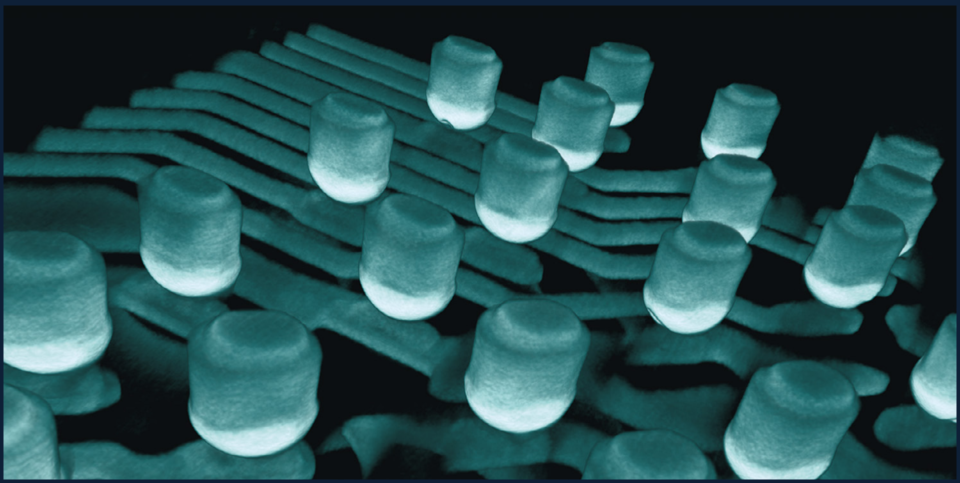
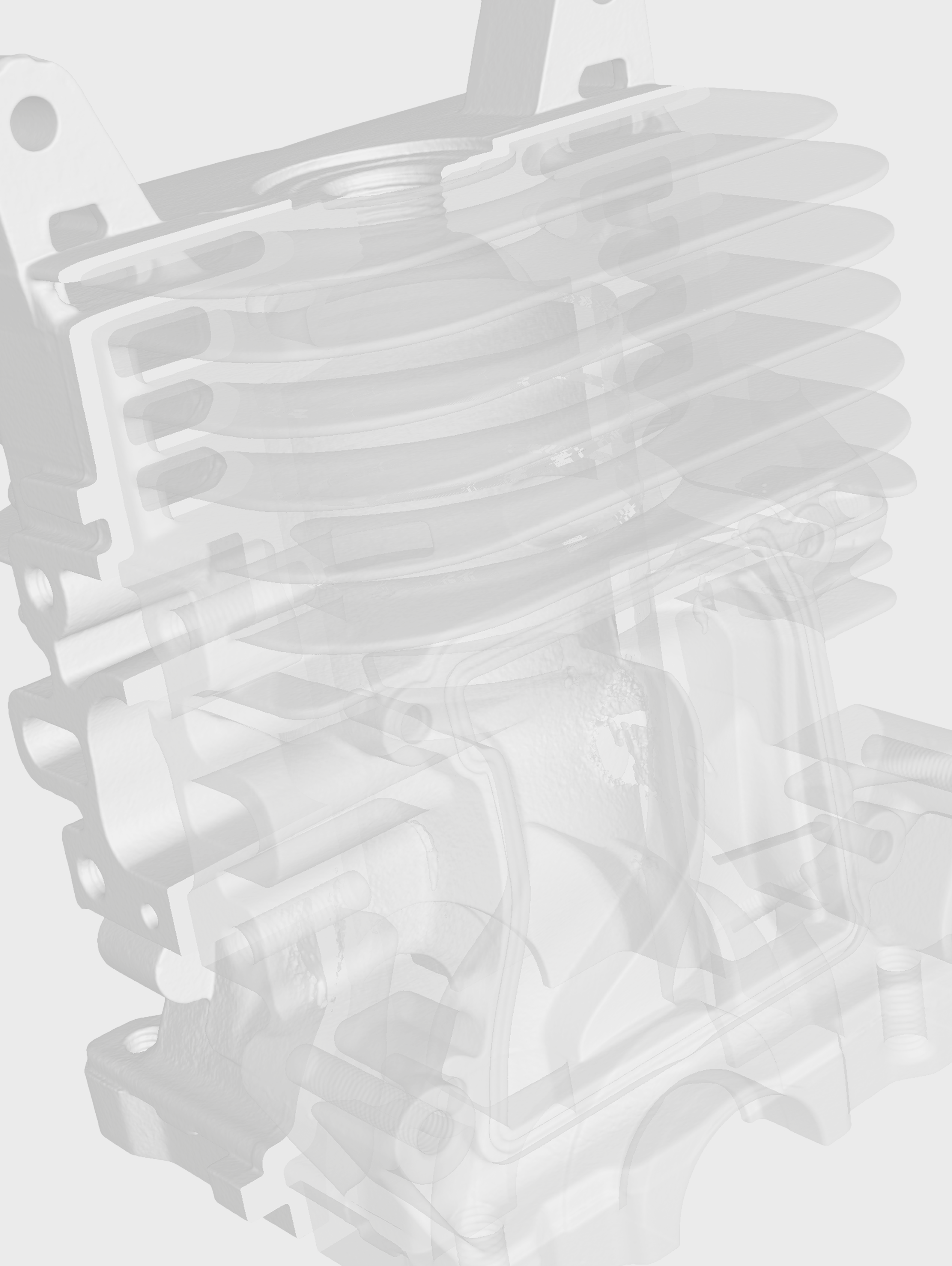


CT HANDBOOK

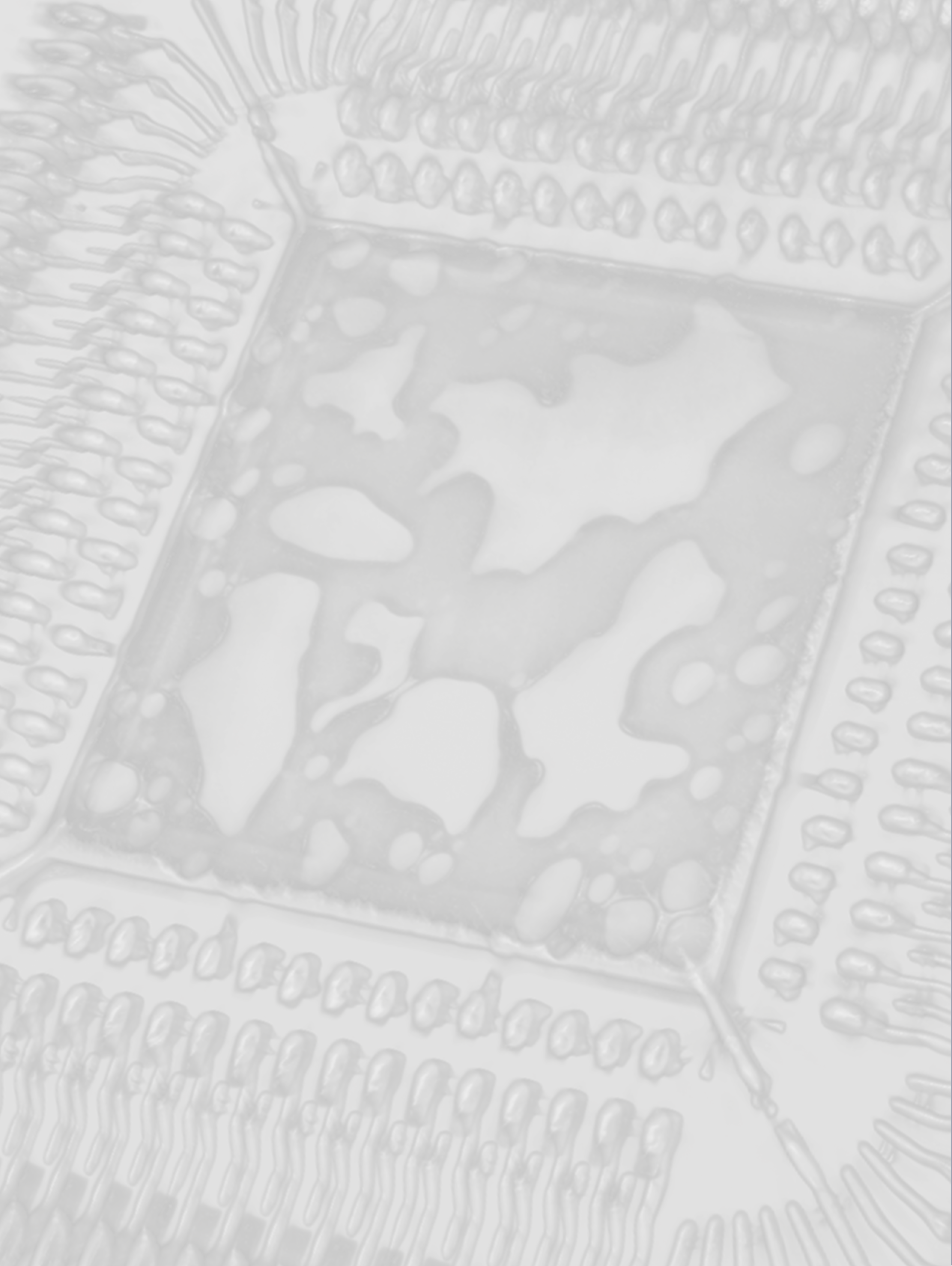
Computed Tomography (CT) for Industrial Applications – the Outstanding Performance of Advanced CT Systems

What you will learn:

- What is Computed Tomography
- Components of a CT system
- Typical CT applications in diverse industries
- What to know when choosing a CT system
- System implementation and user training



CONTENTS



Introduction

Computed tomography (CT) is the most effective technology for non-destructive testing (NDT). The dataset obtained from a CT scan allows users to examine material samples, observe defects, perform measurements and identify materials with different densities. Engineers, builders, researchers and scientists can therefore discover features that could not previously be examined without destroying the test object.

The data obtained permit the development of new geometries and new materials. A complete specimen framed in a single scan allows us to detect possible defects and dimensions. In the past, these scans and the subsequent processing phases lasted several hours, sometimes even days; with the modern hardware and software systems available today, scans and analyses are available in just a few minutes.

The term tomography consists of the Greek terms *tomos* (to cut) and *graphein* (to write), and literally means "depiction in sections or layers". A CT scan generates a series of single or two-dimensional projected images from many different angles. The reconstruction software uses the images to reconstruct and generate the three-dimensional volume of the object to be analyzed.

The origins of CT scanning technology date back to the nineteen-seventies. Computerized tomography was developed by two researchers - Godfrey Hounsfield and Allan Cormack – who won the Nobel Prize for physiology or medicine for their research in 1979. CT was initially designed to analyze the human brain, but the fields of application quickly expanded into the industrial and research sectors.

ACQUISITION AND RECONSTRUCTION

To generate a CT dataset, a series of two-dimensional x-ray images must be created, usually on a complete 360° rotation. The two-dimensional dataset is primarily a sequence of hundreds or thousands of tomograms. A reconstruction algorithm calculates the tomograms, starting from the individual projections obtained.

The tomograms are virtual 2D "slices" of a three-dimensional object, in which each shade of gray represents a different density value; the darker the shade of gray, the denser the material of the object. White corresponds to emptiness or air.

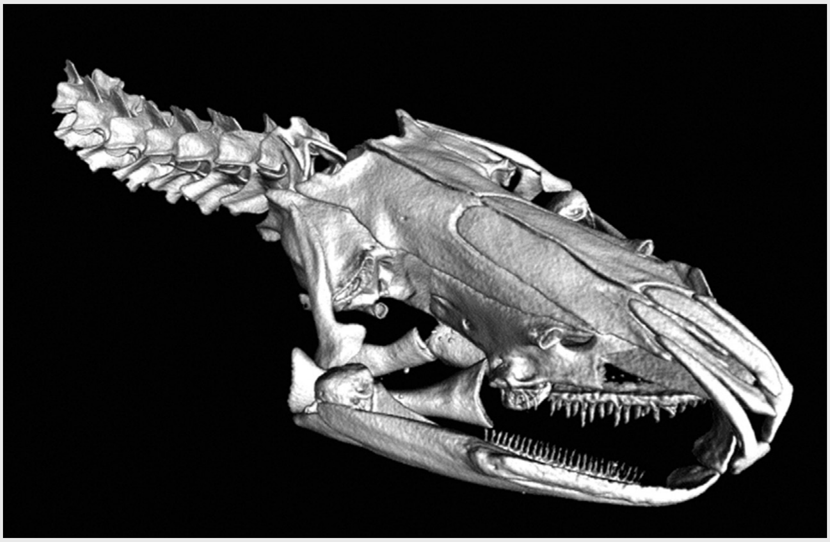


Fig. 1: 3D CT volume of a Sirene Intermedia realized with the high-resolution computed tomography system YXLON FF35 CT

Typical CT applications

Before addressing computerized tomography and system components in depth, below, we outline and compare some typical industrial applications.

IDENTIFICATION OF POROSITY AND INCLUSIONS

The example application refers to an essential component of a respirator. The component consists of two cast elements welded onto two sides of a plate. The CT allows the identification of typical fusion and welding defects, including porosity, in the two cast elements. The information obtained allows the manufacturer to optimize the production processes, minimizing porosity in the welded seams.

The three-dimensional representation of the dataset of the welded plate (Fig. 1) has a transparent surface to allow an internal view of the piece. We used different colors to represent defects of various volumes.

The section through the welding seam shows the porosity caused by the welding procedure.

In the lower section of the welding seam (Fig. 2), the defects are color-coded to make their severity immediately evident. It is also possible to display the defects to highlight their shape and position (Fig. 3). Often, pores below a certain size are not critical to the functioning of the component. Position is also important in this kind of application: the defective points just below the surface are more critical than the internal ones, which are surrounded by a greater material mass.

This list of automatically detected defects (porosity) includes features such as "Size" and "Position". The histogram (Fig. 4) indicates the number of defects by different severities. In this example, most of the defective points are relatively small, with a dimension of <0.08 mm^3 (highlighted in blue).

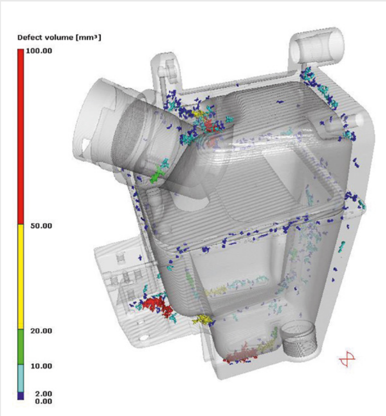


Fig. 1: Components of a respirator. Volumetry of defects (mm^3)

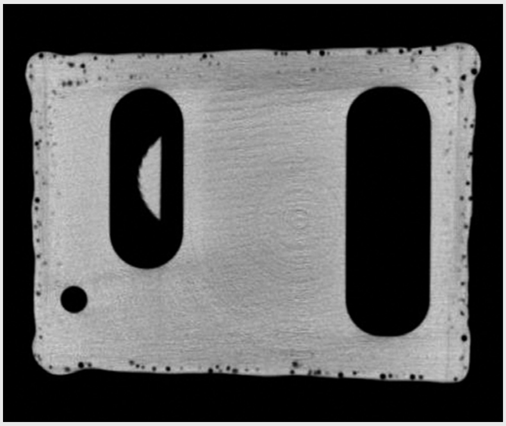


Fig. 2: Porosity formed during the welding process

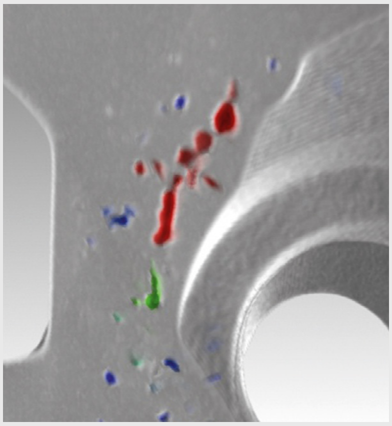


Fig. 3: Defect classification according to severity

METROLOGY (COMPARISON OF NOMINAL AND ACTUAL VALUES)

Three-dimensional scans are often used for a comparison of surfaces. CT can provide precise and clear models of surfaces, including internal surfaces and interface, for a non-destructive analysis of internal features and their relationship to the external surface.

In particular, it is possible to compare a CT scan with a CAD model, or to compare two scans with each other. Once the datasets have been aligned, the differences between the respective surfaces are typically illustrated by color classes.

This function is used for comparison of:

- the surface distances of a casting with those of the CAD model to detect changes in shape with respect to the theoretical value
- two pieces made at different times from the same mold to evaluate the degree of wear over time
- a cast piece with a CAD file to identify pores close to machining surfaces that could trigger losses and/ or leakages

METROLOGY (DIMENSIONAL SURVEY OF INTERNAL STRUCTURES)

CT is often used to collect data for compliance records on individual cavities of multi-molds in plastic injection molding. The same procedure is also indispensable for drawing up the first article inspection report (FAIR) for a given production procedure. For plastic molding, too, CT allows the identification of tool wear simply by scanning pieces produced at different times. Dimensional changes can be obtained and displayed in this way.

In recent years, computerized tomography has become a recognized alternative to coordinate measuring instruments as it allows the measurement of internal characteristics without having to destroy the specimen. Modern technical constructions use the GD&T system (Geometric Dimension & Tolerancing) to check the design and engineering tolerances. Standards such as ASME (American Society of Mechanical Engineers) Y14.5 and ISO (International Organization for Standardization) 1101 are framework regulations that are currently applied throughout the industry.

High-quality CT datasets allow you to quickly and accurately verify many features, with reports generated by the software. The software packages available include VGStudio MAX, Geomagic, PolyWorks and any other program capable of processing large STL files (Standard Tesselation Language – a format for interpreting the surface using triangles) or point cloud datasets.

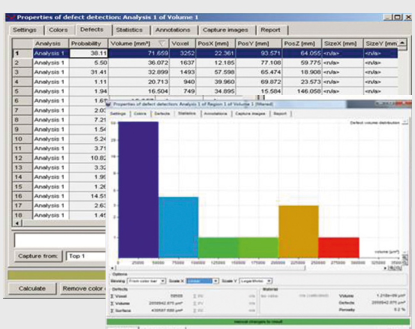


Fig. 4: Histogram of defects

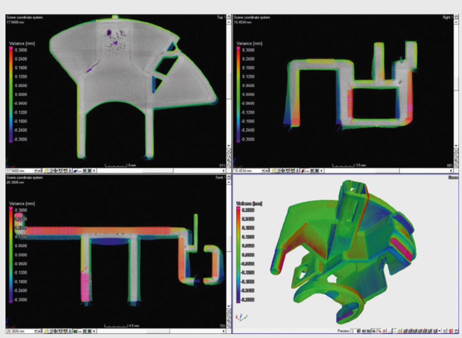


Fig. 5: Comparison of datasets

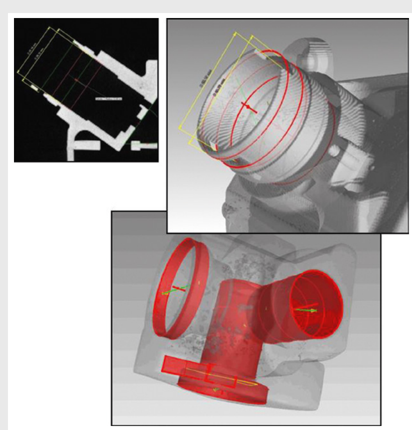


Fig. 6: The metrological software provides support during verification.

CT metrology offers several advantages:

- Simple repeatability: Measurement templates can easily be applied to different scans of the same part type.
- Homogeneous datasets: CT does not require data fusion or smoothing. Therefore, the surface STL datasets are "hermetic".
- Non-destructive tests allow non-contact measurements directly on the digital reproduction of the detail: any dimensional characteristic can be investigated after generating the volumetric data, even after some time, and even if you no longer have the physical piece.
- Non-contact measurement at the CT volume is particularly valuable for soft materials (such as rubber) since the virtual object does not give way.

REVERSE ENGINEERING WITH CT

CT offers several support processes for reverse engineering.

One method (Fig. 1) allows dimensional characteristics to be measured in CT, and then reconstructed with the help of CAD software (e.g. AutoCAD, SolidWorks, Catia NX or others).

Another method consists of extracting regular geometrical elements (cylinders, planes, etc.) from a CT dataset and transforming an STL file (Standard Tesselation Language) into a STEP file (Standard for the Exchange of Product Model Data – the norm for descriptions of product data), as shown in Fig. 2.

A further possibility of reverse engineering is to buy software specifically designed for this purpose (Geomagic Design X by 3D Systems, PolyWorks by InnovMetric, Verisurf X9 by Verisurf, and VGMetrology by Volume Graphics are some examples of products on the market). As shown in Fig. 3, different methods for detecting contours can be applied. A three-dimensional surface model is created based on the quality of the scans derived from the CAD data and using a special algorithm. The definitive mesh (polygon grid) can be stored as an STL file.

In additive manufacturing applications (3D printing) you can send correct 3D STL files of excellent quality directly to the printer, after carrying out minor modifications with appropriate modeling software. Often, this application does not require real reverse engineering software. In the image at the top right of Fig. 3, the "hermetic" mesh (without holes and without voids) is made up of about 500,000 triangles.

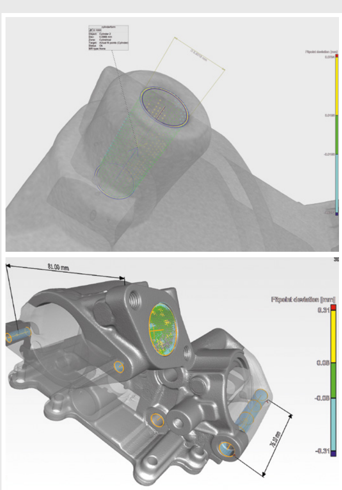


Fig. 1: Reverse engineering with measurement

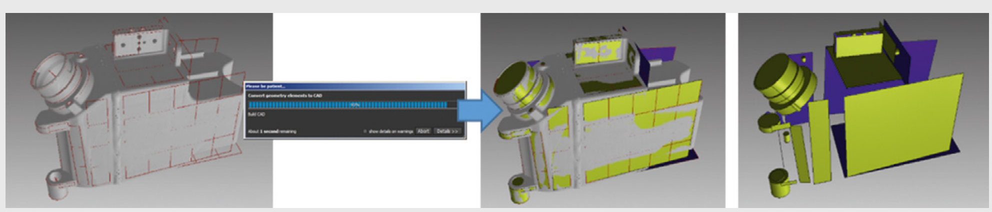


Fig. 2: Reverse engineering with the extraction of regular geometries and storage as a CAD file

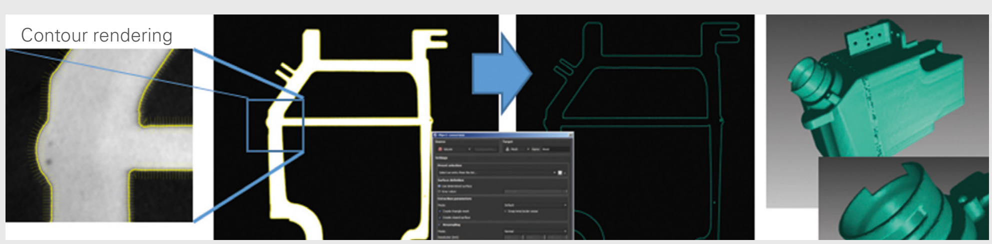


Fig. 3 Software for reverse engineering.

STRUCTURAL ANALYSIS: BLOCK OF CONCRETE/ CEMENT/GEOLOGICAL SAMPLES

CT allows the inside of many geological and synthetic material samples to be examined. This technology is used for a wide range of applications:

- Core analysis: to evaluate the granularity of the sample and simulate the permeability characteristics of a fluid passing through porous materials.
- Studying the characteristics of building materials used for the construction of roads and bridges: concrete samples can be analyzed quantitatively before and after fatigue or loading.
- In the materials sector, to examine the integrity and size of lightweight building materials used to reduce the weight of passenger cars, aircraft and spacecraft.

ANALYSIS OF ASSEMBLED UNITS

The ability of CT to digitize different densities is often used to check how well assembled samples fit together. Computerized tomography is also often used to analyze individual components of an assembly, verifying their presence and disposition. Fig. 5 illustrates the internal position of the spiral in an electronic cigarette.

The external CT analysis software VG Studio MAX allows the operator to break down the assembly into the constituent components, assigning each of them a color (e.g. yellow for the cigarette spiral in Fig. 6).

The following example concerns the Pitot tube, an apparatus for measuring airflow at high altitude, with which the pilot's pre-flight inspection system has identified a problem. Thanks to the CT scan, it was possible to precisely identify the position of the broken wire (upper right in Fig. 7) that caused the problem.

The scan also allows the structure of the component, made about 50 years ago, to be examined (Fig. 8).

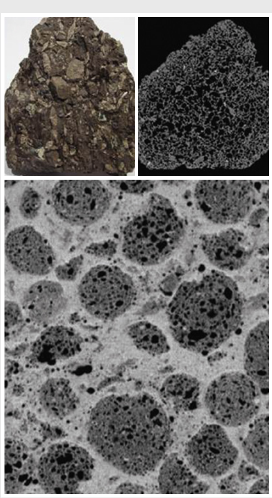
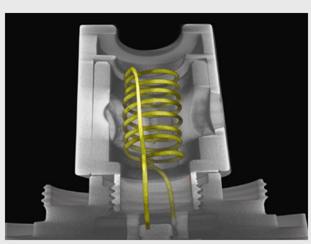


Fig. 4: Analysis of rock samples



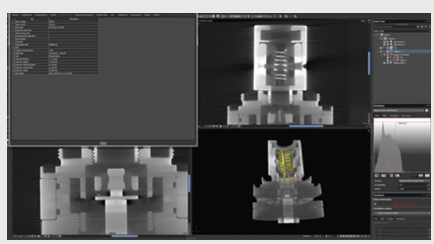


Fig. 5 + 6: Position of the heating element in an electronic cigarette, highlighted with the CT software

Fig. 7: Broken wire in a Pitot tube

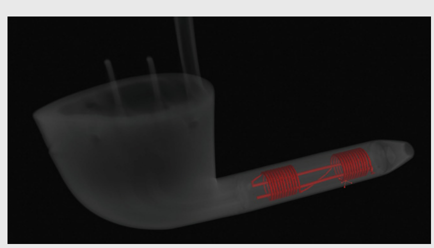


Fig. 8: Complete scan of a Pitot tube

ANALYSIS OF COMPOSITE MATERIALS

For some manufactured products such as composite materials, the direction of the fibers is a critical operating factor.

CT enables the operator to visualize and quantify the direction of the fibers in a specimen. Special software assigns a specific color to each corner of the space. Figures 1–3 show the matrices of the composite carbon fibers in different specimens. Serious errors in direction are thus easy to identify.

ANALYSIS OF ELECTRONIC COMPONENTS AND PRINTED CIRCUIT BOARDS (PCB)

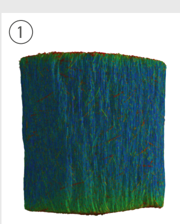
This application allows the analysis of electronic components by identifying defects using CT with specific micro-focus x-ray sources (μCT) (Fig. 4 and 5).

This method allows small components to be examined using optical magnification of the framed area. In this way, 3D information is obtained on the defects present, such as the extension of the withdrawal points, the dimensions of the contact surfaces (the so-called pads) with raised solder paste or the structure of the contact surface if the solder paste is not welded. This detailed information simplifies the analysis of the causes of failure.

The Ball Grid Array (BGA) methodology shown in Figure 5 is a solution in which the welding points are hidden between the component and the circuit board. The quality of welding spots can only be optimally monitored with the help of x-ray technology.

Let's examine the inspection of semiconductor units: high-resolution radioscopy systems allow the analysis of micrometric structures inside their housings. Thanks to this analysis, any defects in the production process or in the product development phase can therefore be identified.

– Copper wire/gold wire
– Broken or chipped bond wires
– Missing bond wires
– Touching bond wires
– Analysis of glued surfaces



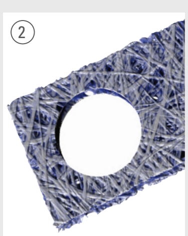


Fig. 1: Composite carbon fiber matrix

Fig. 2: Carbon fiber plate

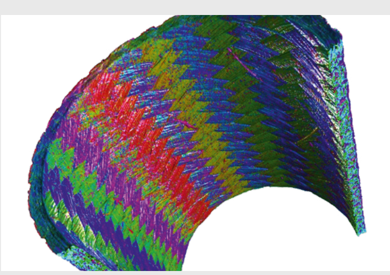


Fig. 3: Analysis of carbon fibers with color classification

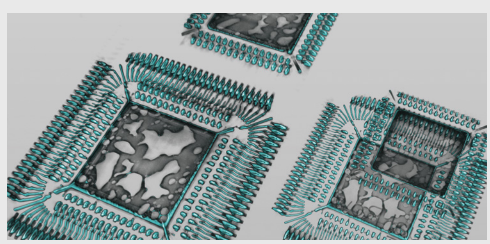


Fig. 4: Micro-focus CT (μCT) for tests on small components.

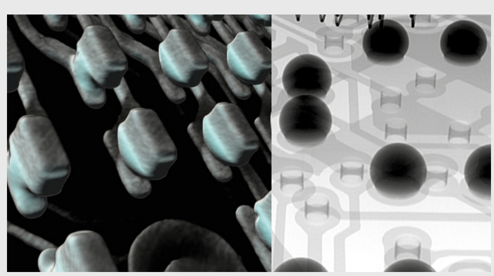


Fig. 5: The Ball Grid Array – BGA methodology (spheres aligned in a grid) can only be fully monitored using radiological examination (3D/2D).

CT system components

MANIPULATOR

As the name suggests, the manipulator moves the specimen and, if necessary, the detector and/or x-ray source, for an optimal acquisition of the radioscopic images or projections. Depending on the application and the degree of precision required, some manipulators consist of a steel frame, while others have a granite base with linear actuators. Solid, robust foundations guarantee high mechanical stability and simple calibration, which improves the accuracy of the CT system.

X-RAY SOURCE

Modern CT systems (see Fig. 6) essentially exploit two types of x-ray sources, as shown in Fig.7.

Mini-focus x-ray tubes are more powerful than micro-focus x-ray tubes, with energy ranging from ~20 keV (Kiloelectronvolts) up to ~600 keV, with maximum power from 100 W up to ~1500 W. The focal point size (or spot) for the mini-focus ranges from ~0.25 mm to ~2 mm. They are ideal for the examination of structured components in automotive, aviation and aerospace applications.

Micro-focus x-ray tubes are available with energy from ~20 keV up to ~750 keV. Output power is within the range of less than 1W and up to ~300 W. The focal point size of the microfocus is between ~1 μm and ~300 μm.

To evaluate the x-ray source of a CT system for a particular application, the following important operating parameters should be taken into account:

Dimensions and stability of the focal spot:
This characteristic influences the output power of the beam and the sharpness with which the CT images are acquired, a factor that affects the level of detail of the specimen. Microfocus x-ray tubes exploit small focal spots, which allow for enlarged representations and resolutions at the micrometer level (~1 um).

Mini-focus x-ray tubes instead have larger focal spots and much higher energy radiations. They are usually used for large, solid samples, such as aluminum die-cast, gray cast iron or cast steel elements. High temperature variations can cause expansion of the x-ray tube housing and subsequent instability of the electric field, causing the focal spot to drift. The consequence is an unclear reconstructed image. Cooling the housing limits temperature fluctuation and focal spot drift, greatly improving the quality of the images.

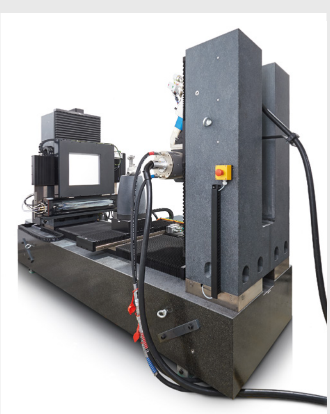


Fig. 6: The manipulator with a granite base guarantees precise CT acquisitions.

System components: mini-focus x-ray source
- Energy from ~20 keV up to ~600 keV
- Power: from approx. 100 W up to ~1500 W
- Dimensions of focal points from ~0.25 mm up to ~2 mm
- Available as single-pole (up to 225 keV) or bipolar systems (> 225 keV)

Micro-focus
- Energy from ~20 keV up to ~750 keV
- Power: <1 W up to ~300 W
- Size of focal points from ~1 um up to ~3 um
- Mechanical structure as transmission or direct emitter

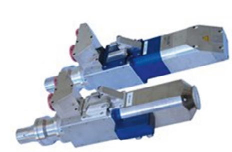


Fig. 7: X-ray tubes with mini-focus and micro-focus

keV (Kiloelectronvolts):
This is the potential difference needed to accelerate the electrons between the filament and the target to create high-energy x-ray photons by deceleration (bremsstrahlung). The higher the photon energy of the source the greater is the penetrating power of the radiation. The larger or denser the object to be inspected the more energy is required.

Milliamperes (mA):
Milliamperes indicate the current flowing. The higher the current flow the greater the number of electrons that will hit the target and, therefore, the greater the amount of x-rays emitted by the source.

In order to obtain the best possible image quality for the respective application, a balance must be obtained between the above-mentioned factors of the x-ray sources. There is no universal solution for all applications.

Four essential techniques for computerized tomography can be distinguished: fan-beam CT, cone-beam CT, spiral CT (helical) and laminography (Fig. 3, 4, 5).

DETECTOR

Modern CT systems are usually equipped with a flat-panel Digital Detector Array (DDA) or a Linear Detector Array (LDA).

DDA detectors are becoming the best alternative to traditional x-ray or CR film applications. Modern models guarantee excellent sensitivity, resolution and bit depth and allow you to obtain clear images with exceptional contrast. The flat surface and the square pixels avoid distortion issues. Pixel sizes vary mainly between ~50 µm and ~400 µm. They usually have a repetition rate of between ~2 fps and ~100 fps, with adjustable sensitivity settings.

LDA detectors are particularly suitable for precise CT fan-beam scans on thick components. They are available with pixels from ~80 µm to ~800 µm. In many cases, temperature can be regulated, which allows high yields and stable performance to be maintained. In some models, the detector consists of easily replaceable single modules with consequent savings on maintenance costs. LDA detectors can reach image repetition rates from ~30 fps to ~600 fps.

*Fig. 1:
Digital Detector
Array (DDA)*

*Fig. 2:
Linear Detector
Array (LDA)*

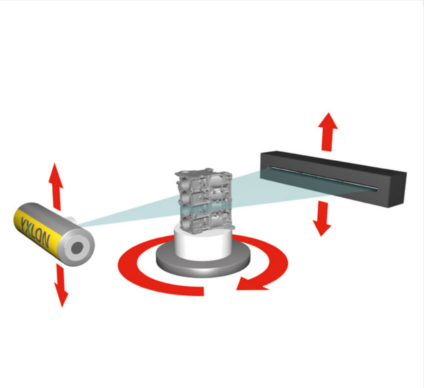


*Fig. 3:
Fan-beam CT
operating principle*

CT SCAN TECHNIQUES

Fan-beam CT:

This technique exploits a fan-shaped x-ray beam detected by a linear detector (Linear Detector Array – LDA). In fan-beam CT systems, the single slice layer is detected at each complete rotation of the object. A second complete rotation allows a scan of the next layer. The sequence repeats until the complete area of interest is scanned. Given the high scanning times, fan-beam CT systems are ideal for high-energy scanning (≥ 450 kV) of very large, dense components, limited to the area of interest, not the entire sample.

Cone-beam CT:

With this technique, the conical x-ray beam is detected by a flat-panel detector (Digital Detector Array - DDA). Cone-beam systems are particularly suitable for medium-sized cast elements, electronic components and other objects <300 mm Ø. Cone-beam CT is often the best compromise in applications where a complete 3D model of a good quality object is required with relatively short scan times. With a single complete rotation of the object (circular scan), it is possible to record a normal dataset in a quarter of an hour or less.

Scanning very large or dense parts (e.g. super alloys), cone-beam CT can give rise to CT artefacts in the image. In this case, it is better to use fan-beam CT which can offer better images, focusing the scan on the single area of interest.

Helical (or spiral) CT

During the scan, the sample follows a helical path (simultaneous rotation and vertical movement) with respect to the x-ray source. A DDA detector measures the radiation emitted by the conical beam coming from the source. This technique offers numerous advantages: first, it minimizes the artifact of the conical beam, allowing better quality data to be obtained. Helical CT is particularly suitable for tall objects as it avoids the laborious mosaic process (the "stitching") of mechanical and digital image compositions, but it usually takes longer.

Computed Laminography (CL):

This technique allows a two-dimensional area (plane) of a section of the object of specific interest to be scanned, ignoring the areas above and below, and determining the desired height for the CL section of interest. Laminography is very useful for high-volume samples which, due to the considerable lateral ratio, cannot rotate during scanning. In fact, the sample or – when this is not possible, the x-ray source and detector – can be rotated around the immobile sample, depending on the application. In this case, the conical beam penetrates the sample from different angles and the image is processed into single or multiple CL layers.

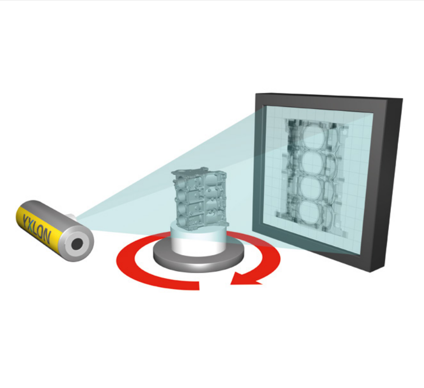


Fig. 4:
Cone-beam CT
operating principle

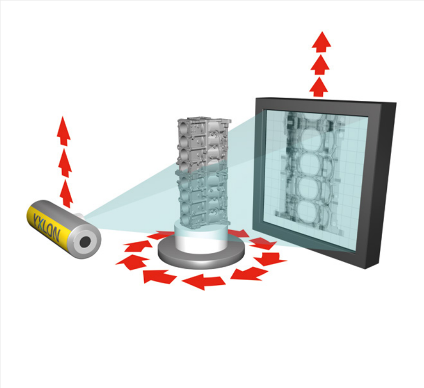


Fig. 5:
Helical CT
operating principle

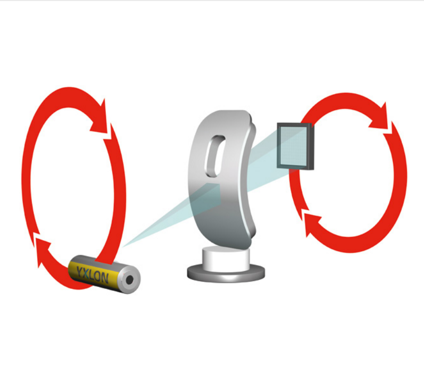


Fig. 6:
Computed Laminography
operating principle

SOFTWARE

Although hardware performance defines the operating limit of a system, questions should always be asked to correctly evaluate the software suitable for a CT system:

- Is the user interface easy to use?
- How can I improve the quality of the 3D scan generated by the CT system?
- How accurately can an object be displayed?
- Which accessory tools can be used to support the analysis of materials (porosity/inclusions, fiber composite materials, foamy structure, transport phenomena, etc.) and dimensional analysis (measurements, dimensional comparison of the theoretical and real model, wall thickness, etc.)?
- Which reporting tools are included in the package?
- Can the analysis software be integrated into the company's software environment?
- Which of the following features does the CT system software have?
  - 180° scans
  - Sequential scans of pieces
  - Measurements according to ASTM E1695 directive
  - Automatic calculation off-set detector
  - Detector calibration
  - Extended scan (Field-of-View-Extension)
  - Geometric calibration
  - Helical CT
  - Computed Laminography
  - Correction of the effect of beam hardening
  - Algorithms to reduce artifacts
  - Scan of an area of interest
  - DICONDE data format

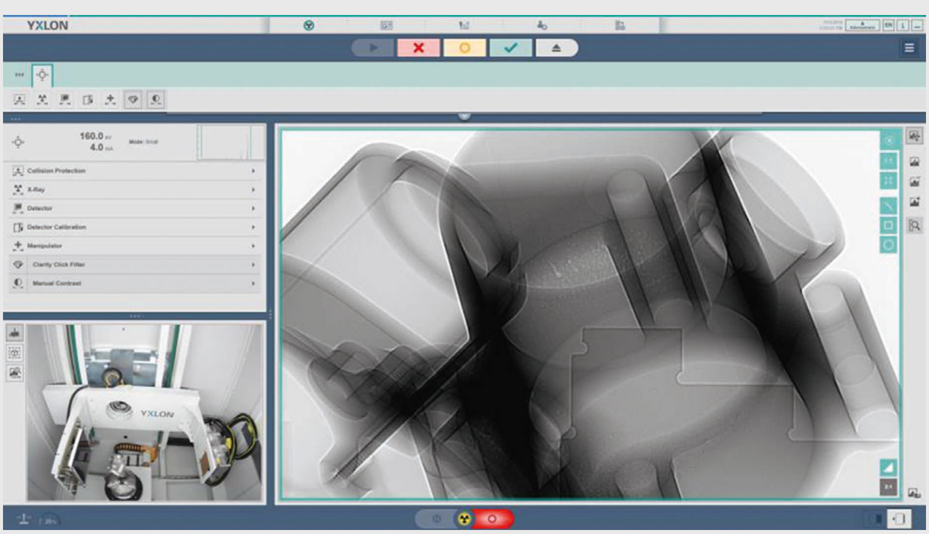


Fig. 1:
Easy inspection with a clearly structured Graphical User Interfache (GUI)

Geminy software for machine control, DR and CT workflow. All elements of an inspection position such as tube, detector, manipulator, filters, CT, etc. are represented by intuitive graphical icons.

Digital reconstructions

FIELD OF VIEW (FOV) AND FIELD OF VIEW EXTENSION (FOVE)

The Field of View (FoV) of a CT determines the volume portion of the object that can be acquired as an image by the detector during a scan. The scan field reaches a maximum value when geometric magnification is minimal, i.e. near the detector. In this case, resolution depends substantially on the physical dimensions of the single pixel of the detector. The scanning field, on the other hand, reduces with increasing geometric magnification when the component moves away from the detector. In this case, the scan's resolution increases even though the level of image detail also depends on the size of the focal point of the x-ray tube.

For scanning large objects, there are two options for expanding the scan field (Field of View Extension – FoVE):

- Use the software to virtually magnify the size of the linear detector (LDA) if the object does not completely fit within the scanning range (FoV). This procedure may generate a sharper image or prolong the scan time.
- Physically move the flat-panel detector (DDA) during scanning to acquire additional projections. This procedure requires a higher scan time and software that supports the described functionality.

FROM PIXEL TO VOXEL

The pixel is the basic element of a two-dimensional image, while the voxel (volume pixel) is the basic element of a three-dimensional volume (see Fig. 2). The reconstructed volume is therefore discretized into voxels, to which an estimate of the relative density is associated at each point of the scanning field thanks to a reconstruction algorithm which obtains the average of the attenuation coefficient of the scanned material, see Fig. 3.

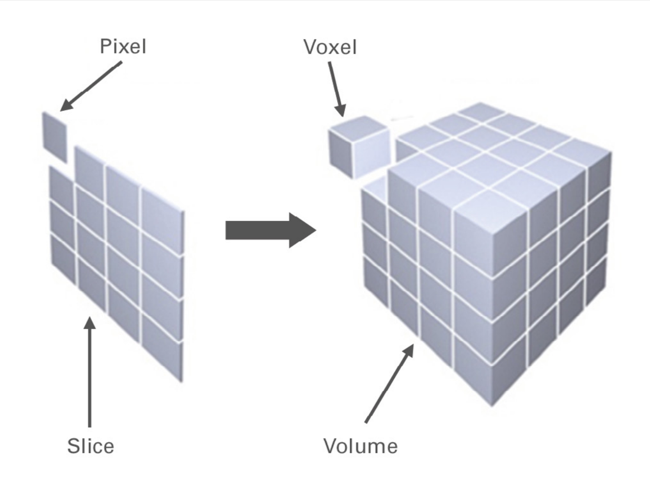


Fig. 2: From pixel to voxel

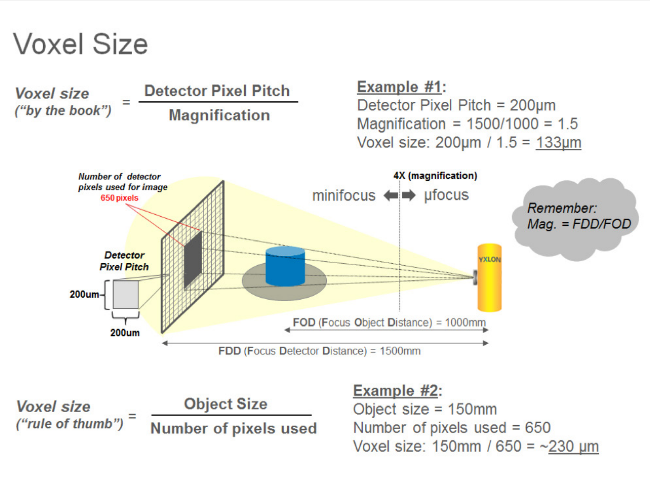


Fig. 3: Calculation of the voxel size

DURATION OF A CT SCAN

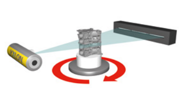
The scanning duration of a specimen can be calculated using the formula shown in Fig. 1.

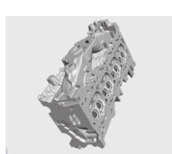
(Number of projections) x (Exposure time) x
(Number of integrated frames) x (Number of layers)

DETERMINATION OF THE SURFACE

As soon as the three-dimensional volume has been generated, a surface can be defined in the CT volume. There are several methods for defining the surface of a three-dimensional model, such as the ISO 50% method, the localized limit value and many others, generally chosen according to the quality of the CT images. After determining the surface, the border points that delimit the internal and external surfaces of the scan, called the "point cloud", are saved in a file that can have different formats. For example, the point cloud saved as the surface of triangular elements generates an STL file (.stl). The obtained dataset can be used by specific software to detect measurements or to carry out reverse engineering.

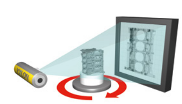
Example: Aluminum motor unit – Fan-beam CT	
Number of projections:	1440
Single frame exposure time:	33 ms = 0.03 seconds
Number of frames in each position:	1
Number of wlayers (LDA):	500





(1,440 projections) x (0.03 seconds) x (1 frame)
x (500 layers) = 21,600 seconds = 360 minutes = 6 hours

Example: Plastic connector – Cone-beam CT	
Number of projections:	720
Single frame exposure time:	300 ms = 0.30 seconds
Number of frames in each position:	4



(720 projections) x (0.30 seconds) x (4 frames) =
864 seconds = 14.4 minutes

Fig. 1:
How long does the scan of my component take?

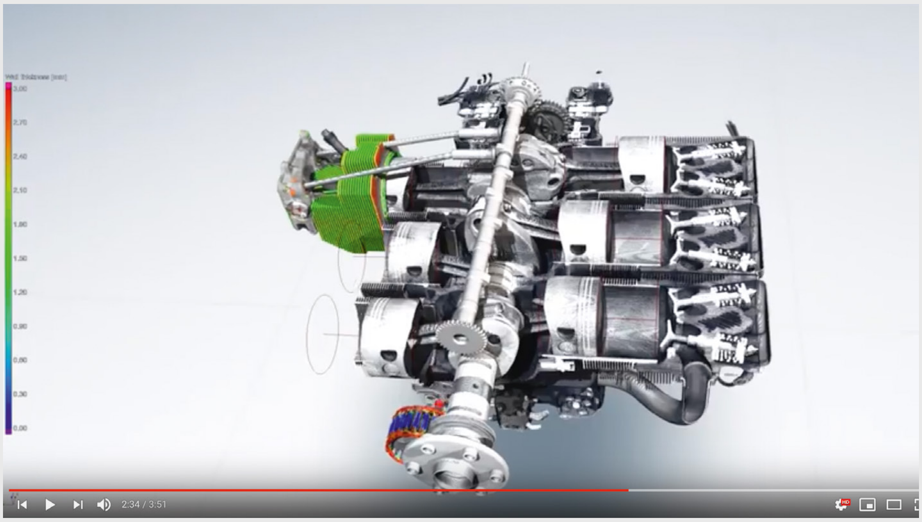
CT + Metrology

Traditionally, without destructive testing, full metrology has only been performed on the exterior dimensions of components. If a highly detailed component required inspection, it meant using a time-consuming coordinate measuring machine (CMM), touch-probe inspection process, or a vision system to map exterior surfaces. Past internal inspection methods would require using a two-dimensional x-ray of the component or the use of destructive testing.

With computerized tomography, it is possible today to digitize in detail the internal and external surfaces of the scanned object, giving access to areas that are unattainable with traditional tactile and optical systems. Many samples are hardly measurable from the outside with a tactile system, since the force applied by the measuring probe can deform the surface or provide false readings. With CT, you get an almost unlimited number of surface points, performing not only point-to-point measurements, but also precise comparisons between the acquired 3D object and the theoretical CAD model, including the measurement of geometric tolerances (planarity, circularity, cylindricity, etc.).

With industrial CT, it is possible to detect the volume of an object in a non-destructive way, examining the internal structure in real operating conditions. It is also possible to examine components connected to each other without resorting to disassembly. Some industrial CT scanning software allows measurements to be taken directly from the volumetric rendering of the acquired dataset, useful for obtaining the real distances between coupled parts.

CT techniques are widely used in various fields: material analysis, defect identification, failure analysis, statistical process control, dimensional measurement, assembly analysis, finite element analysis, reverse engineering applications, identification of faulty electronic components in circuits, and checking components for aircraft. CT is used to obtain feedback on the operating parameters in additive manufacturing and to identify even two-dimensional internal defects such as cracks or fissures, inclusions or residues of additive powder.



Click here to view a video of metrology + CT of Volume Graphic, YXLON and Victor Aviation Services.

Today, many components are designed, manufactured and assembled in multiple production facilities, or even in different countries or continents. It is therefore essential to check whether a component complies with the tolerances of the CAD model, especially if it is an integral part of an assembly made in different plants. Industrial CT allows the comparison of a 3D model with CAD data so that possible deviations in internal or external geometry are immediately visible, through the 3D illustration of the chromatic map, or through the so-called "whisker plots" in the 2D screen. The procedure is particularly useful when comparing components from different suppliers, examining the differences between pieces in each cavity of a mold, or when verifying compliance of the sample with respect to the original design.

The YXLON FF20 CT Metrology and YXLON FF35 CT Metrology systems have been designed specifically for metrology applications. They have features essential for making correct measurements:

- Precise and non-destructive measurement, including measurement of internal structures
- Measurements of small structures
- Rapid, non-sequential data acquisition with an almost unlimited number of measuring points
- Significant time saving thanks to defect analysis and comparison of nominal/actual data
- Reduced correction cycles
- Decreased correction costs
- Compliance with the VDE/VDI 2630 guideline

Choosing a CT system

A tomographic system is an important investment, and it is not only important but necessary to properly determine which system to acquire. Below, we list some important factors to consider when choosing the ideal CT system:

Be aware of your application(s), providing detailed information to the specialized retail staff, whose job it is to suggest the ideal solution for the customer. Often, this procedure is much more complex than expected - unless you look for a system that is suitable for a single, specific operation, which rarely happens. Sometimes, it is also difficult to describe what is really necessary for each type of sample. It is therefore important to clarify in detail the cycle time of the operation, together with the performances required in terms of identifying the defect in both form and size.

If you intend to use the tomographic system for different tasks, it is a good idea to classify all applications and ensure that each of them is carried out equally by the chosen system.

Establish priorities and accept compromises for the proposed needs.
Although it is important to aim for a "perfect solution" for the specific needs of the customer, it must be remembered that, in many cases, it is impossible to cover 100% of requirements with a single CT system. Some systems come close to the "perfect solution" but often are decidedly more expensive than necessary.

In the preliminary phase, the required applications should be divided into groups, assigning each of them a ranking priority. The groups could be, for example, "Object size", "CAD comparison", "Metrology", or "Wall thickness measurement", then associate a weighting value that gives a clear idea of their importance with respect to the financial investment. Probably, from this procedure, it will emerge that an application of low importance (such as a large component produced only once a month) causes an unsustainable budget overrun.

In these cases, it would be convenient to assign low repetitive and/or critical applications to an external CT service company. Often, the same manufacturers or retailors of CT systems offer these services to their customers.

Know the technical possibilities of your CT system in depth.
Depending on the type of applications, some technical choices can guarantee better results than others. If a fan-beam or cone-beam CT does not provide the image to meet your needs, perhaps spiral CT or laminography can bring better results.

Know how to interpret figures and data.
The data sheets can be misleading, especially if you focus on individual factors, such as maximum magnification, resolution, speed, etc. The evaluation of a system must be based on the adequacy of the features to the actual applications, and not on simple maximum, minimum, faster, more frequent values, etc. The possibility of obtaining a magnification of 1,000 times, for example, is not relevant if your object can only be magnified up to a maximum of 50 times due to its size. High resolution should also be considered with caution. A high-resolution detector can have a reduced dynamic range or a high delay, providing a poor-quality image, despite the stated optimal resolution.

Inspect the operator interface carefully.
As each manufacturer claims to offer easy-to-use software, we recommend displaying and using the software interface to future CT system operators in the decision-making phase, at the system supplier or via remote sessions. It is also advisable to appropriately evaluate the relationship between hardware and software.

Choose a dealer with qualified support staff.
We recommend using a retailer able to offer suitable personnel for regular maintenance and prompt support in case of an emergency. It is important to clarify the number of technicians available for emergency interventions on the specific CT system used (and not those generally available), the years of experience gained, the operational headquarters, and the average waiting times for arriving at the site.

Ensure the dealer offers appropriate training courses.

When purchasing the first CT system, employees must follow a general computed tomography training course. Operators must acquire the skills for using the system in close correlation with the specific applications with which they are asked to work. Ideally, courses should take place on the same CT system as that purchased by the client. Not all retailers can offer such a solution; therefore, it is advisable to check the contractually provided training courses to determine if they are suitable for your needs. If you consider the training insufficient, we recommend asking the retailer for an exemption from the standard training offer, as well as checking the costs of training a new operator, so as to be prepared for eventual employee turnover.

Collect references.

After limiting the range of possible retailers, it is advisable to ask each of them for a list of previous customers. We also recommend preparing a list of questions about normal use and/or system malfunctions (like what was the reaction time for the retailer or did they immediately appoint a responsible person to deal with the problem?).

From this survey, you can gain an understanding of whether the dealer’s specialized field is in line with the required skills, and if their priorities correspond to your own.

Installing a CT system

Once the decision is made to invest in a CT system, a system implementation plan must be drawn up with the chosen retailer, detailing the expected costs, the expected time of return on investment, an implementation schedule and a summary of the objectives to be achieved. It should be stressed how important it is to provide sufficient time and resources for correct installation, training and refresher courses, and to make sure all parties contribute.

DOCUMENTATION OF TECHNICAL DATA

The documentation of the technical system data is fundamental for adequate implementation.

The CT system specifications must indicate the environmental operating conditions. It is important to ensure that the layout of the installation site is ready in time for delivery. In some cases, the supplier requests a certificate attesting the adequacy of the destination, both for delivery and for system connection.

Other optional features include the quality of the available electrical network, the layout of the network configuration, the grounding installation, etc. The IT department is also usually involved; some companies require certain hardware components for computers, specific network protocols or data backup strategies.

Another topic of fundamental importance concerns the radiation protection directives in force for the company, region and country. Ideally, the purchase and sale documentation should contain the procedure used to test the system, with clear indications of the monitoring operations to be followed. The plans must include items such as image quality in accordance with current regulations, a specification of the digital display device, including the "Bad Pixel Map", expected cycle time, reports of the operating times of the system, etc.

For more complex CT systems, it is advisable to invest more resources in the acceptance phase, for monitoring the project under construction, and for periodic updating meetings.

It should be noted the technical data specified in writing is not always useful from a practical point of view. Personally checking the software interface at the CT system manufacturer's premises is therefore often a more valid control support. Final acceptance, especially in the case of complex CT systems, should always be done in person.

Fig. 1: Theoretical and practical training courses guarantee the desired results for operators

SKILLS TRAINING AND OPERATOR CERTIFICATION

The time necessary to train skills and to certify operators can often be underestimated. Many new users await the provision of the CT system before seeing to the necessary training measures, slowing down the time until the system can be fully used. In some cases, the CT system is approved by the client without having completed the necessary training, and so it remains inactive while the operators reach an appropriate level of competence.

Beginning use of the CT system as early as possible is a solution that often leads itself to better results for operators. It can provide the opportunity to make the most of the applicative resources available during installation, qualification and acceptance. It is strongly recommended that the training and certification phase of the operators be included in the purchase of the system, by requesting a draft of the installation and training plan. This measure also speeds up the testing procedure.

Although the training phase is planned towards the end of the CT system installation, in many cases, it is possible to follow courses prior to delivery. For example, operators can be trained by acquiring digital images from other systems in different locations (digitally transmitted), in order to accumulate the digital inspection hours required for certification.

INSTALLATION AND TRAINING COURSES

The training phase on a CT system is one of the key points for commissioning the investment.

We recommend carefully planning the installation date, taking into account the production needs during the transitional installation phase and training, and taking care to inform all the departments who are involved either directly or indirectly.

AN ADDITIONAL TRAINING STRATEGY

A few weeks after the original training course, invite the teachers back to the site to deepen the acquired knowledge. This measure is particularly useful in the case of complex CT systems and for new imaging procedures. It achieves two objectives: first, it compensates for the overload of information to which operators are normally exposed, who are normally not accustomed to the technology of CT systems. It is unrealistic to expect operators to process the teaching material provided within two or three days. The second benefit lies in the personal approach developed during the first weeks, thanks to which operators gain experience with the system, consolidate the accepted theory and discover aspects worthy of further study. It is at this point that a second meeting with the system provider provides the greatest contribution, recovering faded or not understood concepts and encouraging in-depth analyzes of high specialization value, based on specific requests of the trainee operators.

SUPPORT FOR FINAL CUSTOMER TESTING

Once the CT system is installed and the training courses are complete, it could be necessary to run final customer testing before tests can begin on products, as it is not always possible to have the specific scanning and analysis procedures approved in advance.

Fortunately, it is easier to collect data and share images after installing the digital system. All stakeholders must be constantly updated on planning deadlines in order to avoid difficulties due to lack of availability of personnel.

Once the CT and/or software system has been tested, it may be necessary to meet other industrial requirements, such as those provided for by the International NADCAP Cooperation Program (National Aerospace and Defense Contractors Accreditation Program) for the aerospace industry. It is therefore necessary to ensure that the current industrial standards have been understood and handled accurately during the training courses. Some providers offer special training courses to obtain relevant licenses and audits. In this sense, the availability of specialists can represent a strategic contractual component.

Concluding note

Computed tomography has opened new horizons in the field of non-destructive testing.

Users from all sectors, from research & development and engineering to manufacturing production, can use this technology to:

- inspect the components in a more precise and complete way
- automatically identify defects
- conduct accurate metrological activities
- generate surfaces that, through reverse engineering, support additive manufacturing
- collaborate with users from all over the world

For questions or requests
for specific applications,
please call (+49 40 52729-0)
or send an email to
yxlon@hbg.yxlon.com

Visit our blog www.yxlon.com/blog

North America
Phone: +1 234 284 7849, yxlon@yxlon.com

CT Glossary

Additive manufacturing (AM): A process that creates a physical object from a digital design. Also known as **3D printing**.

ASME: The American Society of Mechanical Engineers: Founded in 1880 as the American Society of Mechanical Engineers, ASME is a not-for-profit professional organization that enables collaboration, knowledge sharing and skill development across all engineering disciplines, while promoting the vital role of the engineer in society. ASME codes and standards, publications, conferences, continuing education and professional development programs provide a foundation for advancing technical knowledge and a safer world. It's the globally-recognized, trusted source of standards used around the world. *(Source: www.asme.org)*

ASTM: ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

Attenuation: The reduction in intensity of a beam of x-ray or gamma radiation during its passage through matter caused by absorption and scattering.

Ball Grid Array (BGA): is a type of surface-mount packaging used for integrated circuits (micro-processors, chips).

CAD Software: Computer-Aided Design, is used by architects, engineers etc. to create precision 2D- or 3D drawings and technical illustrations

CMM: Coordinate Measuring Machine, a device that measures the geometry of physical objects by sensing discrete points on the surface of the objects with a probe.

Computed Tomography (CT): An object is scanned from different angles capturing a large number of x-ray images which are reconstructed by powerful software. The so-called 3D volume can extensively be examined and analyzed even in the interior by use of dedicated visualization software.

CT Dataset: the complete dataset generated from the x-ray images of a CT scan and their reconstruction

Data acquisition: The process of sampling signals that measure real-world physical conditions and converting the resulting samples into digital numeric values that can be processed by a computer.

Detector calibration: The compensation of slight differences of the output signal among the different detector pixels.

DICONDE: as defined by ASTM as 'Digital Imaging and Communication in Non-Destructive Evaluation' which is a standard for handling, sharing, storing and transmitting information between DICONDE compliant systems. DICONDE is an NDT standard based on the medical DICOM standard.

Digital Detector Array (DDA) also known as **Flat Panel Detector:** DDAs can convert incident radiation into electrical signal that can be read out by a computer. This technology presents high-quality images and supports the use of a variety of post-processing filters.

FAIR (First Article Inspection Report): A First Article Inspection Report is the document that certifies that each sample was produced and inspected according to the customer's specifications. First Article Inspection is the process of planning, manufacturing, and verifying a production process. *(Source: www.inspectionxpert.com)*

Focal spot: The area of the anode surface that receives the beam of electrons from the cathode. The size of a system's focal spot affects how sharply the internal details of an object can be visualized.

GD&T (Geometric Dimension & Tolerancing): GD&T, short for Geometric Dimensioning and Tolerancing, is a system for defining and communicating design intent and engineering tolerances that helps engineers and manufacturers optimally control variations in manufacturing processes. *(Source: www.formlabs.com)*

Histogram: An image histogram shows the representation of the gray value distribution in a digital image. It helps e. g. estimating, if an image is underexposed or overexposed and informs about the dynamic range and contrast of the image.

Implementation plan: The series of steps and associated schedules involved in choosing, preparing for and installing a DR system.

Inclusion: With any production technology, especially casting and 3D printing, foreign matters can enter the material and affect the quality of the final product.

ISO: The International Organization for Standardization is a nonprofit organization that develops and publishes standards of virtually every possible sort, ranging from standards for information technology to fluid dynamics and nuclear energy. Headquartered in Geneva, Switzerland, ISO is composed of 162 members, each one the sole representative for their home country. As the largest developer and publisher of standards in the world, ISO fills the vital role of a medium for agreement between individual standards developers, spreading progress made by one country's local developers across the world to further the goal of standardization.

Metrology: the science and technology of measuring.

Micro-focus x-ray tube: Micro-focus tubes have small focal spots to perform very high magnification imaging. Typically these tubes have a focal spot between 300 µm and less then 1 µm. This makes them suitable for many types of electronics, automotive, and aerospace inspection applications.

Mini-focus x-ray tube: Mini-focus tubes have larger focal spots (typically between 0.3 mm and 1.5 mm) and provide much higher tube currents in mA. They are generally recommended for larger or denser samples such as castings.

NADCAP: National Aerospace and Defense Contractors Accreditation Program

Non-destructive testing (NDT): A broad group of analysis techniques used to evaluate the properties of a material, component or system without causing damage.

Operator certification: Documented proof that an operator has been properly trained in the use of the DR system. For more information, consult the International Atomic Energy Agency's "Guidelines on Training, Examination and Certification in Digital Industrial Radiology Testing (RT-D)," available at https://www.iaea.org/publications/10833/guidelines-on-training-examination-and-certification-in-digital-industrial-radiology-testing-rt-d.

Optical System: is a non-contact CMM which uses white light or laser for sensing the points of an object

Pixel: A minute area of illumination on a DDA or computer display screen; an abbreviation for picture element. It is recommended that the display provides at least the same quantity of pixels as the detector to prevent loss of image information.

Point cloud: The starting point for creating and using point clouds is the acquisition (scanning) of an object (component) with a coordinate measuring machine, a computer tomograph or 3D laser scanner. Computer tomography not only records the surface of the object, but also all internal structures. The unorganized spatial structure of the measured coordinate points is called point cloud. The coordinate points belonging to the object surface connected to triangles result in a triangular mesh, which is usually provided in STL format.

Porosity: Especially in the casting process, increased air inclusions in the product can lead to porosity and thus instability.

Reverse engineering: also called back engineering, is the process by which a man-made object is scanned with computed tomography and the data achieved are transferred into CAD data for reproduction.

STEP: Standard for the Exchange of Product Model Data, a common term for the international standard ISO 10303 which focuses on the representation, exchange and integration of product model data between different computer systems.

Stitching: the process of combining several images by computer software to produce the complete 3D image of a large object.

STL files (Standard Tessellation Language): An STL file stores information about the surfaces geometries of 3D models. These files are usually generated by a computer-aided design (CAD) program. The STL file format is the most commonly used file format for 3D printing.

Tactile System: The working principle of a tactile CMM is to contact the object and to measure the location of the taken point on the object's surface.

CT Glossary

Target: A high melting point metal (typically tungsten) on the end of the anode of an x-ray tube on which the electron beam impinges and from which the primary beam of x-rays is emitted.

VDE: The VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V. is a technical and scientific association in Germany founded in 1893 under the name Verband Deutscher Elektrotechniker (Association of German Electrical Engineers). It combines science, standardization, testing, certification, and application consulting under one umbrella, and has been synonymous with the highest safety standards.

VDE/VDI: In the VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (Society for Measurement and Automation Technology), GMA for short, Association of German Engineers bundles (VDI) and the Association for Electrical, Electronic & Information Technologies (VDE) are bundling their joint activities in the field of measurement and automation technology.
Each association creates industrial guidelines for industrial applications based on latest studies.

VDI: The Verein Deutscher Ingenieure is a German technical and scientific association founded in 1856, which is the largest association of engineers and natural scientists in Germany today. The members of the VDI group perform technical-scientific work in standardization and as project sponsors of public research funding.

Void: A hole or empty space in the structure of an object.

X-rays: Electromagnetic radiation (photon) with a higher energy than visible light or ultraviolet radiation. X-rays have the ability to penetrate matter, dependant on its density and material thickness.

YXLON

GERMANY – HEADQUARTER

YXLON International GmbH
Essener Bogen 15
22419 Hamburg
Germany
yxlon@hbg.yxlon.com
T. +49 40 527290

www.yxlon.com

USA

YXLON Sales & Service Location
c/o Comet Technologies USA, Inc.
5675 Hudson Industrial Parkway
Hudson, OH 44236
USA
yxlon@yxlon.com
T. +1 234 284 7849

CHINA

YXLON (Beijing)
X-Ray Equipment Trading Co., Ltd.
C07, First Floor, Building 2
Zhongke Industrial Park
103 Beiqing Road, Haidian District
100004 Beijing
China
T. +86 10 88579581

JAPAN

YXLON International KK
New Stage Yokohama Bldg.
1st Floor
1-1-32 Shinurashima-cho
Kanagawa-ku
221-0031 Yokohama
Japan
T. +81 45 4501730