



High voltage microfocus CT for inspection of dense, complex parts

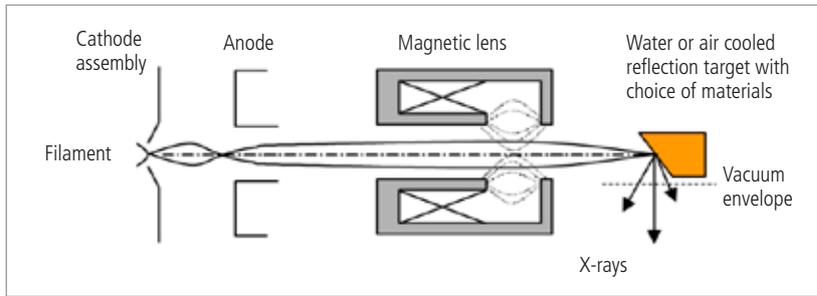


By now most of us in the metrology world have seen beautifully rendered images from Computed Tomography (CT) data. We see images of bones, fossils, dinosaurs, teeth, and of archaeological treasures, and hear about various universities that use CT systems. But perhaps we are left wondering, is this a viable inspection tool in terms of capabilities and cost, or is it just an experimental toy? Don't be fooled. CT's accuracy, ability to measure internal and external dimensions simultaneously without destroying the part, and the insight it provides through the additional fourth dimension of material density, are rapidly making it the must-have tool of quality and production departments. And constraints of material density or large parts? The unique Nikon metrology high voltage microfocus XT H 450 is capable of measuring large parts and penetrate dense materials, opening new CT inspection applications for turbine blades, aluminium castings or for sizable parts such as fossils or rock samples.

Better insights and higher productivity: the reality of today's manufacturing

Today manufacturers face ever-shorter lead times for introducing new products at lower costs. Therefore it is desired that the number of prototype cycles or physical prototypes are reduced. Destructive testing is no longer wanted as a multitude of tests need to be carried out on a single prototype. To realize these gains, the traditional methods fall short. Tactile or scanning CMM inspections only provide dimensional insight of outer dimensions. Complex structures in the internal object can only be investigated by disassembling or cutting the part. And structural deficiencies are invisible or impossible to quantify, leading to sub-optimal production parameters or inferior product quality.

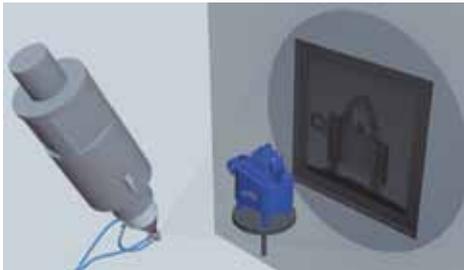
CT offers a solution that is easy-to-use, fast and provides detailed insight, both in dimensional inspection, material structure and assembly. These insights result in faster problem solving and more effective decision making. Production engineering will also need less expensive prototypes and have little or no scrap. This saves both money and time in optimizing the manufacturing process. This all leads to higher productivity and shorter time to market.



The electron beam is focused using a magnetic lens onto a reflection target.



A microfocus X-ray source equipped with a rotating target increases X-ray flux by a large factor, allowing for faster data acquisition or higher data accuracy



X-rays that penetrate through an object are captured by a flat panel detector to create a 2D radiography image

A few words to explain how CT works

CT is fundamentally a very simple process. You place an object on a rotation stage between an X-ray source and a detector. The detector acquires simple 2D radiographic images of the object as it rotates. After the object has rotated through 360 degrees, the 2D X-ray images are reconstructed into a 3D volumetric map of the object. Each element is a 3D cube (voxel) which has a discrete location (x,y,z) and a density (). Not only do you have the external surface information, like you would with a 3D point cloud from laser scanning, but you also have internal surfaces and additional information about what is in between the surfaces from the fourth dimension, the density.

CT works very well if you follow four simple rules:

1. You need enough X-ray power or flux to penetrate and get through the object.
2. As the object rotates it has to stay inside the cone created by the X-ray source and the detector.
3. For high magnification, the smaller the X-ray spot size, the better the resolution.
4. The closer you can get the object to the source (and maintain rule 2), the better resolution and accuracy you will obtain.

In-house X-ray sources at the core of CT

The X-ray tube is at the core of a CT system. Several different tube designs exist, but essentially an X-ray source consists of a tube or cylinder in which there is a filament (think light bulb) at one end, along with a high voltage cathode and anode, a magnetic lens and a metal target (normally Tungsten). The X-ray source is an open or closed tube source. Nikon Metrology provides in-house designed open tube sources, which allow you to replace the filament on a regular basis, typically having a much lower cost-of-ownership than closed tube sources, which have to be replaced when they fail, normally at great cost.

A current is applied to the filament, which causes it to heat up and emit electrons. The electrons are repelled by the cathode and attracted to the anode by the high voltage field. This field accelerates the electrons up to 80% of the speed of light toward the end of the tube. Before they leave the tube, the electron beam is focused onto a target material, typically tungsten, using an electro-magnetic lens. The electrons slam into the target and the sudden deceleration of the electrons as they interact with the target pretty much just heat it up. Indeed that is what happens to over 99% of the energy in the electron beam; it goes into heating up the target. Less than 1% produces X-rays that are generated in a cone beam from the target.

These X-rays emanate from the region where the electron beam hits the target. In general, the higher the voltage applied, the more power is in the beam, and consequently more power is transferred to the target. The more power on the target, the larger the X-ray spot size, and the more X-ray power produced.

Rotating target increases X-ray intensity

There is often a balancing act between X-ray power and spot size. Higher power generates more heat and in case the target could not take the high levels of power, it would quite literally start to punch holes in the target. With the Nikon Metrology rotating target – i.e. sort of an aluminum disk with a thin Tungsten track on the chamfered edge- the electron beam falls on a moving surface, so the power in the electron beam can be increased considerably without incurring damaging heating effects. The power can be doubled without significantly degrading the spot size, while the X-ray flux can increase 3-5 times, allowing for either higher accuracy measurements, or for objects to be measured quicker.



XT H 450 system : to prevent X-rays to escape, the enclosure is shielded with lead, making it a 14ton system

The need for high-power microfocus CT

Up till now it seems that CT offers us only advantages. But where are the pitfalls? One important limitation for many industrial (metal) objects is the density of the materials. Denser samples will attenuate the X-rays more, as can be seen on the table.

	Maximum X-ray penetration depth by material (mm)			
Source power	Plastic	Aluminum	Steel	Lead
225 kV	250	150	50	3
450 kV	500	300	75	9

Many system suppliers only offer microfocus sources up to 225kV, while more powerful sources in their offerings are minifocus. Minifocus sources produce more X-ray flux, which is great (good for rule 1), but the spot size of these minifocus sources is orders of magnitude bigger compared to microfocus sources (bad for rule 3), heavily reducing the accuracy of the data. Don't be mistaken: you need a microfocus source to acquire accurate and detailed CT data for most high-accuracy industrial CT applications, and a supplier's spec sheet might not distinguish between the two types of sources. The standard 450 kV microfocus source features a spot size of 50 to 320 μm depending on the power, 3 to 8 times smaller than corresponding minifocus sources, providing industry leading performance for inspection of small high density parts or aluminum castings with unrivalled accuracy and resolution. Thanks to its open-tube design with user-replaceable filaments, the source has a virtually unlimited lifetime with a very low maintenance cost.

For most demanding applications, the high-brilliance version utilizing a rotating target delivers 450 W continuous power, without any measurement time restriction, whilst maintaining a smaller spot size of 50 to 113 micron depending on the power, up to 10 times better than a minifocus source. Compared to the standard source, the high-brilliance version allows data to be collected faster, typically 3-5x, for a given spot size and power." Alternatively for a given power or measurement time, the available resolution will be higher so the data quality is improved.

Leading to a unique XT H 450 microfocus system

The newly designed walk-in cabinet features a large pneumatically controlled door and the measurement volume of 400x600x600 mm is sufficient to measure larger parts such as aluminum engine parts or large fossils. The manipulator can accommodate samples with weights up to 100kg. Generators, safety systems, power distribution and pneumatics are easily accessible through the wide service doors enabling easy maintenance. Also benefiting ergonomics and ease-of-use are the new designed controls, including joysticks and twin control monitors as well as the cabinet CCTV monitor that are mounted on a swing arm.

The system is available with a flat panel (for 3D cone-beam CT) or a proprietary Curved Linear Diode Array (CLDA) (for 2D fan-beam CT) that optimizes the collection of the X-rays. Today, most high-end industrial CT systems are using amorphous silicon flat panels. The size of the panel is important because it can determine the size of the object you can measure with CT. For example, using a 16" x



Flat panel type detector



The CLDA is optimized to measure X-ray slices without scatter

16" panel, the maximum object width is around 12". One can go beyond this object size limit by applying panel shifting. For example, by taking multiple scans using different object positions, customers are able to scan large parts.

One-dimensional linear detectors have a line of small scintillators which generate light when bombarded with X-rays. The scintillators are backed by a row of photodiodes that capture this light. Such a device only captures one slice at a time as opposed to an entire two-dimensional image. One-dimensional detectors are useful when measuring materials where there is a lot of scattering (think very dense materials or single crystal turbine blades). Nikon Metrology's unique curved linear diode array (CLDA) detector have been introduced as a means of removing path length difference errors found in linear systems. By avoiding image pollution and associated contrast reduction, the CLDA realizes high quality data with stunning image sharpness and contrast.

Applications for high voltage CT

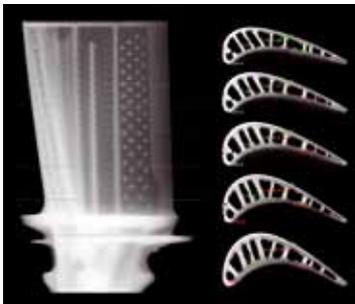
Turbine blade inspection

A challenge for today's turbine blade manufacturers is to produce lighter turbine blades to optimize fuel efficiency. The wall thickness of modern blades as well as the correct location

of cooling channels is of utmost importance for optimized performance. With an XT H 450 combining a 450kV microfocus source and a CLDA, blade wall thickness measurements with an accuracy of $\pm 25 \mu\text{m}$ can be achieved. In a production environment, the system runs automatic data acquisition, high-speed CT reconstruction and inspection, generating pass/fail status for each inspected part.

Automotive cast parts inspection

Also in automotive industry there is a need for lower fuel consumption. Manufactures are developing more compact, aluminium engines with thinner walls to reduce engine weight. As consequence, it is critical that smaller voids in the aluminium needs are detected. Where previously a minifocus system was capable to detect larger voids in cast engine parts, these tinier voids can only be detected by microfocus X-ray system. Also other automotive cast parts such as impellers, turbine housings etc. require a high voltage microfocus source to run highly accurate inspection. The XT H 450 is designed to give industry leading performance in the scanning of such objects. By calibrating the CT system it is possible to use for dimensional inspection for both internal as external surfaces and features. As such automotive manufacturers benefit from the combination of NDT defect analysis and dimensional inspection using a single system or facility.



X-ray image and CT slices of a single-crystal aerospace blade created using an XT H 450 system with a CLDA detector



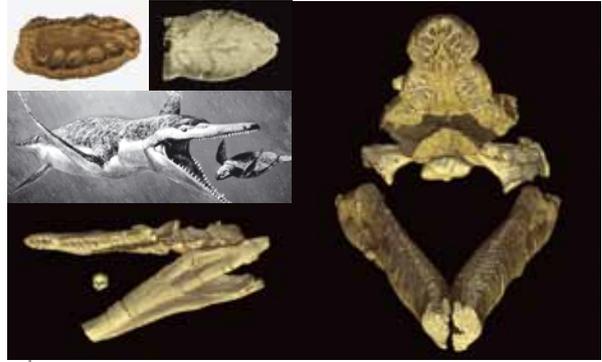
The XT H 450 X-ray source is powerful enough to scan small castings with micron accuracy



CT provides dimensional insight in areas that are impossible to reach by laser scanners or touch probes



A Pliosaur's jaw fossil is being prepared for X-ray inspection



3D rendering of a Pliosaur jaw, reconstructed using scans taken in the Nikon Metrology CT system

Paleontology / Archeology of larger samples

Scientists will always desire to learn about the evolution of species. Destructive tests are simply unthinkable to destroy the precious samples which may be millions of years old. CT offers the perfect solution to uncover secrets from previous eras or older civilizations. To explore larger samples or dense (e.g. bronze) objects, the XT H 450 offers the perfect solution. The large Nikon Metrology X-ray system is ideal for scanning large, dense lumps of fossil. By looking at the inner architecture of the skull and bones, scientists may gain new insights into the species and its evolution. For example at the University of Southampton, X-rays are helping to build up a 3D picture of a Pliosaur, a ferocious predator, which terrorized the oceans 150 million years ago.

And one of the most famous historical objects is the Antikythera Mechanism. Here high voltage was important to penetrate the bronze corroded artefact. X-ray technology revealed the inner structure including the design of the gearing system for the first time, revealing that the device was made to calculate the motions of celestial bodies.

Conclusions

X-ray and high-accuracy micro CT technology has evolved over the last ten years to the extent that it has become a mainstream metrology technology. It has accuracy and resolution, speed, flexibility, and unimaginable detail, and it provides fourth dimension insight through density mapping. And importantly, the price point and scan times are attractive enough to make it competitive with other techniques. With the advent of high voltage microfocus source and advanced detector technology, applications are growing constantly across the automotive, aerospace, energy, medical and consumer sectors, dealing with denser materials or larger parts. Using a CT helps manufacturers trace both visible and invisible material and geometry-related flaws that in most cases cannot be identified using other NDT methods. Software tools enable the analysis of the volume against the CAD model, either via direct volume to CAD comparison, or through GD&T measurements. This makes CT the upcoming challenger for true 3D inspection providing BETTER INSIGHTS and HIGHER PRODUCTIVITY.



Antikythera mechanism (Scientific data ©2005 AMRP)



Exploded view of the Antikythera Mechanism (©2012 Tony Freeth)