increasing application for dimensional measurement in industry and research.

The CT principle is based on reconstructing a virtual object based on radiographic, X-ray images of the workpiece that have been taken in various, precisely known rotational positions (projections). The image points from the X-ray images contain the information of the length of the workpiece that was penetrated by radiation at each position and of the X-ray absorption coefficients of the penetrated material.

When operated correctly, the precision of a CT measurement first depends fundamentally on the machine technology and on the environmental conditions. The machine properties that are relevant here are the magnification (determined by the spatial arrangement of the X-ray source, workpiece, and detector), the properties of the X-ray components (e.g., detector resolution, cathode voltage and focal spot size of the X-ray source, software correction of sensor properties), the runout of the rotary axis, and the performance of the software algorithms for reconstructing the measured volume for determining the location of the surface points (point cloud, e.g. in STL format) from the volume data.

When using classical tactile and optical sensors the influence of the workpiece can often be negligible. For tomography, particularly for measuring large workpieces that are more difficult to penetrate, this is not the case due to the penetration of the workpiece by X-ray radiation and the measurement deviations (artifacts) that this causes.

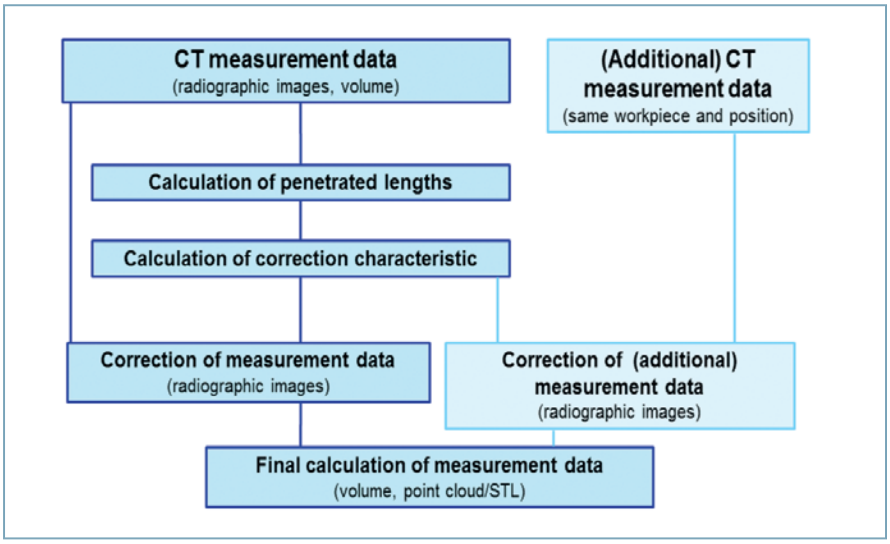

Figure 2. Principle of "Empirical Artifact Correction" (EAC)

Typical Artifacts in Computed Tomography Measurement

Among the most significant physical effects that lead to artifacts and therefore influence measurement results are beam hardening, scattered radiation, and the influence of cone beam geometry. Beam hardening artifacts occur due to the different rates of absorption of various frequency ranges within the relatively broad spectrum X-ray radiation. This effect is not necessarily accounted for in the reconstruction of the radiographic image. This leads to measurement deviations, especially for large penetration lengths. Scattered radiation occurs due to the attenuation and deflection of X-ray photons from the original direction when colliding with electrons of the workpiece material. For multiple scattering, the scattered radiation becomes noticeable as background radiation and also influences the measurement result.

To be able to measure quickly, modern machines use flat panel detectors. The utilization of a conical X-ray beam that this requires allows measurement outside of the ideal center plane (the plane through the focal spot of the X-ray tube, perpendicular to the axis of rotation). This means that reconstruction is only approximately possible, and measurement deviations (cone beam artifacts) occur that increase as the distance from the center plane (cone angle) increases.

Correcting artifacts

Since the introduction of CT in coordinate measuring technology, various proven methods for correcting artifacts have been adopted and new processes developed for precise dimensional measurements. Depending on the measurement task, the techniques of "Empirical Artifact Correction" (EAC), "Virtual Autocorrection" (VAC), or "Multisensor Autocorrection" are used today.

The starting point for "Empirical Artifact Correction" is the consistency of the relationship between penetrated length and attenuation of the X-ray energy (greyscale value in the radiographic image). A material-dependent correction curve is created for this purpose from an empirical reference measurement and is used for correcting the radiographic images, including subsequent measurements of identical workpieces (Figure 2). The advantage of this process is rapid correction of the effects of several artifacts using a single characteristic curve. The correction essentially applies to beam hardening and, to some extent, scattered radiation effects. Especially for very pronounced artifacts, extraction of surface points is not even possible without this method (Figure 3). Due to the considerably simplified correction approach, the precisions that can be obtained in this manner, especially with geometrically complex workpieces, are not always sufficient.

The method referred to as "Virtual Autocorrection" (VAC) is based on the (virtual) simulation of the CT method, starting with measurement data (e.g., master part measurement) or nominal data (e.g., CAD data) of the workpiece itself (autocorrection). The simulation is done for each workpiece type, once with and once without applying the artifact correction. The simulation includes workpiece geometries and material (absorption behavior), the machine properties (e.g., X-ray spectrum and machine geometry) and the physical models for artifact occurrence (frequency-dependent attenuation, statistical simulation of scattering, etc.).

Figure 3. Volume cross section through an injector nozzle prior to (left) and after (right) Empirical Artifact Correction EAC

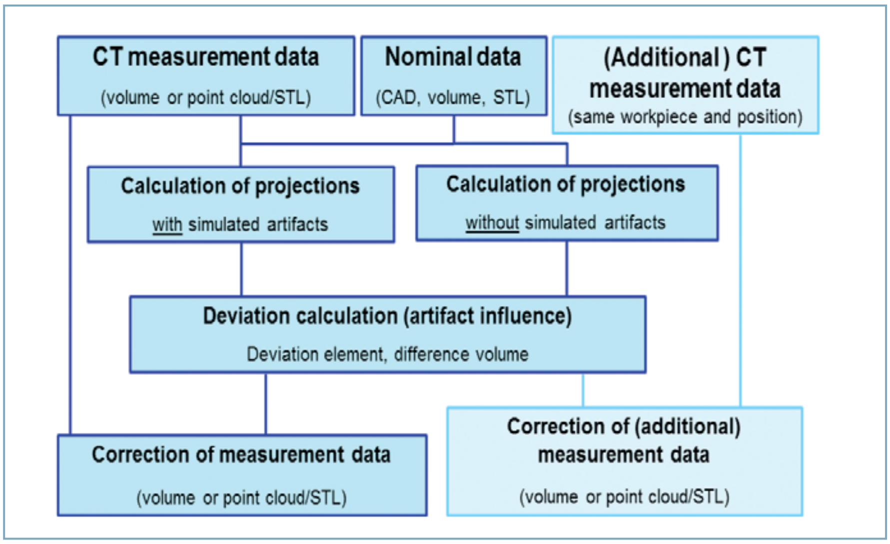

Figure 4. Principle of "Virtual Autocorrection" (VAC)

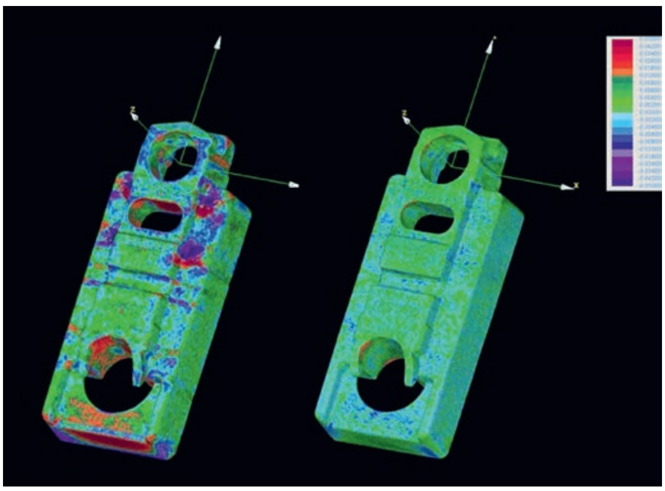

Figure 5. In comparison with the measurement without Virtual Artifact Correction, VAC (left), the measurement deviations with VAC (right) are significantly reduced.

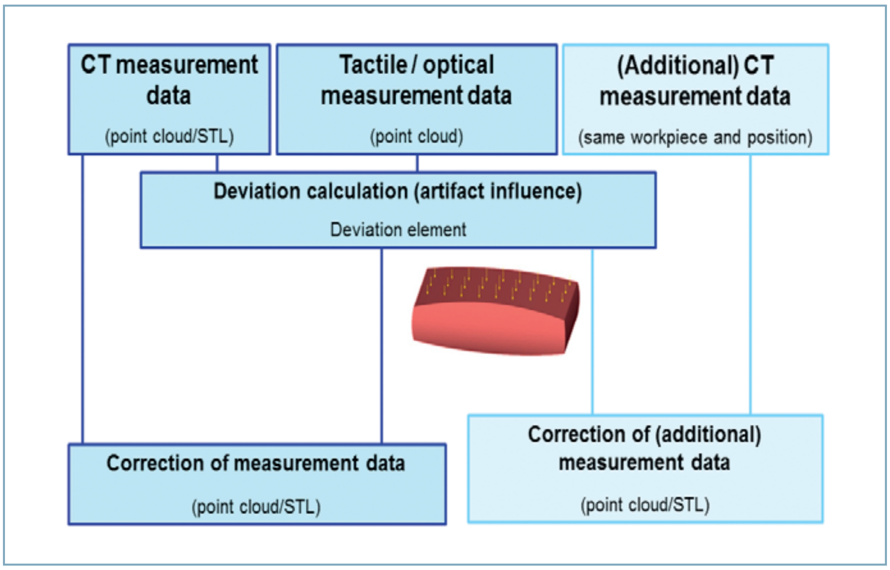

Figure 6. Principle of "Multisensor Autocorrection"

The comparison ("subtraction") of the two simulations results in the correction data that can be applied to series of parts measurements (Figure 4).

The subtraction method eliminates most deviations. This method can be used to address the influence of different artifacts individually. Thus, this method is particularly flexible, so its effort and precision can be adjusted to the task at hand. The VAC can be applied to a wide spectrum of measurement tasks (plastic components, fuel injectors, engine blocks, and much more) (Figure 5). The time required for the simulation depends on the artifacts included and shifts from minutes to hours if scattered radiation is included.

With "Multisensor Autocorrection", the CT measurement is corrected on the basis of a reference measurement of a master part using high precision tactile, optical, or tactile-optical sensors. This can be done on the same measuring machine if appropriate sensors are installed (a multisensor machine). The data sets from the CT measurement and the reference measurement are then already in the same coordinate system and no subsequent adjustment is needed. The deviations that are determined through this comparison for individual dimensions or even for entire surface regions are used to correct the series CT measurement of identical workpieces (Figure 6).

The "Multisensor Autocorrection" is currently the most precise correction method. When introducing X-ray tomography into coordinate measuring technology, high precision traceable measurements of workpieces without "Multisensor Autocorrection" would hardly make practical sense. Nowadays measuring with X-ray tomography alone can produce precisions on the order of a few microns. For high-precision measurement tasks with permissible measuring deviations of less than one micron, the use of "Multisensor Autocorrection" is often still the only viable solution today. With this technique, it is possible to measure the injection holes of a diesel fuel injector with a precision of about 0.5 µm (Figure 7). □

Dr.-Ing. Ingomar Schmidt

▶ Werth Messtechnik GmbH
T 0641 7938 0
mail@werth.de
www.werth.de

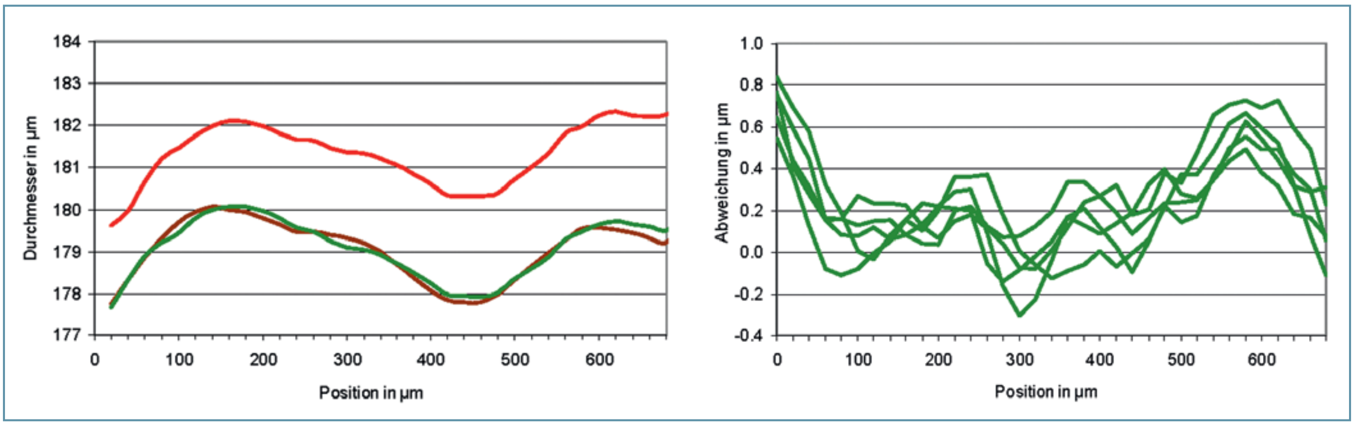

Figure 7. After correcting the CT measurement of the diameter (curve along the injection hole) of a diesel injection nozzle (left, red) by means of a reference measurement with the Werth Fiber Probe (left, brown) the measuring deviations of several corrected CT measurements (right) stay below one micron.