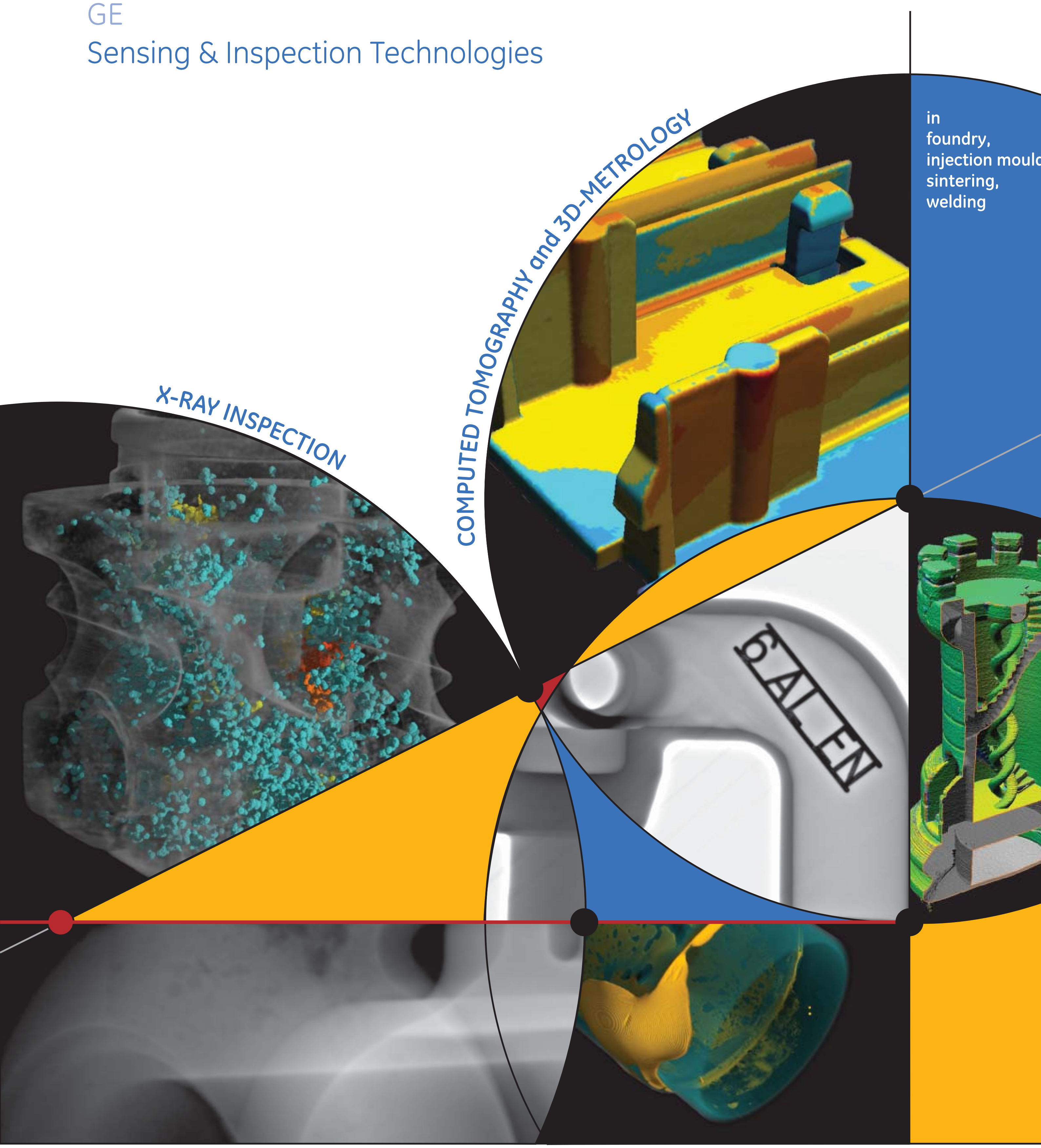
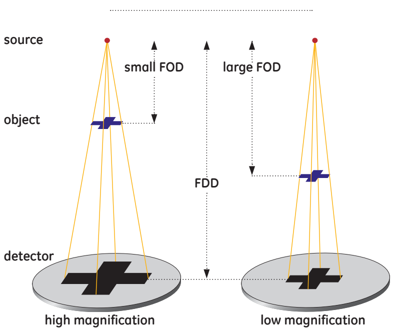
GE

Sensing & Inspection Technologies



with phoenix|x-ray microfocus and nanofocus X-ray systems

FAQs about X-ray



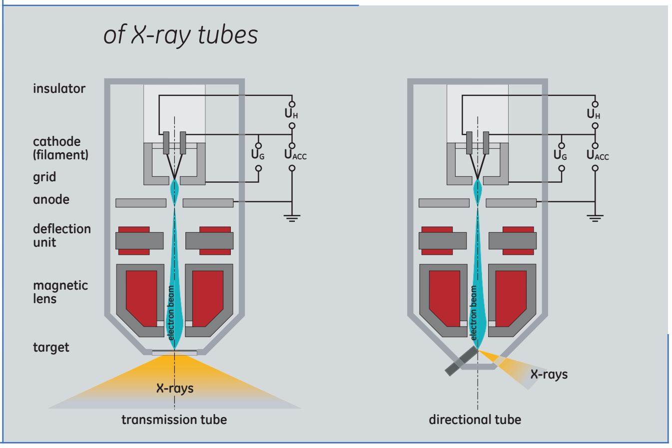
How X-ray inspection

works

X-ray starts with a sample being irradiated by an X-ray source and projected onto a detector. The geometric magnification M of the image is the ratio of focus-detector distance (FDD), Focus-object distance (FOD): M=FDD/FOD. The smaller the focal spot, the greater the resolution. With the nanofocus technology a unique detail detectability up to 0.2 microns can be achieved. phoenix|x-ray systems reach geometric magnifications over 2 000x resulting in total magnifications beyond 24 000x.

Functional principle

of X-ray tubes

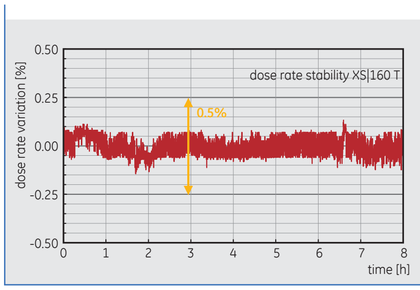


In an evacuated tube, electrons are emitted from a heated filament towards the anode. Through the anode, the electrons enter a magnetic lens which focuses the electron beam to a small spot on the target. The target either consists of a thin tungsten layer deposited on a light metal plate which also is the exit window for the X-radiation (transmission tube) or a massive tungsten cylinder (directional tube). In the tungsten the electrons are abruptly decelerated whereby X-rays are generated. The focal spot represents a very small X-ray source which enables sharpest imaging with micrometer resolution. The latest nanofocus tubes achieve a detail detectability up to 200 nanometers (0.2 microns).

What makes an excellent

X-ray?

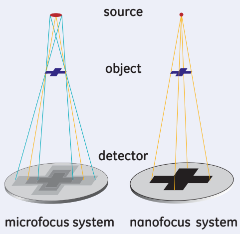
In addition to resolution, maximum voltage, and power, stability is very important for reliable results and highest uptime. One of phoenix|x-ray's key technology competencies are tube design and manufacturing.



- High power nanofocus X-ray tubes up to 180 kV and unipolar microfocus X-ray tubes up to 300 kV maximum voltage
- Up to 200 nm (0.2 microns) detail detectability
- Dose-rate stabilization: the emitted intensity only varies by less than 0.5 % within 8 hours (see diagram)
- Anti-arcing: dedicated surface treatment during fabrication and automated warm-up procedures prevent discharges
- Self adjustment: all tube adjustments are performed automatically during warm-up to achieve optimum results
- Plug-in cathodes: pre-adjusted spare cathodes prevent malfunction due to wrong filament adjustment and minimize downtime to less than 20 min.
- Target check: target condition is checked automatically; automatic target wear is indicated

Technology

What is the difference between nanofocus and microfocus tubes



Although the focal spot of microfocus tubes is as small as 3 microns, it is still large enough to cause a half shadow, known as the penumbra effect. This results in a residual unsharpness and can be avoided by using nanofocus technology. Nanofocus provides focal spots well below one micron while maintaining the highest intensity needed.

Technology

Closed tube or open tube?

Closed tubes: All tube components are contained in a sealed vacuum vessel container. Closed tubes are maintenance-free and are completely replaced at the end of their lifetime.

Open tubes: All components and wear-out parts are accessible and replaceable, the tube is continuously evacuated by a turbomolecular pump. Open tubes yield higher resolution and magnification and are not limited in lifetime.

GE Sensing & Inspection Technologies´ product line phoenix|x-ray offers two series of systems in versatile configurations to meet customer requirements for non-destructive testing in many industries. All systems come equipped with quality|assurance — phoenix|xray´s comprehensive image processing and CNC programming software package.

x|argos

large samples - high resolution

The x|argos is able to handle samples up to 100 kg (220 lb) with ease while offering microfocus resolution and high precision. The x|argos contains a 6-axis manipulation system including a C-arm for tube and detector. Like all phoenix|x-ray systems, the x|argos comes with CNC programming and digital real-time imaging. The 9" image intensifier digital camera (2 MPixel) offers excellent contrast with superior resolution. The x|argos combines automated digital 2D inspection with full 3D computed tomography (CT) in a single system.

As an option the control panel can also come mounted on an adjustable arm. In order for the x|argos to meet industry requirements and safety regulations, the operator's console was designed in accordance with IP 68.

Automatic inspection

comes standard

phoenix|x-ray inspection systems come with a comprehensive software package enabling fast teach-in of automatic inspection routines. It is easy to create or customize solutions for specific inspection tasks with Xe^2 (X-ray image evaluation environment).

Technology

How does my company benefit from using phoenix|x-ray inspection technology?

Unlike many other manufacturers, phoenix|x-ray's X-ray tubes and generators are developed and manufactured in-house. With the purchase of a phoenix|x-ray system, you will benefit from the latest technology:

- Tube voltages as high as 300 kV (directional), 225 kV (transmission tubes) and 180 kV (nanofocus tubes).
- Higher tube voltages provide greater measurement accuracy and significantly reduce image artifacts due to high-intensity X-rays.
- Ultra-stabilized high-tension for even crisper nanofocus images.
- Active temperature-stabilized high-dynamic digital detectors ensure higher contrast resolution
- High up-times and fast response-times due to in-house manufacturing.

ndt|analyzer

versatile high-performance system for small to medium sized samples

The ndt|analyser allows the inspection of samples up to 10 kg (22lb). It comes with a versatile 5 or 6 axis manipulation unit. The ndt|analyser is available in variety of configurations and can be outfitted with either a transmission or directional tube providing detail detectability as low as 200 nm (0.2 microns) and voltages up to 240 kV (320 Watts). The customer may also choose from a wide range of high-quality image chains, including the fully digital high-contrast|detector. The ndt|analyser is perfectly suited for a wide range of applications — from small, sintered objects to medium sized castings.

Technology

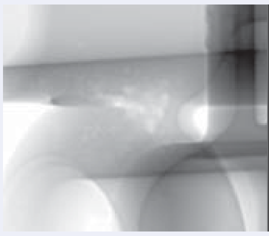
Image chain or digital detector?

Image chains consist of an image intensifier and a digital CCD camera. The image intensifier amplifies the image signal while the CCD camera feeds the digital signal into the image processing device. Image chains provide high gain, high spatial resolution and real-time images.

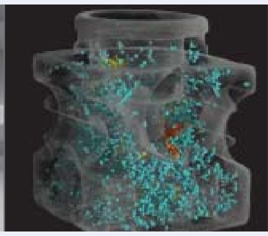
Fully digital detectors, which consist of a scintillator foil and a diode array, put out a digital 16-bit signal without the need for extra equipment. They provide a contrast resolution several times higher than regular image chains.

Inspection and Analysis

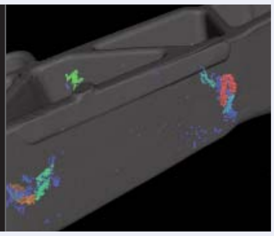
2D X-ray inspection and 3D computed tomography compliment each other and combined, are a very useful inspection tool for a wide range of industries:



Shrinkage cavities in an aluminum casted carburetor.



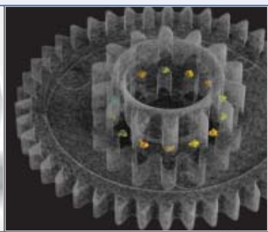
3D visualization of cavities in an aluminum casting. The colour indicates the size.

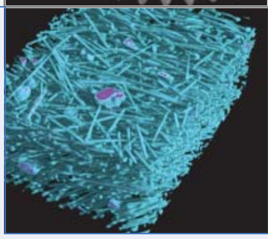


Automatic pore analysis in an automotive control arm.

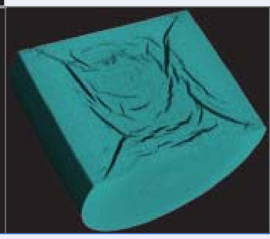
X-ray image of gas pores in an injection molded plastic part.

3D visualization of shrinkage cavities in a plastic gear wheel. The colour indicates the size.



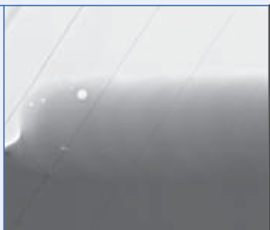


nanoCT® image of glass fibers (Ø 10 µm) and fill material in a reinforced plastic.

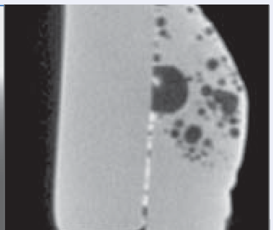


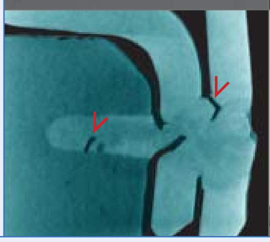
Shrinkage cavities in a sinter sample as revealed by CT.

Microfocus X-ray image of a weld seam joining aluminum plates showing small gas pores, with wire penetrameter EN 462-1 W 13 AL.



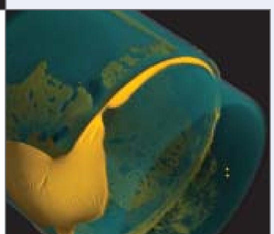
Microfocus CT slice across a laser spot weld (D = 1 mm) revealing gas pores and a zinc layer between the plates.





Microfocus CT slice across a laser weld interconnecting two inconell tubes with a steel cylinder: Porosities and fatigue cracks are revealed.

2D image of a braze interconnection between two copper tubes (D = 12 mm). A crack is detected.



The 3D visualization of the brazing (yellow) shows the gap to be nearly empty.

Foundry

Traditionally, X-ray testing has been used to non-destructively find defects in aluminum, magnesium, iron, and zinc castings including gas holes, shrinkages, foreign materials and discontinuities. Computed tomography provides another important advantage — it shows the exact location of the defect inside the sample. The exact three — dimensional data allows quantitative defect analysis of the sample. This provides information on size, volume and density of inclusions and cavities. Lastly, CT images are richer in contrast; therefore, revealing even smaller defects.

Injection Moulding and Sintering

2D X-ray inspection and computed tomography are used in production and process control to detect defects like gas holes, shrinkages, foreign materials, and discontinuities. CT images clearly show fill materials and enforcement fibers; therefore, helping to improve both production process and tools.

Welding and Brazing

Another typical X-ray application is the inspection of weld seams and brazing joints. Process control and optimization of today's laser and friction welding technologies require defect detection in the micrometer range and 3D visualization.

3D-Dimensioning

In many cases, CT offers considerable advantages compared to conventional coordinate measuring machines especially when measuring complex parts with hidden or difficult-to-access surfaces, such as high density of measurement points and fast capturing even of the complete internal geometry of the object.

3D-dimensioning is performed in 2 steps:

1. Measurement

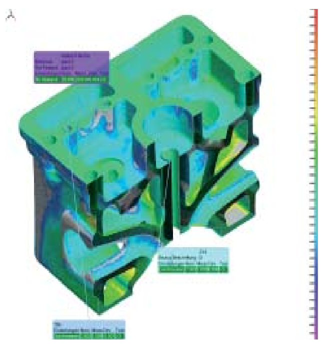
The acquired X-ray data sets are used to reconstruct a 3D rendering of the sample from which the workpiece surface is then extracted for further evaluation.

The accuracy of the final results depends greatly on the precision of the measured CT data.

With superior X-ray technology and mechanics working in conjunction with advanced software tools, the systems in the phoenix|x-ray CT line are ideally suited for 3D metrology. The tracebility and optimum accuracy of the CT measurement results is ensured by calibrated and DKD-certified test specimen.

2. Evaluation

Extensive software packages are available which allow e.g. the fitting of geometric primitives, geometric dimensioning and tolerancing (GD & T) according to DIN/ISO and also the complete automatic generation of first article inspection reports within one hour.



CAD variance analysis and measurement of three features of a cylinder head

Precision & Compliance

phoenix|x-ray specifications are in accordance with the upcoming standard VDI 2630. For a 30 mm object (position tolerance ± 1.5 µm) and at a voxel size of 40 µm, the v|tome|x L shows a sphere distance error SD of < ± 1 µm. Both parameters where determined at a diameter measurement error PS of < 3.5 µm by using a special sphere plate designed and calibrated by the German Metrology Institute PTB.

Precision comparable to CMMs

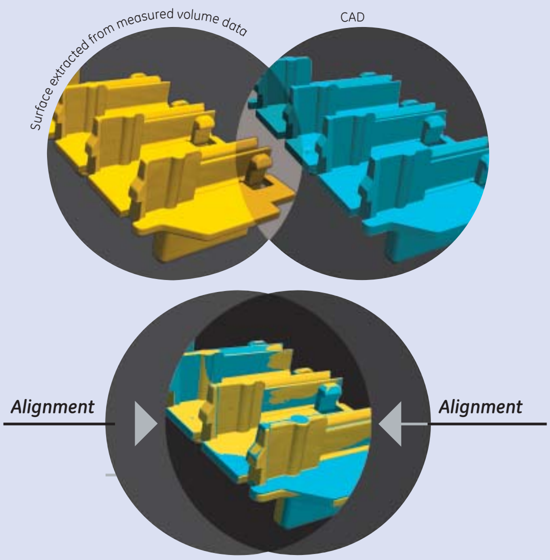
In order to demonstrate the accuracy of the CT data, an aluminum valve block was analyzed in parallel by means of a high precision CMM. The table contains a small extraction of the first article inspection report showing a very good correspondence of the two methods (deviation ≤ 6 microns for diameters and distances).

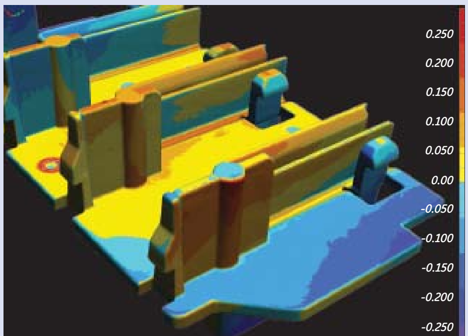
Feature	Ø Z 1 [mm]	Dist. D1 [mm]
Nominal CAD	28.000	70.500
Tolerance	0.050	0.100
Measured CT	28.035	70.442
Measured CMM	28.034	70.447
Deviation CT / CMM	0.001	-0.005

For further analysis, the surface extractions can be aligned with the CAD data. Differences are displayed using pseudo-colors and may also be virtually sectioned apart.

Example of CAD variance analysis

Injection moulded plastic connector
(courtesy of Phoenix Contact)





Deviation in pseudo colors (performed with PolyWorks®)

What is it that makes an accurate CT measurement system?

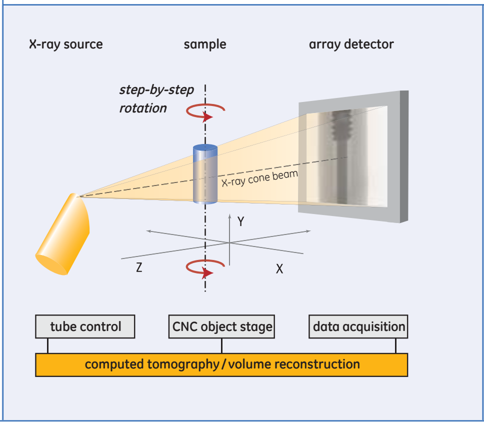
The basis of dimensional measurement using CT is the tomogram from which the geometric surface is extracted. The measuring uncertainty is mainly determined by voxel size and focal spot size. Further, in X-ray tomography local wall thickness and shape of the workpiece may cause measurement errors due to beam hardening effects which should be minimized; therefore, essential features for an accurate CT system are as follows:

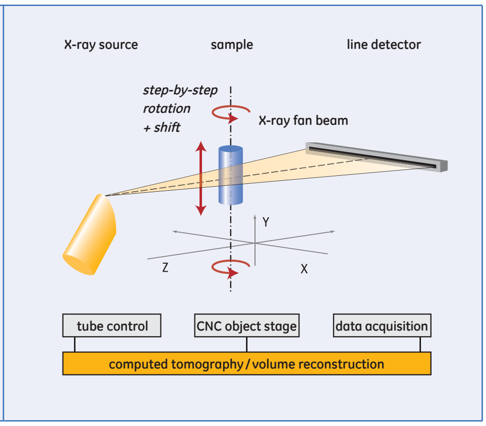
- Minimized focal spot and voxel size
- High mechanical and thermal stability including dedicated compensation methods
- High tube voltage and power (up to 300 kV / 500 W) to enable beam filtering
- Beam hardening corrected reconstruction software
- Surface extraction with local gradient algorithms
- Specifications following ISO 10 360 / VDI 2617 / 2630

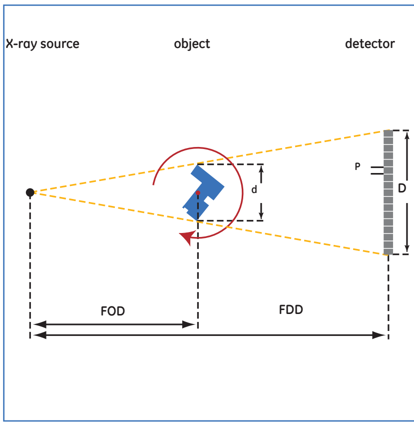
FAQs about CT

How does a CT system

work?







Cone beam CT:

Generating three-dimensional images using microfocus CT starts with acquiring a series of two-dimensional images. The images are progressively rotated 360° at increments of less than 1° per step. The projections contain information on the position and density of the sample. This accumulation of data is then used for the reconstruction of the volumetric data.

Fan beam CT

For each slice, a set of X-ray line profiles are acquired while rotating the sample 360° at increments of less than 1° per-step. The line profiles contain information on the position and density of the internal features of each sample slice. This data is used to reconstruct the tomographic image. By vertically shifting the sample through the fan beam repetitively, a set of slices are compiled to create a representation of the volume.

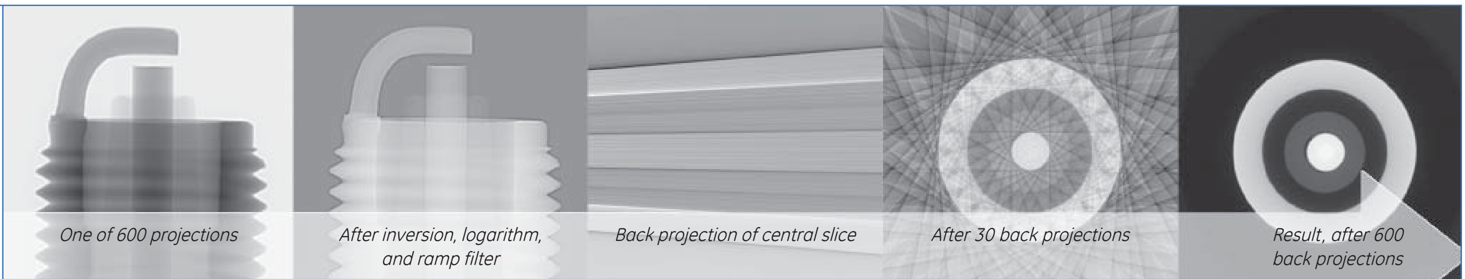
What is the voxel resolution in CT systems?

In order to reproduce an accurate reconstruction of the volumetric data, depth and diameter, the sample should remain within the field of view and cone/fan of radiation throughout the entire 360° rotation. This also ensures that the full sample is completely displayed in each projection or line profile captured in the acquisition process. The magnification is limited by the sample diameter d and detector width D to $M = D/d$. For a detector with the pixel size P, this results in a voxel resolution of $V = P*d/D$.

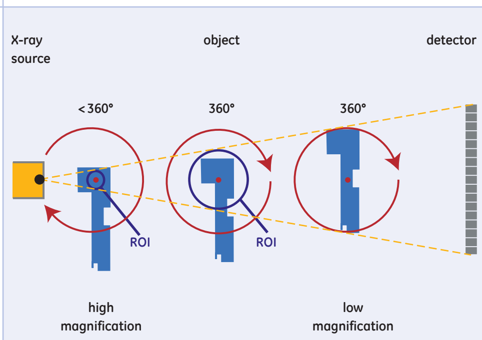
How does reconstruction of

the volumetric image works?

The CT image is reconstructed using three-dimensional filtered back projection.



One of 600 projections — *After inversion, logarithm, and ramp filter* — *Back projection of central slice* — *After 30 back projections* — *Result, after 600 back projections*



What is ROI CT?

For optimum image quality the sample should remain in the cone beam during the full 360°. This condition if strictly applied would limit the magnification and therefore the archievable voxel size. Advanced phoenix|x-ray algorithms enable region-of-interest scans at higher resolution with a minor loss of image quality.

Technology

Computed Tomography Systems

GE offers a variety of CT systems ranging from compact laboratory CT systems to granite-based walk-in systems. All systems are designed for high-precision CT for 3D metrology and analysis and are equipped with phoenix|x-ray's proprietary data acquisition and tomography software datos|x for easy system control as well as rapid and accurate volume data reconstruction.

v|tome|x L 300

highest magnification for 300 kV

The v|tome|x L 300 benefits from a new unipolar 300 kV / 500 W microfocus source. Due to this unique technique the system can be used for high magnification applications as well as scans of strongly absorbing samples. Major components of the system, like the X-ray tube and the temperature stabilized detector are proprietary technology of GE . The v|tome|x L 300 comes standard with a granite-based manipulation and an air conditioned X-ray safety cabinet allowing samples of up to 50 kg (110 lb) and up to 600 mm length / 500 mm (23.6 x 19.6 in) diameter to be scanned.

v|tome|x s

compact and versatile

The v|tome|x s CT system is suitable for a wide range of 2D and 3D applications for samples up to 10 kg (22 lbs). To give customers a very high versatility, it may be outfitted with a 240 kV microfocus and an additional 180 kV high power nanofocus tube.

nanotom®

highest resolution in three dimensions

The nanotom® comes standard with a 180 kV / 15 W ultra high-performance nanofocus tube and precision mechanics for maximum stability. With voxel resolution as low as 500 nanometer and below, the nanotom® is the inspection solution of choice for 3D CT applications in a wide range of fields. With its small footprint, the nanotom is suitable for even the smallest labs.

For many applications, the nanotom® offers a viable alternative to synchrotron-based computed tomography.

v|tome|x L 450

highest precision for large samples

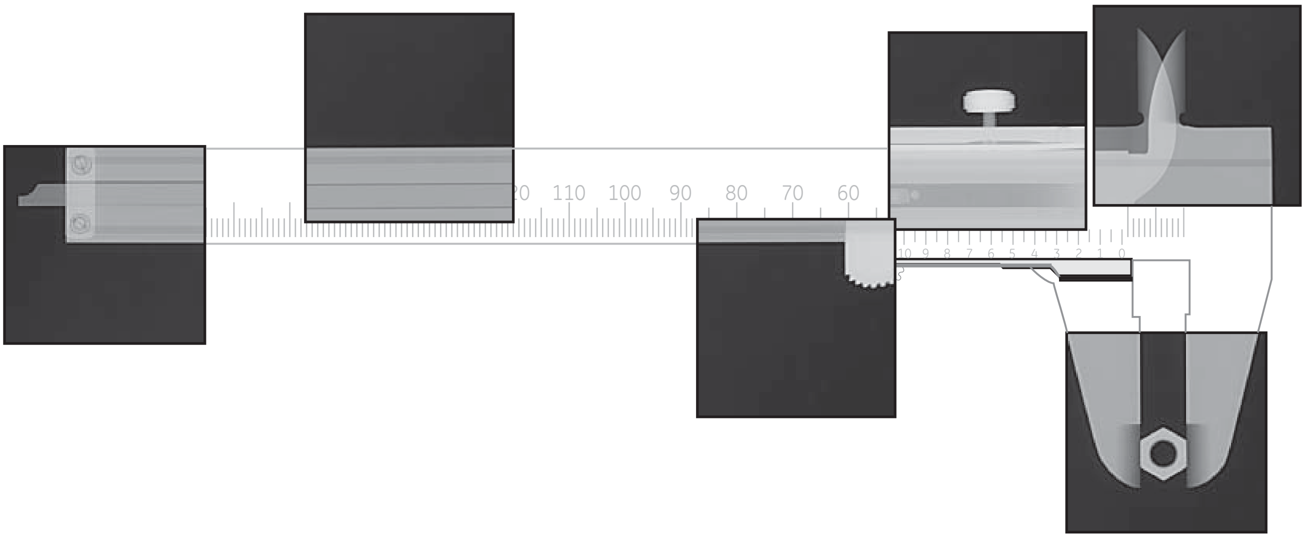
With its granite-base 8-axis manipulation unit, the v|tome|x L handles large samples up to 100 kg (220 lb) in weight, up to 1000 mm (39.4 in) in diameter and up to 1250 mm (49.2 in) in height with great precision. The 300 kV/500 W microfocus directional tube enables voxel resolutions of only a few microns. In dual tube combination, the v|tome|x L comes equipped with an additional 450 kV closed minifocus tube for high absorbing samples. The wide range of available extras like line or multi-line detector as well as its full 2D inspection capability allows the v|tome|x L to adapt to almost any kind of 2D or 3D application.

Detectors used in computed tomography:

Digital Array Detectors are used for cone-beam CT. They allow the acquisition of several hundreds to thousands slices in only a single inspection cycle, which drastically reduces acquisition times even for larger samples. Digital array detectors provide excellent image quality making the same system both CT and 2D-capable. In multi-line configuration, also high precision 2D CT can be performed with an array detector.

Digital Line Detectors are used for fan-beam CT. They acquire the data for one CT slice in one acquisition cycle, but give more accurate results, which, for some applications, especially 3D-dimensioning, justifies the increase in acquisition time.

Digital Image Intensifiers can be used instead of digital array detectors. They are a more budget-oriented option suitable for lower requirements.



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