A „Sharp“ Look into the Workpiece

Structural and Positional Resolution in X-Ray Tomography

PRACTICAL TIP When selecting a coordinate measuring machine with a computed tomography sensor system, the resolution required for the measurement task must be considered. The interplay of the detector, X-ray source, and location of the workpiece is critical. If the machine components are properly matched, micro-features can be measured even within dense, thick-walled workpieces.

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IN COORDINATE measuring machines with computed tomography (CT), the workpiece is positioned between the X-ray source and the detector (Figure 1). Rotation of the workpiece allows 2D radiographic images to be recorded from various different directions. The X-ray radiation is attenuated, depending on the material and radiographic length. A mathematical method is applied to the radiographic images to reconstruct a 3D model of the workpiece. This model is composed of three-dimensional voxels (volume pixels) and is therefore also referred to as the voxel volume.

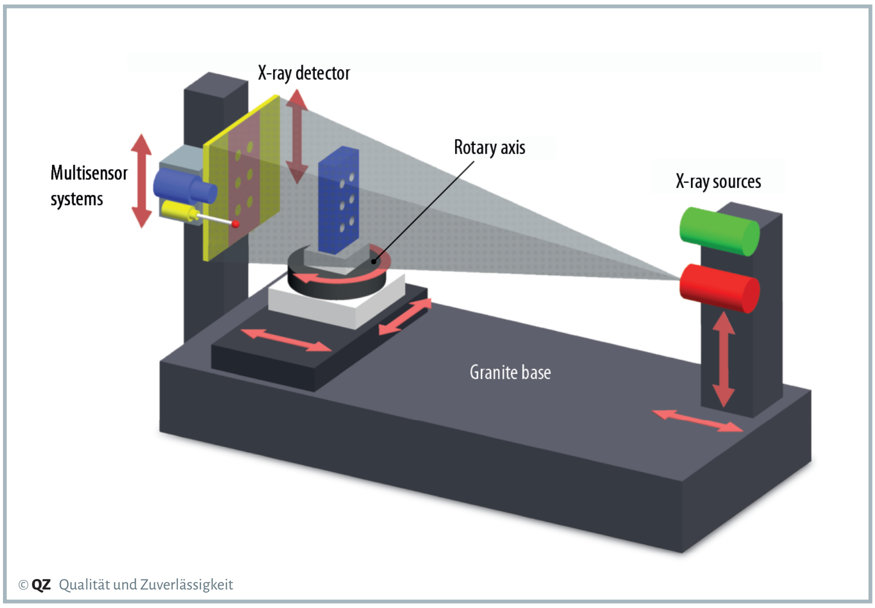

Figure 1. Structure of a coordinate measuring machine with computed tomography (Source: Werth Messtechnik)

Structural...

In addition to high repeatability (using precise machine axes, among other things), a resolution level that matches the measurement task is essential for accurate CT measurements. The structural (spatial) resolution of a system is understood to define the ability to differentiate very small structures from each other. For coordinate measuring machines with computed tomography sensor systems, this corresponds to the ability to detect features of a given size within the voxel volume. For a qualitative analysis of the workpiece, such as detecting cavities or cracks, only the structural resolution in the voxel volume matters.

For dimensional measurements on workpieces, surface measurement points must be generated from the voxel volume and linked to dimensions. The resulting structural resolution for dimensional measurements must be sufficient to calculate the dimension from the measurement points. This places significant requirements on the system. The features (such as holes or radii) must not only be separately detectable, they must also be dimensionally measureable. The structural resolution required for the measurement task is a function of the size of the smallest feature to be measured.

The voxel size must be selected such that the feature covers several voxels in all three spatial directions. This is the only way to be sure that enough material transitions, and therefore measurement points, are reliably detected and defined in order to be able to derive the parameters of the geometric elements such as cylinders or planes.

... and Positional Resolution

The positional resolution also plays an important role in dimensional measurements. The positional resolution in coordinate measuring technology describes the smallest measureable displacement of a measurement point, and substantially influences the variation of the measurement results (repeatability) and thus the measurement uncertainty. The method of local edge position detection patented by Werth allows

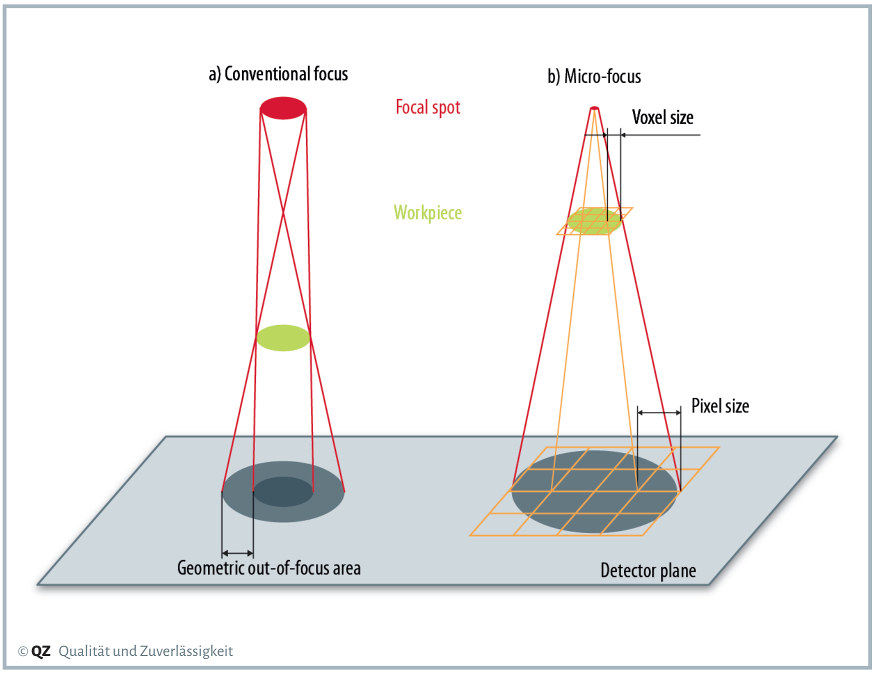

Figure 2. a) X-ray tubes are a limiting factor for structural resolution due to the size of the focal spot (out-of-focus area). b) The structural resolution is also limited by the voxel size, which is determined by the pixel size of the detector and the magnification. (Source: Werth Messtechnik)

the location of measurement points to be determined at subvoxel resolution. This process enables the determination of the edge position within less than one-tenth of a voxel, and also ensures a much lower measurement uncertainty.

Detector and X-Ray Source

The detector and the X-ray source have a critical influence on the structural resolution. The size of the detector limits the size of the measurement range for measurements „in the image", as the entire workpiece must fit into the cone beam between the focal spot of the X-ray source and the detector (Figure 1). The size and number of pixels (resolution) of the detector determines how finely the workpiece or the capture portion of the workpiece is resolved by the 3D voxel raster.

With a large number of pixels and therefore voxels, a high structural resolution is at least theoretically possible. In practice, however, structural resolution is also influenced greatly by the size of the focal spot of the X-ray source. As the size of the focal spot increases, the out-of-focus area becomes larger as the X-rays propagate from different locations of the focal spot (Figure 2a).

Due to the magnifying nature of the CT image, the voxel size depends on the pixel size of the detector and on the position of the workpiece (Figure 2b) within the cone beam. If the workpiece is moved toward the X-ray source, the edge length of the voxel is reduced. Immediately in front of the source the voxel size is minimal, but the measurement range is very small. For machines with a large distance between the X-ray source and the detector, a higher imaging scale is available for the same distance between the workpiece and the X-ray tubes and the same detector. The workpieces can be measured at higher structural resolution.

Measurement Range and Resolution

If the focal spot of the X-ray tube is relatively large, then although the minimal voxel size can be set for maximum magnification, this will not produce the greatest possible structural resolution. The voxel volume will be out of focus. Alternatively, the workpiece can be positioned closer to the detector, and a larger measurement range is achieved „in the image." In practice, the workpiece position is often set so that the influence of the detector and focal spot is about the same, and the optimal structural resolution is achieved. However, the right compromise must be found with respect to the required measurement range.

Using raster tomography, it is possible to precisely merge several detector measurement ranges (measurement „on the image"). This can also be used to measure larger workpieces at maximum resolution. Using ROI tomography, local zones of the workpiece (regions of interest) are measured at higher magnification and resolution than the overall workpiece. This saves measurement and processing time and reduces the size of the voxel volume.

A coordinate measuring machine with a CT sensor must have both a detector with a large number of pixels and an X-ray source with a small focal spot in order to enable the maximum structural resolution for measuring small features. Using a micro-focus tube such as the Werth 300 kV transmission tube in the Tomoscope HV Compact, the size of the focal spot and the size and number of pixels in the detector are optimized. Even at relatively high power levels, the available focal area is just a few micrometers in size. This means that even workpieces that are difficult to penetrate can be measured precisely at high structural resolution. Techniques such as raster and ROI tomography, as well as artifact and drift correction methods, contribute greatly to improving resolution. ■

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