X-rays measure

X-ray computer tomography has become an indispensable medical examination aid. Three years ago, Dr. Martin Simon started Volumetrik GmbH in Singen, Germany, with the intention to apply the CT X-ray technology for industrial inspections. Much older is the family-owned Wenzel Metrology Group in Wiesthal, Germany, a well-known supplier of high-precision coordinate and gear measurement machines. The Wenzel management had the brilliant brainwave to acquire Simon's Volumetrik to expand their measuring machine programme with instruments that are not only able to look into, but also inspect and measure the – often hidden – interior of industrial objects. Combining the disciplines of these two firms proved to be a perfect and fruitful marriage, which led to the birth of two sophisticated measuring machines: the exaCT® M for large objects and the exaCT S for smaller ones.

• *Frans Zuurveen* •

For the exaCT range, see Figures 1 and 2, Wenzel contribute their skills in accurately machining granite and metal base plates and parts including precision slides and position measurement systems, whereas Volumetrik contribute their knowledge of computer tomography including X-ray detector and source technology. This not only applies for the hardware but also for the indispensable software, without which X-ray tomography would be absolutely impossible. Here an essential difference between medical and industrial applications must be emphasized: the human body remains stationary, whereas the industrial object rotates, with the X-ray detector and source remaining stationary.

Figure 1. The exaCT M measuring machine from Wenzel Volumetrik.

Industrial X-ray CT technology, as applied in Wenzel exaCT contactless measuring machines, makes it possible to look into the interior of objects. Thus faults in castings

inside objects

Figure 2. The Wenzel Volumetrik exaCT S.

and forgings can be revealed non-destructively, including cracks, pores, pinholes, inclusions and other inhomogeneities. Such faults not only are made visible but also their quantity, dimensions and positions can be displayed. Other important application areas are wall thickness analysis, tool and plastic component optimization and joining technology testing. The exaCT machines also are highly valuable in designing and prototyping components, and in reverse engineering, where CAD data easily can be obtained from an existing product. Moreover it is possible to measure products in terms of deviations from CAD data, and deviations from a master model, thanks to user-friendly software.

Objects of most kinds of material can be measured, including metals and plastics. But the walls of steel parts should not be too thick and objects from heavy metals like lead are excluded, of course.

How industrial CT works

Computer tomography visualizes the interior of an object by scanning it with an extremely small X-ray source. A complete CT image is being built up from the sum of a series of images on a flat X-ray detector, where each image corresponds to a certain angle of rotation of the object around an exactly defined axis. The detector consists of millions of X-ray sensitive elements, to some extent comparable with the elements in a TV LCD or plasma screen. The object can be thought to consist of a great number of volume elements, called voxels. Each voxel contributes to the attenuation of an X-ray beam that ultimately hits one detector element. This attenuation can be translated in a grey level that corresponds with the X-ray dose on that element. The available number of grey levels depends on the bit rate of the analog-digital converter connected to each detector element. A powerful computer uses specialized algorithms to reconstruct the volume being imaged by attributing a grey level to each voxel. Another software programme calculates sharp transitions in the object by interpolation between voxels, thus creating a higher resolution than purely defined by the size of each voxel. They include transitions from material to air or from one material to another.

For real measurements in objects, the CT process requires precise knowledge of many geometrical parameters, such as the distances between source, detector and the axes of object rotation. The overall accuracy is – among many other factors – a function of the geometric resolution, which is the ratio of the sample diameter and the number of pixels in a detector row. The X-ray spot size also plays an important part when measuring small objects and can be almost as small as 1 μm. Often air bearings are applied for the linear slides and the rotation table.

Configuration and safety

The differences between the M- and S-type exaCT machines firstly concern the minimum and maximum object dimensions: for M 100 to 250 mm, for S 35 to 75 mm. They also differ in the basic configuration. In the exaCT M the rotation table has a fixed place between X-ray source and surface detector and a vertical slide is used for positioning the object with respect to the detector. In the S version the object table is able to move between source and detector, and therefore has been mounted on a Wenzel precision slide with measuring scale. An integrated video camera and marking laser facilitate object positioning.

Of course, working with X-rays demands extra safety requirements. That is why CT measuring instruments are provided with a rather heavy casing and a safety door with X-ray shielding material, i.e. steel of sufficient thickness. Switching on the X-ray tube can only be done when the safety door has been closed. In addition to these and other

Figure 3. Working with the Nikon XT H 225 CT measuring machine.

Figure 4. The Nikon Metrology 225 kV Ultrafocus X-ray source (left) and the silicon flat panel-detector Varian 2520 (right) with a piston as the object to be inspected.

safety provisions, the machines have to conform to DIN 54113.

Essential components

As pointed out before, CT would be absolutely impossible without powerful software. This article, however, deals with the hardware rather than with this essential 'virtual' component. The most important hardware components are the X-ray source, the X-ray detector and the object table with precision bearing and rotation-angle measurement device.

Most industrial CT machine manufacturers source their X-ray tubes. They typically absorb up to 1,500 W electrical power at a maximum anode-cathode voltage of 225 kV. It is very important to concentrate the X-ray emission in a very small spot, with a diameter of a few micrometers. From the electrical power absorption of the tube only a very small part is converted into X-ray energy; the rest is transformed to heat in the anode. This tube part therefore must have a high melting point and thus consists of tungsten, cooled by – mostly – water or by air. Needless to say that the realization of a stable, small and powerful X-ray spot is quite challenging.

At the other end of the X-ray optical system the detector constitutes the second essential component. Wenzel Volumetrik produces this component in-house. Such detectors used to convert X-ray energy into electrical energy via an intermediate conversion step into visible light. But it is not unlikely to presume (company secret!) that modern detectors directly convert the X-ray energy on a detector pixel into electrical energy. A detector typically may have a maximum of $4 \cdot 10^6$ pixels with a minimal size of 20 µm. The depth of the analog-digital conversion for each pixel mostly amounts to 16 bits, which means that every pixel can be read with a resolution of 65,536 grey levels.

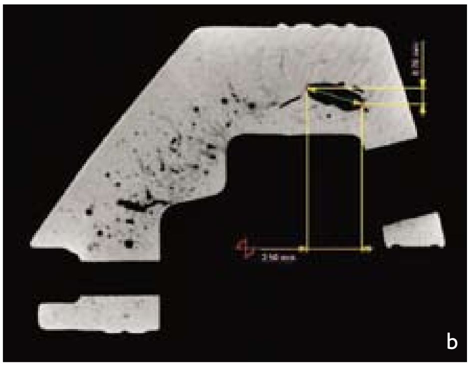
The third essential element in the imaging chain is the table on which the object to be measured turns. The Wenzel mother company shows its skills by providing the exaCT machines with a high-precision table with air bearings or – in cheaper versions – with roller bearings. Optical measuring scales allow rotation of the object with high incremental angle accuracy.

Accuracy

Wenzel Volumetrik makes a bit of a mystery of the overall accuracy of their exaCT machines. This CT manufacturer states that there still does not exist company-wide agreement about the exact definition of the accuracy of CT measuring machines.

With a detector pixel size of 20 µm and a resolution that equals the ratio of object diameter and pixel quantity in one row it seems reasonable to assume that the accuracy of CT measuring machines is positioned in the µm range, obviously not in the nm range.

Figure 5. The Werth Tomoscope HV Compact CT measuring machine.



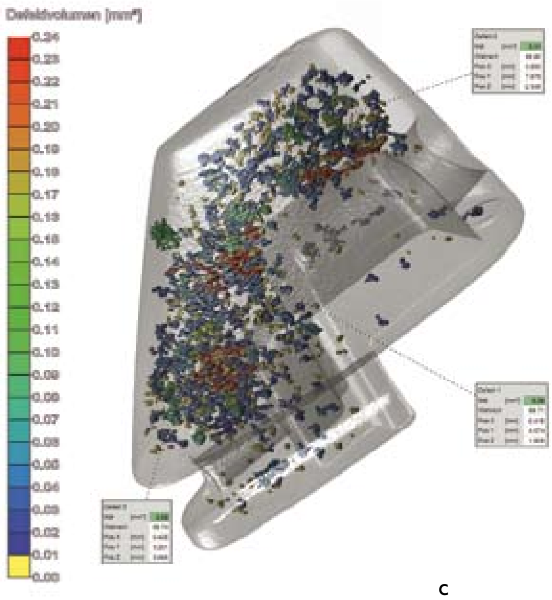


Figure 6. exaCT measuring of a cast-aluminum part.
(a) A seemingly perfect part.
(b) A virtual section of the product, showing porosity.
(c) Presentation showing all flaws in colour; on the left a colour code for pore volume.

Nevertheless, Nikon Metrology (originally X-Tek and an important provider of X-ray and CT systems) states that the accuracy of their XT H 225 industrial CT scanning machine, see Figures 3 and 4, although depending on many factors, has an extreme value of 1 µm with a feature recognition size of 500 nm.

Werth in Giessen, Germany, delivers its TomoScope, see Figure 5, and TomoCheck measuring machines with so-called multi-sensor technology ('Multisensorik'), including a micro-fibre touching sensor with a minimum ball-probe radius of only 10 µm. These complementary measuring devices make the calibration of Werth CT measuring systems relatively easy. For measuring plastic prototype parts, Werth claims an accuracy of a few micrometers. A Werth Tomoscope reduced the release process time for a complicated plastic tool from several days to some hours, compared to measuring with a conventional coordinate measuring machine.

Anyhow, apart from the foregoing discussions about accuracy, industrial CT machines offer many innovative advantages, as discussed below.

Application examples

A fine application example is the measurement of the seemingly perfect cast-aluminum part of Figure 6a. Figure 6b shows a virtual section of the product, provided by an exaCT machine, without really cutting the object. It shows many porosities, with their dimensions, if required. Figure 6c shows one of the presentation options of the exaCT: all flaws are visible and colour coded for pore volume.

Another application example is the measurement of a hydraulic hose with different material compositions in- and outside. Even the reinforcing mesh of the hose can be displayed in a different colour. Industrial CT tomography is also valuable to check the assembly of components. Individual parts can be displayed in different colours. Also the correct assembly can be proved and gap widths can be measured.

To conclude

Industrial computer tomography is a relatively new measuring technology. Looking inside objects combined with precision measuring provides new opportunities for product-quality improvement programmes. When generally accepted accuracy definitions come into being, mutual comparison of the products of various suppliers becomes easier. One can imagine that it will not last long before CT measuring equipment becomes an indispensable part of advanced measuring rooms.

Author's note

Frans Zuurveen is a freelance text writer who lives in Vlissingen, the Netherlands.

Information

www.wenzel-cmm.com
www.nikonmetrology.com
www.werth.de