Guide

How to Select the Newest X-ray Technology: From Nano to Macro

YXLON

Technology with Passion

XRAYCONSULT di Brigida Michele
Via A.Uboldo 2/c
20063 Cernusco sul Naviglio (MI)
brigida.michele@xrayconsult.it
Mob.: 338 3688709
XRAYCONSULT

How to Select the Newest X-ray Technology: From Nano to Macro

By Dr. Thomas Wenzel, YXLON / Comet Technologies USA, Inc.

Introduction

Determining the absolute best fit for your specific application with a CT (computed tomography) system requires many individual decisions, and it can be overwhelming. Whether this is your first time evaluating a CT system for purchase or you have done it before, the process of selecting the right technology has become more cumbersome due to the significant performance increases delivered by today's X-ray systems. Knowing the technology inside the system is important, and this guide is designed to help you navigate through the tough task of determining your specific, unique needs and the many influencing factors.

You'll want to consider: X-ray source, focal spots for tubes, X-ray tube energy bandwidth, detectors, necessary application considerations, available software, standards to follow and data storage. Of all these attributes, which ones deserve special attention from a user’s point of view? Let’s begin by examining each factor and figuring out what you should know for a successful selection of a CT.

- Nanofocus X-ray Source: What is important?
- Focal Spot of Mini-focus Tubes: Which countermeasures and viewing angle?
- X-ray Tube Energies: How high is too high?
- Detectors: How many pixels are enough?
- Metrology: How does your application fit?
- Software: Which features matter?
- Standards: Does it measure up?
- Long-term Storage: How much is enough and where should it be kept?

1. Nanofocus X-ray Source: What is important?

Did you know 99% of the power of an X-ray tube will be converted into heat? There are multiple effects produced by this heat. Unfortunately, one of the effects of this heat is the elongation of the tube housing, which can change the magnification during the process of taking a measurement. Also, the heat can cause a fluctuation of the electrical field within the tube. Due to this heat, it's possible the item being X-rayed could be warmed, and the stability of the position and form of the item can be altered. This can cause a host of issues with the accuracy of your measurement.

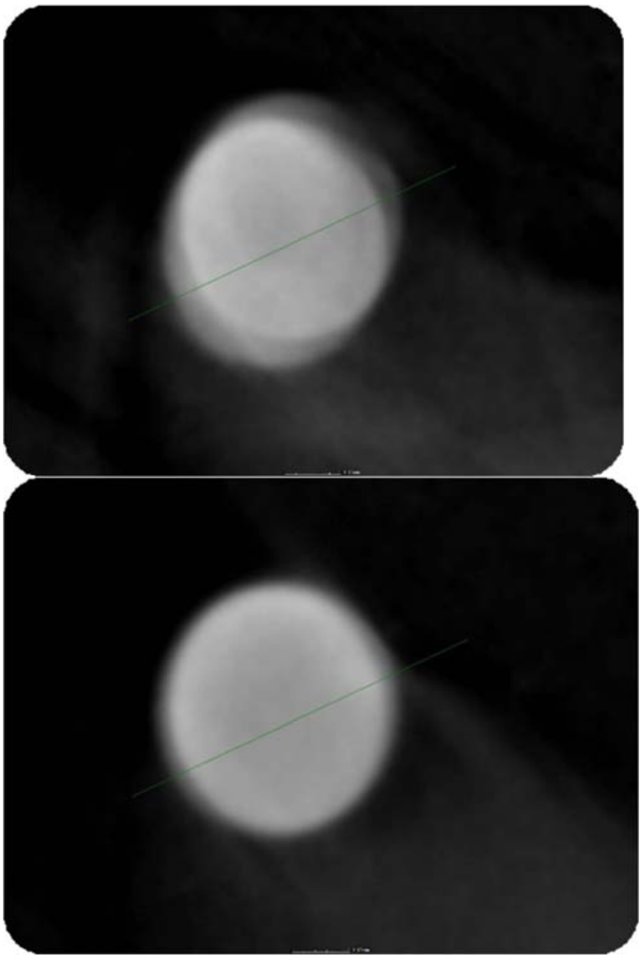


Figure 1: Comparison of the sharpness of a reconstruction using an uncooled (top) vs. cooled (bottom) nanofocus tube.

During the selection of a micro-focus X-ray tube, consideration must be given to the countermeasures the system provides for long-term stability to combat the heat manifested from the tube. Does the system you're considering compensate for the determination of the focal spot drift (the X/Y-plane)? Are the tube body and coil cooled for minimization of the focal spot drift? How long does it take for thermal equilibrium to be reached and the minimum variation of the tube temperature to achieve equilibrium? And lastly, you should know if the system prevents a shift of the focal spot in beam direction.

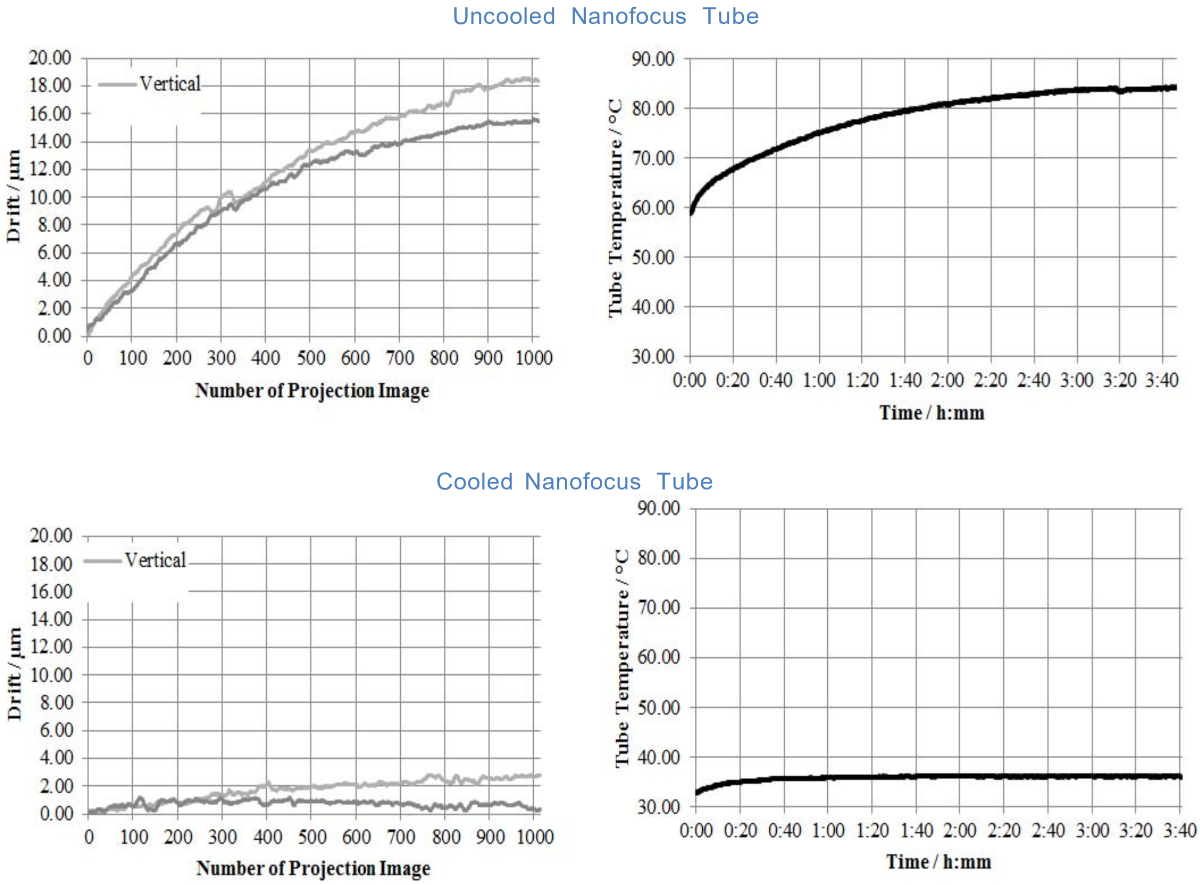


Figure 2: Long-term stability with nanofocus. The first row shows an uncooled nanofocus tube with a tremendous movement of the focal spot in vertical as well as horizontal direction. The second row shows the behavior of a cooled nanofocus tube, where the movement is almost negligible in both directions. The images on the right show how long it takes to reach the temperature equilibrium with an uncooled (first row) and a cooled tube (second row).

X-ray intensity is low with sub-micro focal spots, and good results can only be achieved using longer measurement times. Therefore, the long-term stability (especially of the X-ray tube) is important. This includes the shape of the focal spot as well as its position. A change of position or the shape will decrease sharpness and contrast in X-ray images and even more in CT reconstruction.

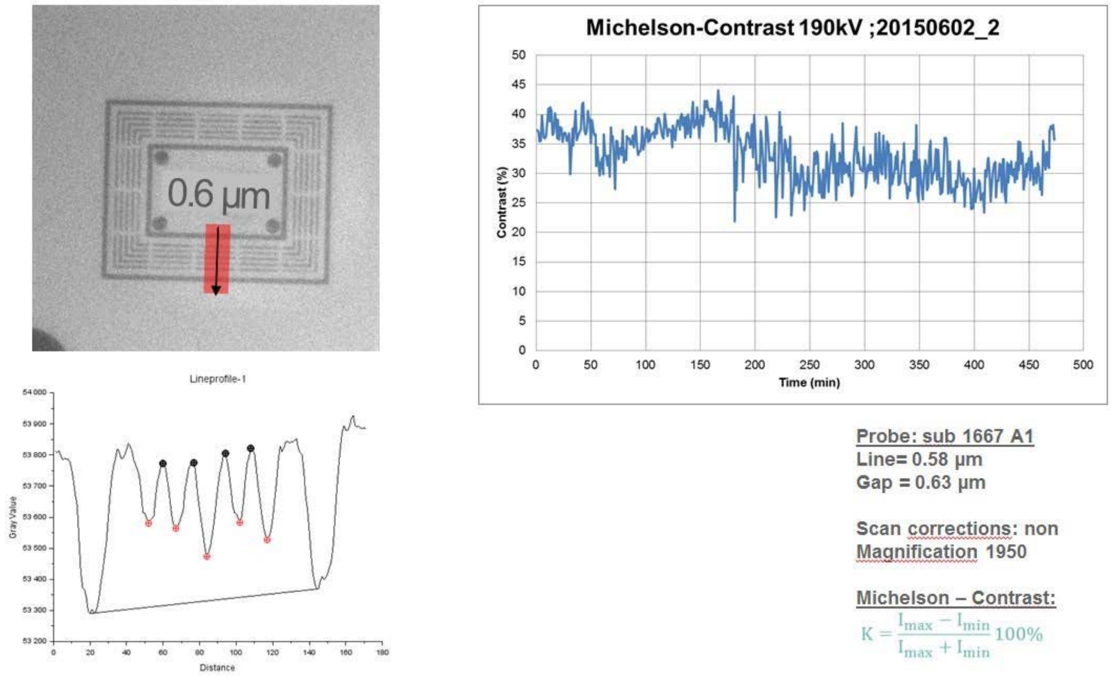


Figure 3: Michelson contrast example.

You can use specially fabricated phantoms as an indicator for the size and shape of the focal spot and to show resolution and contrast. These are very good gauges to use to keep track of the long-term stability of the focal spot. Also, software can automatically derive characteristic values for the contrast. For example, as shown in Figure 3, we used the Michelson contrast, a repeatable standardized test. The graph shows that the long-term stability of the measured tube is very good, with a minimum change over a period of six hours. A tube like this will produce high resolution CT scans with almost no negative impact on resolution and contrast.

2. Focal Spot of Mini-focus Tubes: Which perspective?

As with all X-ray tube types, the focal spot of a mini-focus tube will affect the sharpness of an X-ray image. The important part with any X-ray application in terms of resolution is a stable focal spot. With mini-focus tubes, the focal spot is stable because it is not moving or changing shape. Size and shape are dependent on the viewing angle, or the perspective of the focal spot as seen from different areas of the detector, as illustrated in Figure 4.

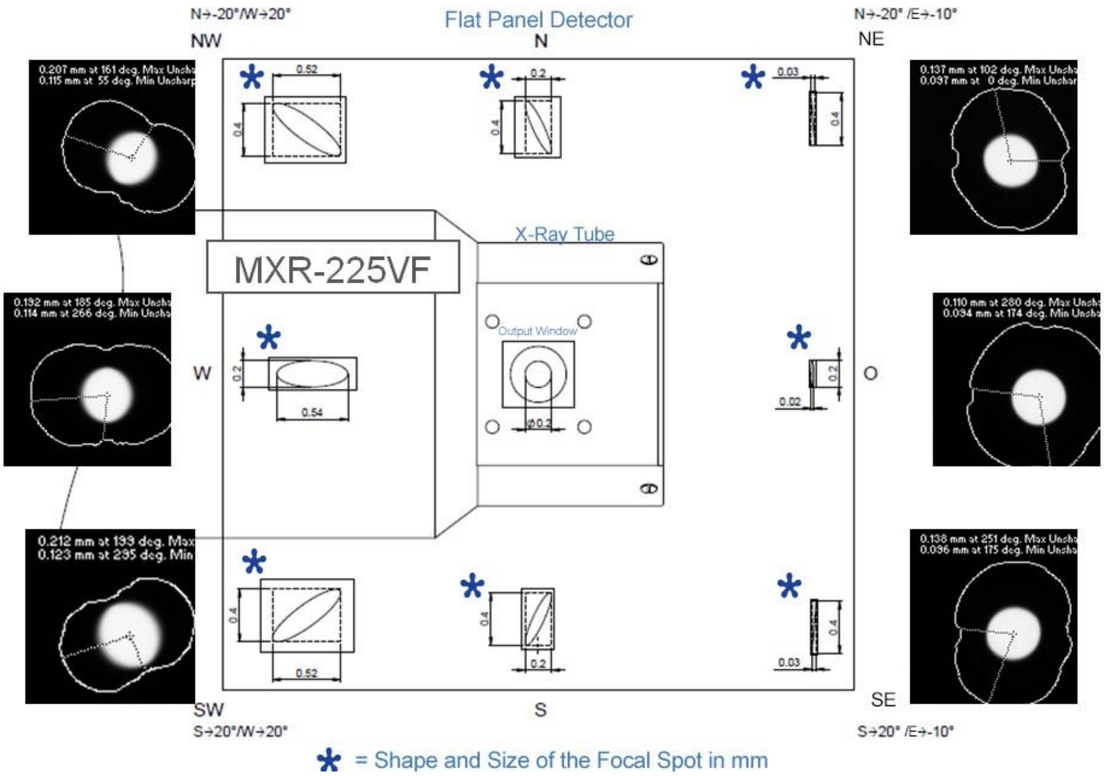


Figure 4: Shapes and sizes of the focal spot of mini-focus X-ray sources as seen from different viewing angles. The outer square black line perimeter represents the flat panel detector. The eight ovals with measurements (and their corresponding output images) illustrate how the focal spot is seen from various positions of the detector. Note how the size and shape of the focal spot changes as perspective changes.

You may wish for higher power in order to decrease inspection time. A smaller target angle can provide both higher power and a small focal spot. But as Figure 5 shows, the dependency between focal spot size and viewing angle increases with smaller target angles.

In addition, one should also take into consideration the inequality of intensity distributions over the entire area illuminated by the X-ray beam. Avoid the use of large detectors (>400mm/16” diagonal) with very short focus detector distances (FDD <1m/3ft); instead, employ the right geometrical setup of the mini-focus tube to achieve better resolutions. Figure 5 illustrates the inequality of the intensity distributions of different target angles.

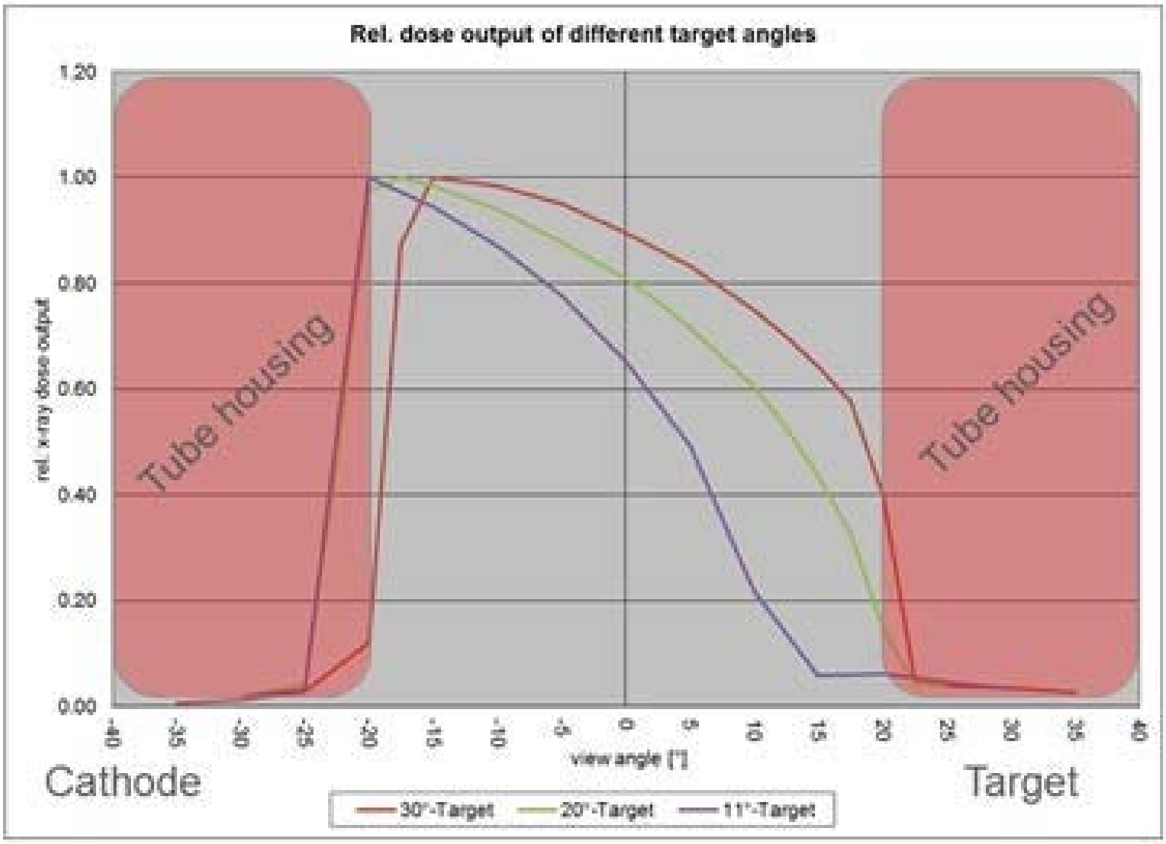


Figure 5: Comparison of homogeneity of X-ray dose as dependent on the viewing angle for different target angles. Smaller target angles lead to less homogenous distribution of the dose.

Mini-focus tubes with small target angles deliver a great advantage: high power with a comparable focal spot. To be able to make use of these advantages, observe the following guidelines:

- Make sure you use a small opening angle (<20°) by getting enough distance between source and detector (FDD).
- Don't tilt the source, as is commonly done in some older systems.
- If you are using an LDA line detector, high resolutions can be generated. By taking advantage of these guidelines, the optical focal spot becomes smaller in directions closer to the target (see Figure 5 for dose distribution).

3. X-ray Tube Energies: How high is too high?

When choosing an X-ray tube, one of the most important criteria is energy bandwidth. Presently within the industry, the trend is to choose a higher energy tube to obtain better penetration of high absorbing materials and larger wall thicknesses. Increasing the acceleration voltage can increase X-ray photons more than when simply increasing the current of the tube. For example, doubling the current of the tube increases the number of photons by a factor of two, but doubling the voltage can increase the number of photons by a factor of four. This is tempting to do because the larger number of photons results in a shorter measurement time, but keep in mind you are in danger of losing image quality by using this method. Here's why.

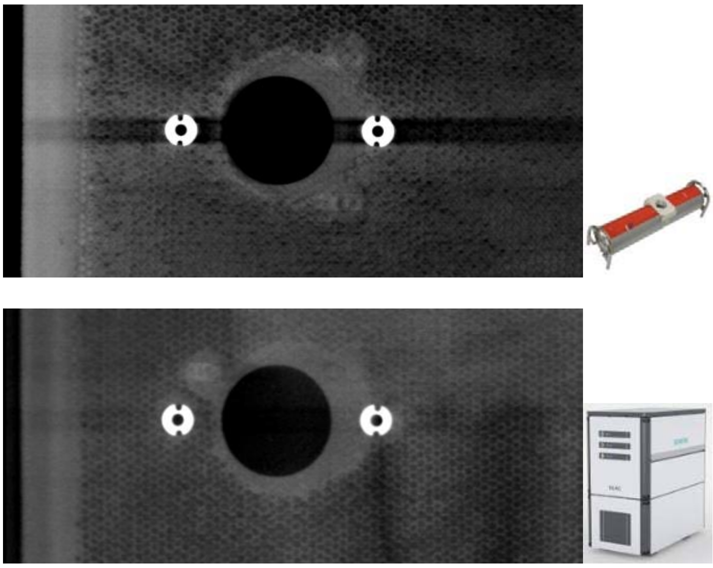
There are a few X-ray photon phenomena that are relevant to a discussion about higher energy tubes: photo absorption, Compton scattering and pair production. Depending on material properties, different effects are observed. It all depends on the materials you are inspecting.

With low energies (<40 keV), photo absorption is the dominant effect for most materials. With low energies, the tube is able to produce good contrast—even between two materials that are physically proximate to one another on the same sample. This is because absorption depends on the atomic number (Z) of the material, and at low energies, the influence of Z is very high. The bad news is that materials with very different atomic numbers will produce enormous contrast, which may lead to an image that cannot be inspected.

With higher energies (>200 keV), Compton scattering is the dominant effect. In this case, the atomic number, Z, is only a linear factor in the absorption equation—it has less of an influence. Materials with very different Z values will produce less contrast and can be seen within one shot. Of course, materials with very similar atomic numbers may show up as one grey value in the image.

At energies beyond 2-3 MeV, pair production is, more or less, the only effect that takes place. Inspection at these energies is less optimal for most nondestructive test applications because there is very little absorption, and thus very little contrast.

If your test objective requires a large contrast of materials that have minimum differences in atomic numbers (like carbon fiber–reinforced polymer or CFRP, where almost everything is carbon), make sure the amount of X-ray energy used stays in a range where photo absorption is the dominating effect. On the other hand, if you have a combination of materials with very large differences in atomic number, such as CFRP and steel, make sure the Compton effect is dominant by using higher energies. When inspected at higher energies, those materials will be visible. See Figure 6.



Lower Energy

Higher Energy

Figure 6: In this X-ray of CFRP, the top image has better resolution but more artifacts—meaning less image quality—because it was taken at lower energy. The bottom image, taken at higher energy, has a better image quality with fewer artifacts but less resolution.

4. Detectors: How many pixels are enough?

In the last few years, several trends in X-ray system detector development have emerged. These include the imaging of larger areas and smaller pixels per image (currently available down to 100 µm with amorphous silicon detectors, and there are even smaller pixels available with CMOS detectors), increased scintillators and energy-resolving detectors with multiple bins. With all this, the range of achievable resolution has expanded. But, due to the reduction of pixel size, with thinner scintillators, there is a significantly increased measurement time. In addition, the efficiency of scintillators is decreasing; the thinner the scintillating material gets, the more you depend on having an energy that fits into the optimum working spectrum. Energies outside that window cause the scintillator to become very inefficient. We also see that the displayable range of wall thicknesses is decreasing, and it comes at the cost of giving us less contrast.

Given all of these trends in detector technology, it means that when you select a scintillator you'll need deep knowledge of your application to achieve your measurement goals. The right detector decision can significantly increase resolution for the chosen application. Due to the large array of detectors and scintillators available, you'll want to make sure your sales consultants are knowledgeable and trustworthy. A good partner will guide you through this part of the selection process.

5. Metrology: How does your application fit?

The highest demands for CT are in metrology. Measurement results with ensured traceability are extremely important in metrology applications and must abide by elaborate standards. There are certain criteria to consider when selecting the best CT system to fit your specific application needs. These include:

- Characteristic values according to VDI/VDE 2630 section 1.3:
    - Maximum permissible error (MPE) certifies the ability of a system in principle, yet the significance for a specific specimen is limited.
    - Characteristic values according to section 2.1 are realistic, yet costly to determine
- Computer Aided Accuracy (CAA) field correction
- Possible measures for temperature compensation (temperature stability, measuring room class X)
- Workflow-specific requirements should be easily determined (calibration, integration measurement software)

Figure 7: The process of producing reliable metrology results.

CT combines X-ray and metrology. X-ray is currently the most demanding portion of the process shown in Figure 7 as we strive to achieve the best possible CT volume and imaging chain that will satisfy metrology needs. The advent of mini-focus and micro-focus tubes, along with the steady progression of better detectors, has given us better control over X-rays. Achieving the best image possible enables you to produce more accurate volume data by using reconstructions, artifact reduction, surface extraction, etc. Today, the best metrology outcomes are achieved by paying close attention to the right standards and by ensuring that your X-ray inspection process optimizes image quality and volume data.

6. Software: Which features matter?

Computer aided detection software solutions abound, and each will come with a range of database tools and programing languages. To navigate through all of these choices, it is important to remember CT inspection system software tools should include the ability to follow your workflow with ease, so you can create the images necessary to meet your needs (for example, laminography, helical, fan beam, etc.). Your software should be able to achieve your formal obligation of proof by meeting standards for image quality, resolution, signal-to-noise ratio (SNR), carrier-to-noise ratio, etc.

It should include documentation of process, have simple calibration options, have the ability to view data during acquisition and should allow the user to enter CT parameters independent of each other, like projections, integration times, detector modes, etc.

When considering database tools, look for a system with an independent viewing station that provides continuous CT scanning. It should also have the ability to do this while simultaneously analyzing previously scanned data. This is the key to efficient scanning.

7. Standards: Does it measure up?

Depending on your need(s) and/or your customer's need(s), industry standards can be extremely important and may even be mandatory. These national and international standards are determined by many organizations, including the International Organization for Standardization (ISO), American Society for Testing and Materials (ASTM) and European Standards (EN), to name a few. You will need to determine which standards you need to meet, how to go about putting these standards in place within your workflow, how you will provide proof of meeting these standards (documentation, record-keeping, data storage), what tools you need to buy in addition to the CT system to provide the measurements, and how you will ensure the integrity of data related to these standards.

8. Long-term Storage: How much is enough, and where should it be kept?

In the past 15 years, data volume in CT imaging has increased exponentially. With greater ability to create more images in less time and larger slice sizes ($512^2 \rightarrow 4096^2$) comes the need for more storage for all of these images. CT is frequently used in applications relevant to security and CT has also been the progressive step from film to digital replacement solutions. The consequence for most companies acquiring CT systems is that they need large data volumes as well as long-term storage. To address this challenge, you need to determine if the storage offered has the solution that fits your immediate and long-term calculated storage needs. If the system you are considering is a combined hardware and software CT system you expect to use for years to come, you'll want to initiate a discussion about the ability to read and visualize the data into the future.

Summary

The growth of functionality and the enhanced performance of components within a CT system make choosing the right one a hard task. With the guidance provided here and some technical know-how, you should know which capabilities are important to consider and why. There is no all-in-one solution when it comes to a CT system configuration. That's why it's always best to determine the best fit for your application(s) when it comes to source, focal spot, tube energy bandwidth, detector, and software. The need for your specific application(s) to meet the specifications of your company or your customer is the priority, and complying with standards and certifications and digital retention best practices in your industry must also remain a concern. Keeping all this in mind during your purchase evaluation process will be to your advantage in the long run.

For more information about the features and technologies discussed here, please contact an YXLON representative in Italy: info@xrayconsult.it.

XRAYCONSULT
XRAYCONSULT di Brigida Michele
Via A.Uboldo 2/c
20063 Cernusco sul Naviglio (MI)
brigida.michele@xrayconsult.it
Mob.: 338 3688709