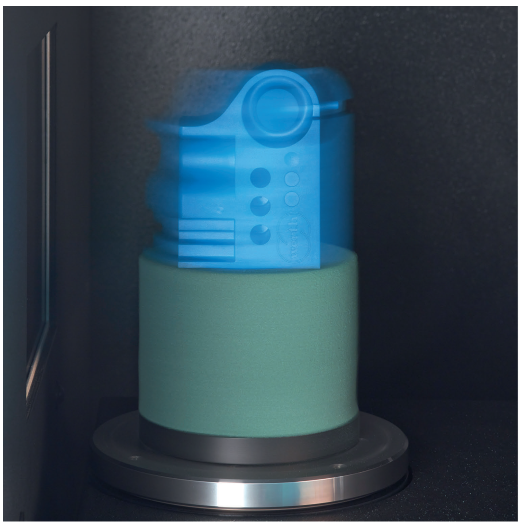
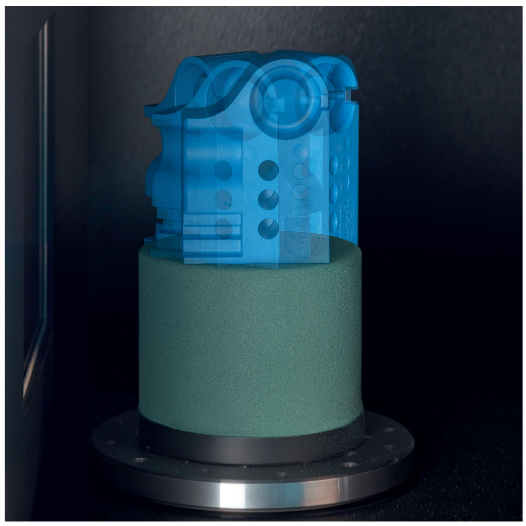
Measuring at the Limit

Special Measuring Methods Extend the Range of Application for Computed Tomography

The requirements of measurement technology vary depending on the measurement task. In addition to the need for high accuracy or short measuring time, the computed tomography sensor also requires the measurability of objects that are difficult to penetrate with X-rays like multi-material workpieces. Different measurement methods are available for such applications.





The OnTheFly-CT (left) enables inline measurement and evaluation in the production cycle by saving the dead times for positioning the sample occurring in the conventional start/stop process (right) © Werth

In coordinate measuring machines with X-ray tomography sensors, the X-ray radiation emitted by the source passes through the sample as a cone beam before it hits the detector (**Fig. 1**). The advantage of this sensor is the non-destructive measurement of the entire sample including internal geometries. The sample is placed on a rotary axis and is completely penetrated by a conical X-ray beam, so that information from all areas reaches the detector. The two-dimensional radiographic images are recorded in different rotational positions. A rear projection in the direction of the focal spot position enables the reconstruction of the sample volume from the radiographic images (**Fig. 2**). The pixels of the detector define a three-dimensional voxel grid at the material transitions. A measuring point for each voxel is calculated from the amplitudes of the surrounding voxels. With this patented subvoxeling process, a significantly better spatial resolution can be achieved than the spatial resolution defined by the voxel size (one tenth and smaller).

Model, Measurement Result, and Deviations Displayed

For geometry evaluation, standard elements (such as cylinders or planes) are determined and linked to dimensions using automatic segmentation or by simply clicking on the patented CAD model. CAD model, volume data, measuring point cloud, and color-coded deviations from a target/actual comparison can be displayed individually or in the same coordinate system superimposed in the WinWerth measuring software and analyzed from all sides. Measured geometric properties (such as angles or deviations in form and position) and 2D cross sections are also displayed. Measurement and inspection take place in the same software, so that the traceability of the results is guaranteed throughout and only one software license is required.

Magnification and measuring range depend on the position of the sample in the cone beam. The closer the sample is to the X-ray source, the higher the magnification and the smaller the measuring range in the cone beam (**Fig. 1**). However, the resolution depends to a large extent on the pixel density of the detector and the focal spot size of the X-ray source.

Artifacts are created in the radiographs by various physical effects. These cause measurement errors when determining the geometric properties of the sample. The radiation generated in the X-ray source is not monochromatic. »

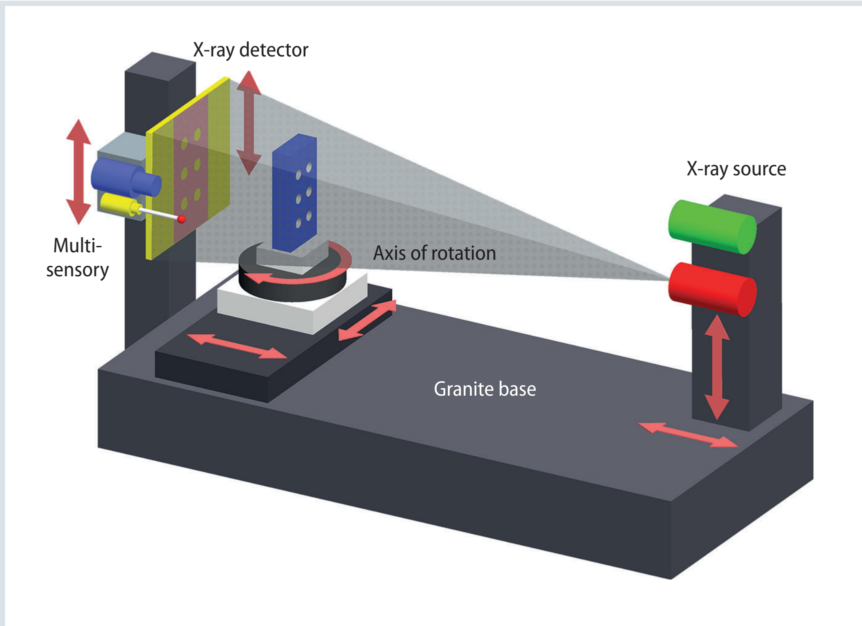


Fig. 1. In the cone beam between the X-ray source and the detector, the sample is penetrated in different rotational positions Source: Werth, graphic: © Hanser

When penetrating the sample, the stronger absorption of low-frequency radiation shifts the frequency spectrum in direction of the higher frequencies. This effect depends on the material and geometry of the respective sample and is therefore not taken into account in the mathematical principle of X-ray computed tomography. This results in artifacts known as beam hardening, although modern correction methods can largely eliminate them.

Wide Measuring Range and High Resolution

In case a sample does not fully fit into the cone beam, the measuring range can be increased to several times the detector area, by successively scanning individual areas using raster tomography. For example, in order to increase the resolution of samples with many small details, the magnification is set to the required level and the correspondingly reduced measuring range can be expanded by raster tomography.

In raster tomography, radiographic images of the various sample areas are recorded one after the other (for example by moving the sample in the cone beam). Compared to a field of view tomography, in which the entire sample is captured in one image, this can also be referred to as "In the Picture" tomography. The images of the various areas are combined to form an overall image; the sample volume is reconstructed from the overall images in the various rotary positions. When using slim samples, the raster scan is arranged along the axis of rotation; with disc-shaped samples the scan will be made perpendicular to the rotary axis. For compact measurement objects, the methods can be used in combination in both directions.

High-Resolution Areas with Multi-ROI-CT

With Region of Interest (ROI) and Multi-ROI-CT, only partial areas of the sample are measured with higher resolution. This

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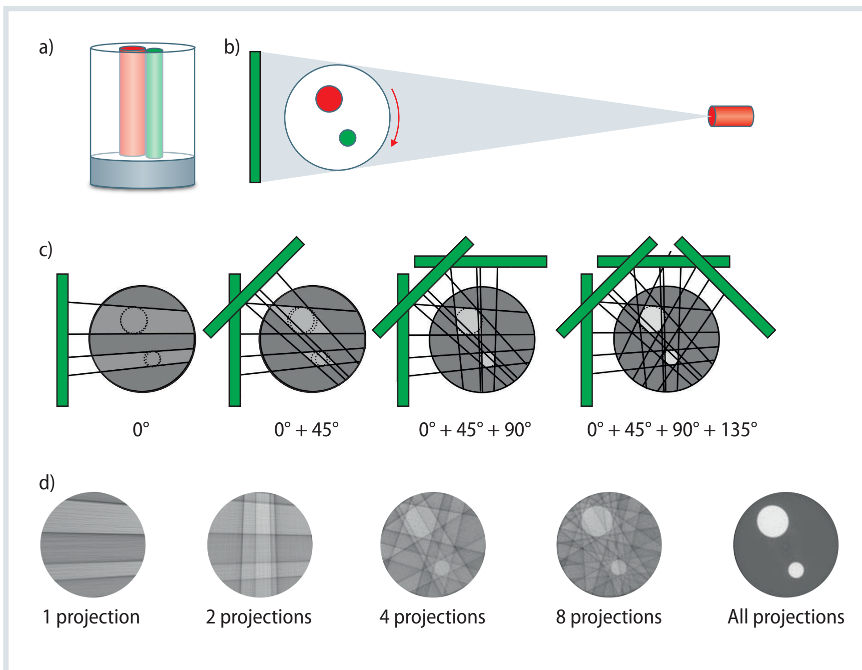

Fig. 2. Calculating volume data by back projection of filtered radiographic images: a) object; b) X-ray beam path in one section plane; c) principle of stepwise back projection and superimposing; d) result of reconstruction with different numbers of back projections for a real sample

Source: Werth, graphic: © Hanser

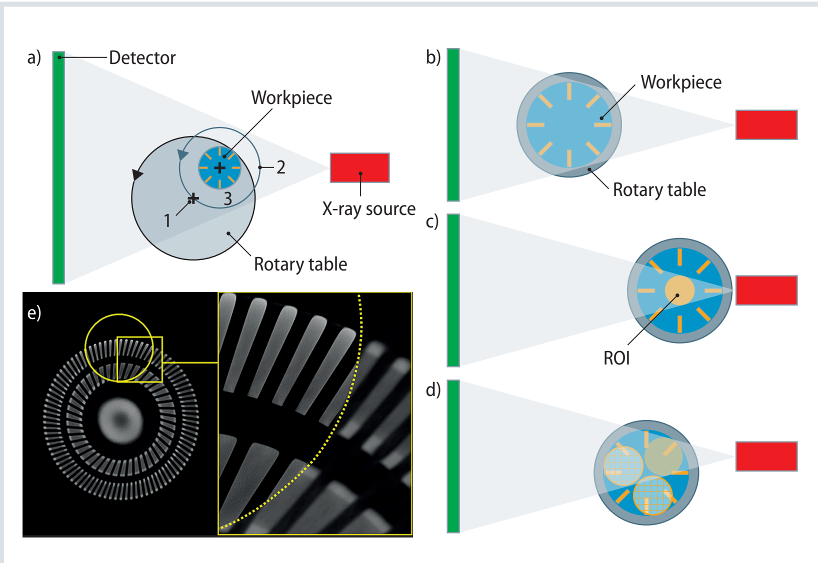

Fig. 3. Measuring principles: a) eccentric CT: as the rotary table rotates around its own axis (1), it is simultaneously moved by an X-Y stage along a circular path (2) around the center (3) of the sample. A virtual axis of rotation result at (3); b) overview CT; c) ROI-CT: zone at the center of the sample; d) Multi-ROI-CT: the principle of eccentric CT is used here to tomographically scan several areas e) measurement result of the high-resolution region

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saves measuring time and storage space for samples with only a few closely tolerated geometric properties or only a few small geometric elements, compared to a raster tomography of the entire sample. The prerequisite for the Multi-ROI-CT is the patented eccentric computed tomography. This means that the sample can be placed anywhere on the rotary axis and does not have to be manually aligned (so that its center point is on the physical rotary axis). This reduces the amount of work and time required and increases operating comfort. The measuring software automatically calculates a virtual rotary axis defined by the operator in the center of the area of interest. The rotary table rotates around its axis as in conventional "In the Picture" tomography, whereby the sample rotates out of the center of the cone beam. Therefore, the rotary axis is moved simultaneously on a circular path around the virtual rotary axis with the help of the linear machine axes. In this way, the sample is in the center of the cone beam in every rotary position (**Fig. 3a**).

Even in the case of abnormalities in the sample volume, an ROI-CT of the corresponding area can be performed, which presupposes an " In the Picture" tomography with lower resolution (**Fig. 3b**). Then, the section of interest is tomographed at a higher magnification and resolution (**Fig. 3c**). During reconstruction, the voxel information from both measurements is combined so that the resulting sample volume has areas with different resolutions (**Fig. 3e**).

The Multi-ROI-CT combines the advantages of ROI and eccentric computed tomography. With this method, it is also possible to select several high-resolution areas at any position on the sample (**Fig. 3d**). During evaluation, the geometric elements from the overview CT and the various ROI measurements can be linked together.

High Density Samples and Multi-Material Objects

In order to penetrate denser materials with X-rays, a higher tube voltage is required, which produces radiation with a higher frequency. With the tube voltage, the focal spot size also increases, so that resolution and measurement accuracy decrease. The microfocus X-ray tubes used in a Werth computed tomography system have a small focal spot even at high tube voltages, so samples that are difficult to »

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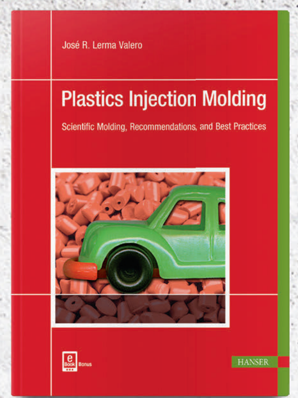

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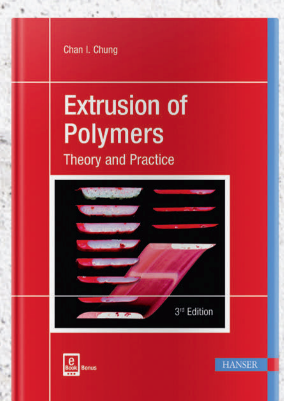

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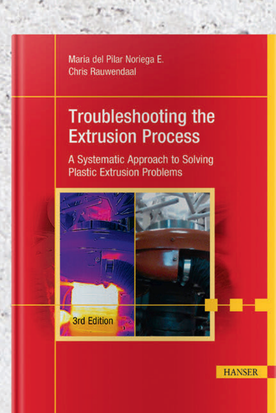

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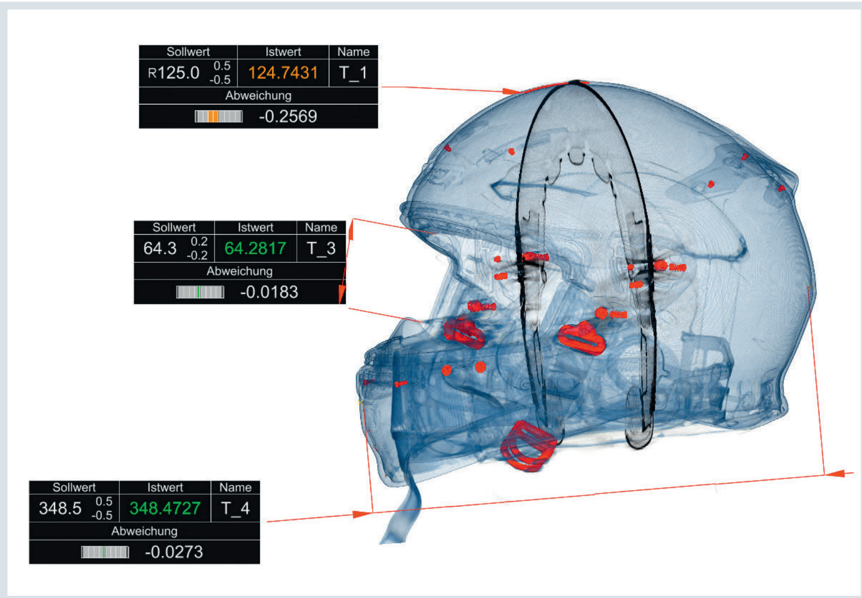

Fig. 4. Two-spectrum tomography can also be used to measure multi-material samples with high accuracy. Here the different materials of a motorcycle helmet are shown in blue and red, a cross section with measured geometric properties in black © Werth

penetrate can be measured with low measurement uncertainty.

In the case of multi-material objects (e.g. metal-plastic components such as assembled connectors) the included metal parts, which are difficult to penetrate, cause artifacts that make measurements of the plastic more difficult. The reduction of artifacts with two-spectrum tomography reduces measurement uncertainty or even makes a measurement possible in the first place. For this purpose, two CT measurements with different tube voltages are linked to one volume in the measuring software. The resulting radiation spectra with different frequencies can be tuned to different materials so that fewer artifacts occur (**Fig. 4**).

Measurements Every Second

Due to extremely low exposure times, OnTheFly-CT enables a strong reduction in the measuring time with constant data quality throughout, with less measurement uncertainty over the same measuring time as in conventional start-stop operation. The normally needed interruption of the rotation of the sample to take each radiographic image to prevent motion blur during exposure is not necessary anymore. The OnTheFly process saves these dead times by continuous turning. The motion blur is reduced (by extremely short exposure times) and the number of radiographed images is increased, resulting in the same low measurement uncertainties as achieved in start-stop operation. Typically, 10,000 radiographic images are captured in a few minutes and the sample volume is reconstructed [1].

As in conventional start/stop operation, the sample volume is reconstructed in real time so that it can be evaluated immediately after the scan. The OnTheFly-CT is a prerequisite for inline measurement and evaluation in the production cycle with CT sensors. For example, the desired dimensions for aluminum samples with a size of approx. 150 mm can be determined in 30 s, a nominal/actual comparison is carried out, and the sample is checked for defects. Despite the significant reduction in measurement time compared to conventional start/stop operation, the specification of the CT devices according to VDI/VDE remains unchanged.

Conclusion

Special measuring methods extend the application range of the CT sensor to high demands on measuring range, resolution, measurement uncertainty and measurement time. Initially, computed tomography measurements were widely used in the plastic injection molding industry. However, large and difficult to penetrate objects, such as engine blocks or car seats, as well as multi-material samples, can now be measured with high accuracy. ■