

Finding the X-ray inspection sweet spot

Balancing Resolution, Speed, Reliability, Integration, and Cost

This focus topic explores the challenges and limitations of conventional X-ray tube technologies in providing cost-efficient quality control for battery inspection, for complex casts in the automotive industry, or for large and additively manufactured parts in aerospace. Also introduced is Comet X-ray's MesoFocus technology which offers a better balance for production lines between resolution, speed and reliability in the NDT X-ray inspection process.

Balancing Resolution, Speed, Reliability, Integration, and Cost

Manufacturing optimization has always been a series of trade-offs. Maximizing throughput must be balanced with employee and equipment safety. Maximizing profits must be balanced with quality raw materials. And so on.

The same is true for quality control processes. Finding the right X-ray source for specific quality control processes can be challenging, particularly when it comes to balancing the requirement for high resolution detail recognition with the need for reliable uptime, fast inspection throughput and the

ease of integration into a production environment. All those parameters determine the performance, reliability, and costs of non-destructive quality inspections.

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Wanting It all: Resolution and ease of integration

X-ray inspections are an important tool for many industries, providing a non-destructive method for examining the internal structure and quality of a wide range of products. However, with today's industrial X-ray solutions, users are facing significant trade-offs when it comes to the key requirements for a reliable and cost-optimized quality inspection.

On one hand, stationary sealed X-ray solutions offer good uptime and are easy to integrate into a production setting, making them a popular choice for inline inspection systems and other applications that require stability, repeatability, and ease of care. However, sealed X-ray tubes are limited in resolution and not well suited for detail recognition below 200 micrometers, which can be a drawback for some applications that require high-resolution imaging.

On the other hand, open microfocus X-ray modules provide excellent resolution and perform well in research laboratories, making them the preferred choice for applications that require the highest resolution possible. However, these tubes are more difficult to integrate into a volume production environment, and tend to require more maintenance and unplanned repairs, which can lead to downtime. This can be especially problematic in industries where an inspection system is integrated into a production line and that downtime can have costly consequences. As manufacturing moves towards more advanced materials and components, such as in manufactur-

ing of lithium batteries, complex aerospace components, and large and dense automotive parts, engineers are requiring better inspections with higher resolutions while also maintaining good uptime and improved throughput to reduce liability and maximize profits. For example, in lithium battery applications, faulty batteries can be extremely dangerous, with the potential to catch fire or even explode leading to potentially dire consequences for the public. To reduce risk without sacrificing profitability, it is critical to be able to perform fast and reliable inspection of all produced parts and components to ensure safe products for the end user without increasing the production costs of each part inspected.

Is finding a suitable industrial X-ray solution that combines advanced detection of features in the 25-200 micrometer range, with stable operation, and easy integration into a production environment even possible?

To answer this question, it is first necessary to understand the trade-offs and limitations of the X-ray modules of the past, then to examine some of the more recent advances in X-ray tube technology.

Finding the right balance for your application

Traditional Mini Focus and Micro Focus X-ray modules

X-ray sources are classified based on the size of their focal spot (Focus). The sealed and metal ceramic isolated Mini Focus technology offers excellent uptime and is easy to integrate into a production setting, making it a popular choice for inline inspection systems and other applications that require speed, stability, repeatability, and ease of care.

They are best suited for 24/7 operation and can reduce inspection times by up to 60% compared to standard open-microfocus modules. In terms of maintenance, sealed X-ray tubes do not require frequent maintenance and are not sensitive to dust, oily environments, or humidity. The result is less maintenance and service interventions, ensuring an improved uptime and therefore less downtime costs during quality inspection processes.

Micro and Nano Focus X-ray sources offer high and detailed resolution with feature detection down to

0.6 μm . While they may not be suitable for 100% inspection due to their slower speed and shorter service intervals, they are excellent choices for applications that require a high level of detail and accuracy. Micro and Nano Focus technologies are typically used to examine samples of electronic components, advanced semiconductor packaging or microelectromechanical systems (MEMS).

Looking at the characteristics of Mini, Micro, and Nano Focus solutions, it is obvious that there are significant trade-offs to be made when making a choice or high costs involved when integrating both technologies into a single inspection system.

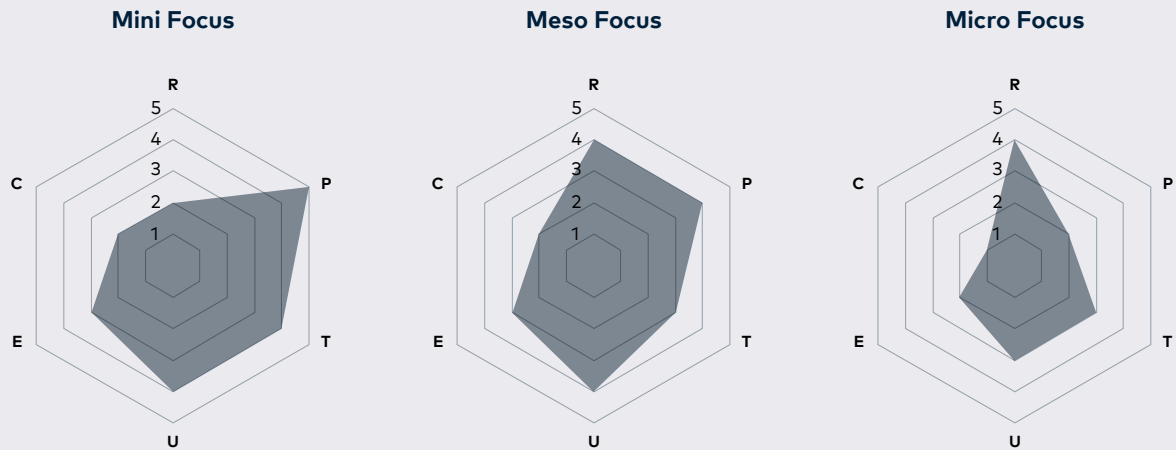
New MesoFocus Technology

MesoFocus technology combines the best characteristics of sealed and open Micro Focus X-ray tubes, bringing lab performance to the production floor with a resolution down to 25 μm allowing high throughput and low downtime which reduces quality control costs in manufacturing.

450 kV MesoFocus
X-ray module with
five focal spots



Fig. 1: Comparison of performance patterns of Mini, Meso and Micro Focus X-ray modules



1. **R (Resolution):** The identification of defects or foreign objects in a part to be inspected. If detection of very small flaws or contaminants is required, an X-ray source providing high resolution will be needed.
2. **P (Penetration):** An X-ray source's ability to pass through different materials and structures. For the inspection of large or dense parts or assemblies, an X-ray source with high penetration capabilities will be needed.
3. **T (Throughput):** The speed and efficiency of X-ray scans. High-power performance X-ray tubes can enable cost-optimized processes with high throughput.
4. **U (Uptime):** An X-ray source's ability to run continuously without interruption. If an X-ray source that can run 24/7 is needed, one with high uptime and dose stability should be selected.
5. **E (Easy-care):** An X-ray source's maintenance requirements and service interventions. Modules with low maintenance requirements and no, or very short, service interventions can help reduce the overall cost of ownership.
6. **C (Compactness):** The size and ease of integration of an X-ray source into the installation. Compact and easy-to-integrate options may be necessary if there are limited space or specific integration requirements.

Resolution capabilities for reliable failure detection in combination with the applicable power (W) that delivers the speed and throughput capacities are the key requirement in many inspection applications. With no doubt, the exact performance of an inspection system is determined by many parameters covering the entire image chain (detector type and resolution, magnification, imaging software, etc.). Nevertheless, standardized focal spot and resolution measurements allow a comparison (Fig. 4) of different systems in terms of the capabilities of X-ray sources.

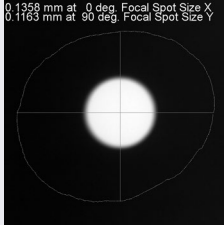
With its multiple focal spot design (Fig. 2), MesoFocus technology enables the user to define the most efficient balance between detectability of features (double wire resolution) and throughput perfor-

mance (W), making the technology a versatile and highly efficient solution for many steps in quality controls whether it is fast recognition of high-level patterns or specific details in high resolution.

The focal spot measurements according to ASTM 1165-12 and ASTM E 2002 illustrate the trade-off between resolution and power nicely. The power performance correlates linear with the focal spot size, except for the for focal spots below 100 in the 450 kV X-ray module.

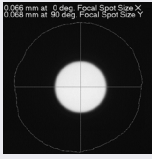
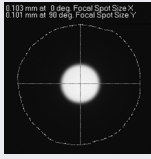
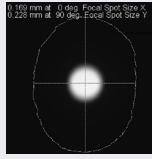
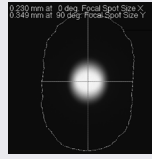
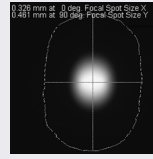
Fig. 2: MesoFocus 225 kV and 450 kV resolution and power performance according ASTM norms

MesoFocus 225 kV – 3 Focal Spots

Focal Spot size and power	50µm - 50W	130µm - 130W	200µm - 200W
Focal Spot Measurement ASTM 1165-12 user-method	0.0554 mm at 0 deg. Focal Spot Size X 0.0554 mm at 90 deg. Focal Spot Size Y 	0.1358 mm at 0 deg. Focal Spot Size X 0.1163 mm at 90 deg. Focal Spot Size Y 	0.1913 mm at 0 deg. Focal Spot Size X 0.2079 mm at 90 deg. Focal Spot Size Y 
Double wire resolution according EN 462-5 / ASTM E 2002	D16	D11	D10

MesoFocus 450 kV – 5 Focal Spots

Setup: Penny ± 0.8 mm, DDA P&E 1620, FOD 83mm, FDD 3000mm;

Focal Spot size and power	65µm - 50W	100µm - 100W	250µm - 250W	350µm - 350W	450µm - 450W
Focal Spot Measurement ASTM 1165-12 user-method	0.069 mm at 0 deg. Focal Spot Size X 0.068 mm at 90 deg. Focal Spot Size Y 	0.110 mm at 0 deg. Focal Spot Size X 0.101 mm at 90 deg. Focal Spot Size Y 	0.160 mm at 0 deg. Focal Spot Size X 0.228 mm at 90 deg. Focal Spot Size Y 	0.230 mm at 0 deg. Focal Spot Size X 0.349 mm at 90 deg. Focal Spot Size Y 	0.328 mm at 0 deg. Focal Spot Size X 0.481 mm at 90 deg. Focal Spot Size Y 
Double resolution according EN 462-5 / ASTM E 2002	D15	D13	D9	D7	D6

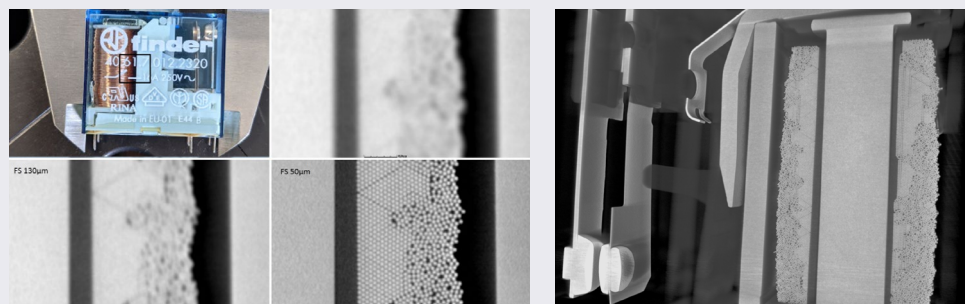
Comparing resolutions

Looking at hands-on application examples, the resolution capabilities and differences can be easily grasped. The example of an electro-mechanical part

shows the resolution of a copper coil in a relay (Fig. 3). Thanks to the symmetrical focal spot, MesoFocus delivers identical resolution in all directions.

Fig. 3: 3D CT example of a copper coil in an electro-mechanical component

Relay at 225 kV - scan time 50W / 18 min, 130W / 10min, 200W / 6min.
Example to demonstrate 3D CT and large span of resolution at highest kV

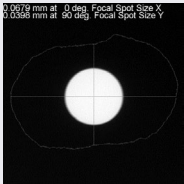
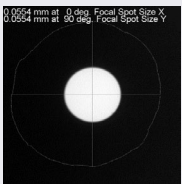
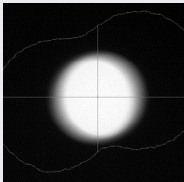
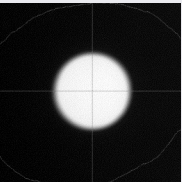
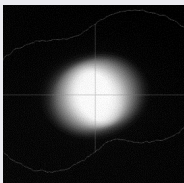
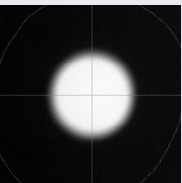


Resolution performance comparison
Meso- vs Open Micro Focus at 225 kV

The comparison with the pinhole method allows visualization of the resolution capabilities of different X-ray sources (Fig. 4).

Comparing an open Micro Focus source with MesoFocus technology, it shows little difference below 100µm at the same power ranges. Above 100µm, the resolution capabilities are significantly higher.

Fig. 4: MesoFocus 225 kV focal spot design and resolution comparison to an open Micro Focus module 225 kV – ASTM 1165-12

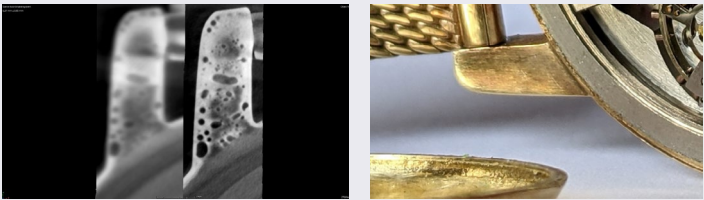
Power	Open MicroFocus	MesoFocus
@50W No significant difference in resolution performance and focal spot symmetry		
@130W Significant difference in resolution performance and focal spot symmetry		
@200W Significant difference in resolution performance and focal spot symmetry		

Resolution comparison Meso- vs
Mini Focus technology at 450 kV

Now that the trade-offs between the different systems are understood, a look at a real world application can provide further insight. For years, many industries such as aerospace and additive manufacturing, have been demanding a high-resolution and robust 450 kV solution for DR and CT

applications. In addition to high resolution and detail recognizability, there are always other requirements such as quick readiness, high voltage stability, maintenance-free, ease of use, and use without special tube know-how. This is where the benefits of the balance found in MesoFocus technology really shine.

Fig. 5: Porosities in gold: Comparison 400µm 450 kV mini-focus (left) vs 60µm 450 kV MesoFocus module (right).



Fit for the future of non-destructive testing

There are several trends in various industries that are driving the need for advanced inspection technologies like MesoFocus.

One is the increasing use of automation and artificial intelligence to perform tasks that are faster, more accurate, and/or more reliable than humans. This trend towards automation is leading to the use of advanced inspection equipment in manufacturing processes. For example, in the manufacturing industry, automation and advanced inspection equipment can be used to reduce the number of defects and prevent costly product recalls. In the aerospace industry, advanced inspection equipment is used to ensure the safety and reliability of aircraft components. In the automotive industry, it can be used to identify defects in car part manufacturing and improve the overall reliability and safety of vehicles.

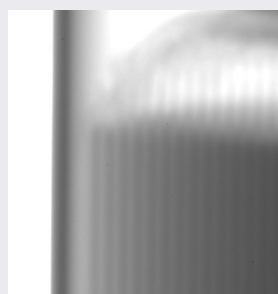
There is also a growing demand for electric vehicles and even electrified air transportation which is creating a large need for batteries in all forms of shapes and sizes. The production of these batteries requires accurate and efficient inspection systems to ensure a safe and reliable operation. MesoFocus technology enables fast and reliable detection of typical defects such as anode overhang, misaligned electrodes, and assembly flaws at the resolution necessary to help ensure public safety.

MesoFocus is a new X-ray technology helping many industries and NDT application experts choose a solution with a better fit for their inspection jobs to be done. It offers an optimized performance package enabling reliable, stable and cost-efficient quality control to provide safe products for users without major trade-offs.

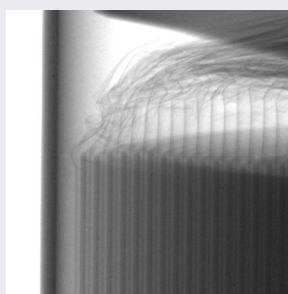
Fig. 6: Comparison of a battery cell inspection with different 225 kV X-ray solutions.



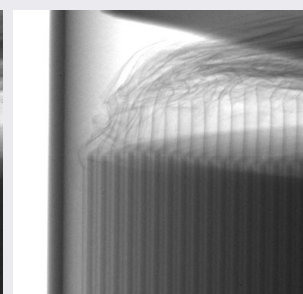
4680 Battery



MiniFocus



MesoFocus

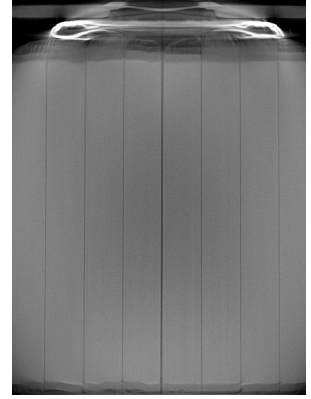


MicroFocus

MesoFocus technology: Application examples

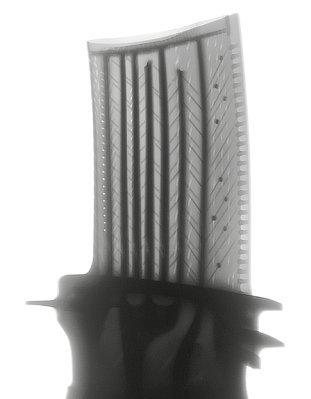
Battery Inspection for E-mobility and Electric Devices

Because of its stability, MesoFocus technology is best suited for both 2D and 3D CT applications. One of the key applications is in battery inspection for e-mobility and electric devices. With the increasing demand for electric vehicles, the need for reliable and efficient battery inspection systems is greater than ever before. MesoFocus technology can be used to inspect batteries quickly and accurately for defects, ensuring that the manufactured batteries are safe and reliable.



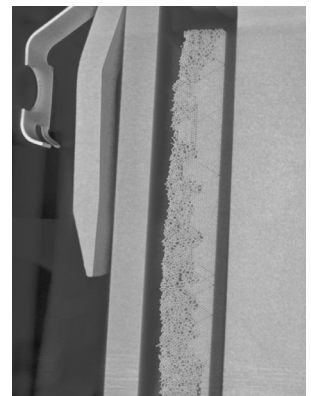
Aerospace Parts

Aerospace parts including additively manufactured components are often highly complex, and at the same time made of dense materials, which are difficult to inspect especially in 3D CT. Because of this, both high detail recognition and high penetration power are needed to fully inspect the components. Examples of parts include air vents, exhausts, engine, or panel components.



Automotive Industry

The inspection of electromechanical components can also be quite complex, having to inspect very small, but dense parts. Examples are connectors, coils and relays used in a variety of parts and electrical motors.

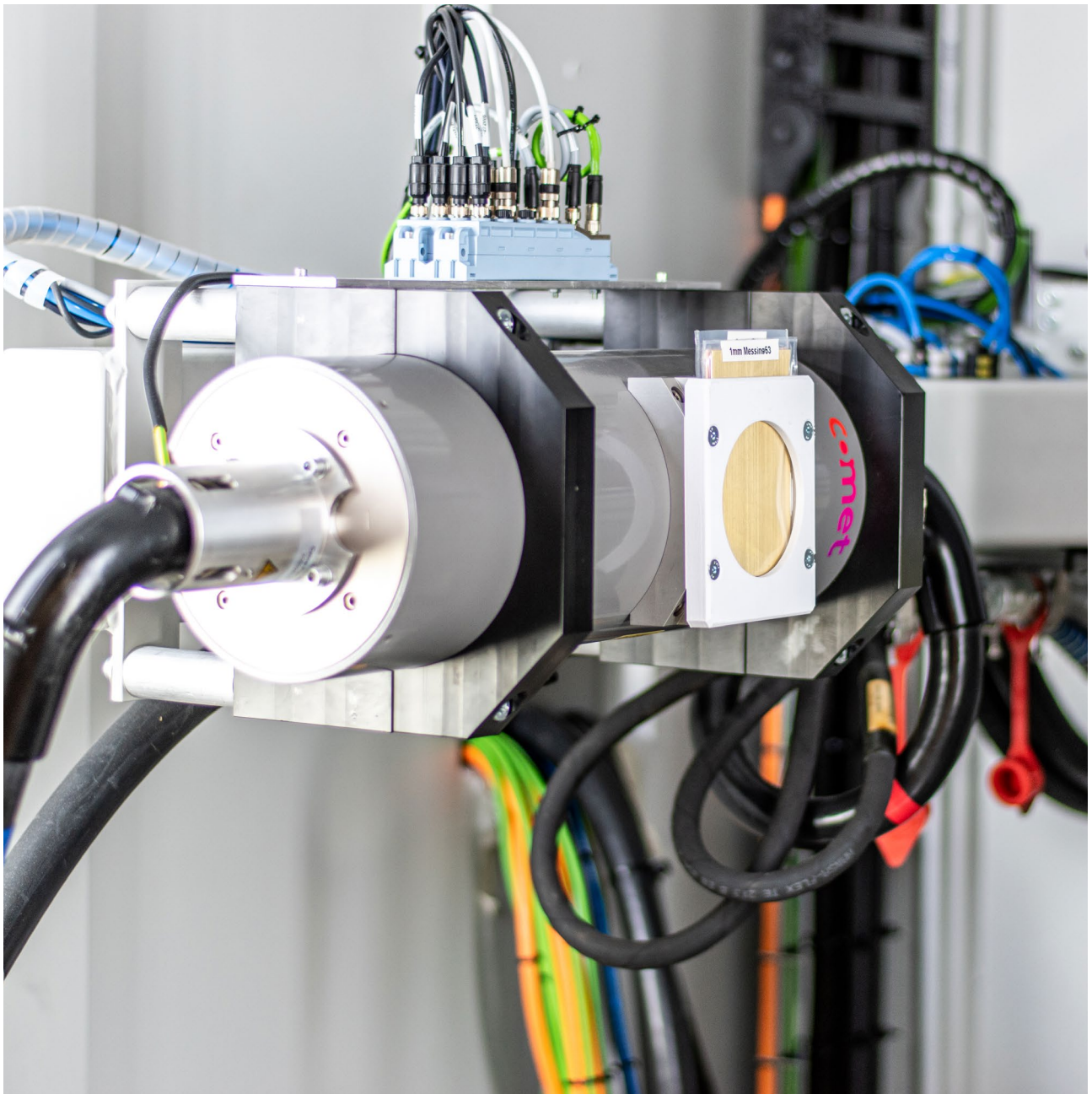


About Comet X-ray

Revealing insights

Customers trust Comet X-ray to challenge the limits of what can be revealed. By pioneering intelligent X-ray technologies, Comet X-ray provides safer, more economical, trail-blazing solutions that enable its customers to navigate their own voyage of discovery.

Accepting this challenge demands extraordinary commitment. Comet X-ray invests talent and resources in creating brighter ways of exposing hidden worlds through the application of energized light. For more information, please visit www.comet-xray.com



You can find us here

Switzerland (Head Office)

Comet AG Industrial X-ray modules
Herrengasse 10
3175, Flamatt
T +41 31 744 90 00

Denmark

Comet Technologies Denmark A/S
Helgeshøj Alle 38
2630, Taastrup
T +45 72 40 77 00

United States

Comet Technologies USA Inc.
100 Trap Falls Road Extension
Shelton, CT 06484
T +1 203 447 31 65

China

Comet Mechanical Equipment Co. Ltd.
1201 Guiqiao Road
Building 10, 1st Floor
Pudong, Shanghai 201206
T+86 21 6879 9000

Japan

Comet Technologies Japan KK
New Stage Yokohama Bldg., 1st Floor
1-1-32 Shinurashima-cho
Kanagawa-ku
Yokohama, 221-0031
T +81 45 450 1730

South Korea

Comet Technologies Korea Co., Ltd.
Suwon Venture Plaza Bldg, Room 402
48 Samsung-ro, 168 beon-gil,
Yeongtong-gu, Suwon-si
Gyeonggi-do, 16676
T +82 (0)70 4337 1282
T +82 (0)70 4332 1580

Taiwan

Comet Mechanical Equipment Co. Ltd.
1201 Guiqiao Road
Building 10, 1st Floor
Pudong, Shanghai 201206
T +86 21 68799000

Comet X-ray

Herrengasse 10, 3175 Flamatt, Switzerland
T +41 31 744 90 00
Web: xray.comet.tech
Mail: info@comet-xray.com

