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CU AI_02 Metrology in Additive Manufacturing for metals and polymers

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Unit Overview



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MODULE 01

1 hrs

**Introduction to Metrology and
Regulatory Standards**

Format: 1+0

(theory + practical)

MODULE 02

2.5 hrs

**Dimensional and Surface
Metrology Technology for
Additive Manufacturing**

Format: 2.5+0

(theory + practical)

MODULE 03

2 hrs

**Measurement Strategies for
Additive Manufacturing**

Format: 2+0

(theory + practical)

MODULE 04

1.5 hrs

**Cases Studies on Dimensional
and Surface Metrology in AM
for Aerospace and Defence)**

Format: 0.5+1

(theory + practical)

Learning Outcomes



By the end of this unit, learners will demonstrate the following competencies:

KNOWLEDGE

Factual and broad understanding of:

- Principles of dimensional and surface metrology techniques
- Limitations of metrology techniques, typical errors in applying these
- Regulatory Standards for Coordinate Measuring Machine calibration, surface texture, and calibration documentation.
- Measurement Strategies for Additive Manufacturing
- Problem-solving approaches and the rationale for selecting measurement methods.
- Industry best practices for metrology applications

SKILLS

Learners will be able to:

- Apply standards for GD&T, CMM, laser scanning, structured light scanning, and surface texture measurement instruments
- Point out and document measurement results for compliance.
- Identify suitable dimensional and surface metrology technologies for the inspection in AM components and processes.
- Differentiate between in-process and post-process inspection applications for AM quality control.
- Evaluate the effectiveness of metrology techniques
- Report metrology findings using a correct wording and reference to standards.



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Introduction to Metrology and Regulatory Standards for AM

Module 1



1 - Introduction to Metrology and Regulatory Standards for AM

- ❑ Additive Manufacturing (AM) has become a key enabling technology in aerospace and defense due to its ability to produce complex geometries, lightweight structures, and customized components. However, these advantages also introduce new challenges in terms of dimensional accuracy, surface quality, and regulatory compliance.
- ❑ Metrology plays a critical role in ensuring that AM components meet strict functional, safety, and quality requirements.

Role of Metrology in Additive Manufacturing

- ❑ Metrology is the science of measurement and is essential throughout the AM lifecycle, from design to final inspection.
- ❑ In aerospace and defense applications, even small deviations can lead to component failure, making reliable measurement systems mandatory.



<https://metrology.news/ai-automatically-detects-defects-in-smart-factory-manufacturing-processes-even-when-conditions-change/>

Main objectives of metrology in AM:

- ❑ Ensure dimensional accuracy and geometric integrity
- ❑ Verify surface quality and internal features
- ❑ Support process control and repeatability
- ❑ Guarantee part performance and safety



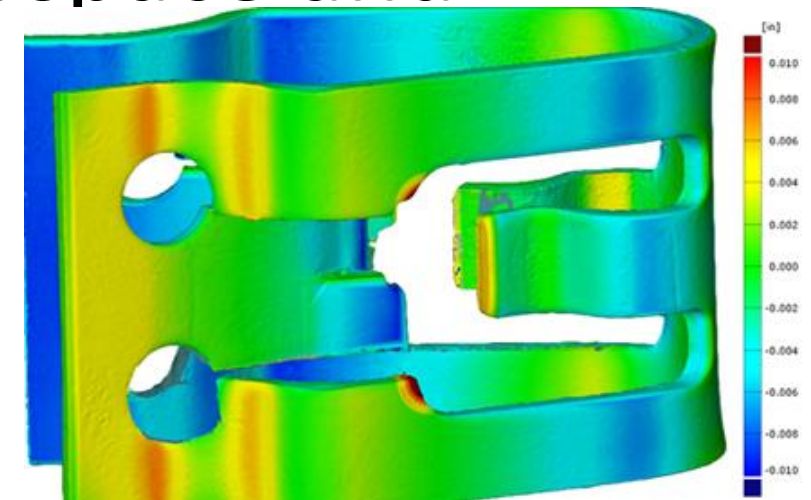
<https://industrial-ia.com/what-is-metrology-in-manufacturing-how-we-use-metrology/>



Importance of Metrology for Aerospace and Defense AM Components

Aerospace and defense industries demand:

- ☐ High precision and tight tolerances
- ☐ Full traceability and documentation
- ☐ Compliance with international standards
- ☐ High reliability under extreme operating conditions

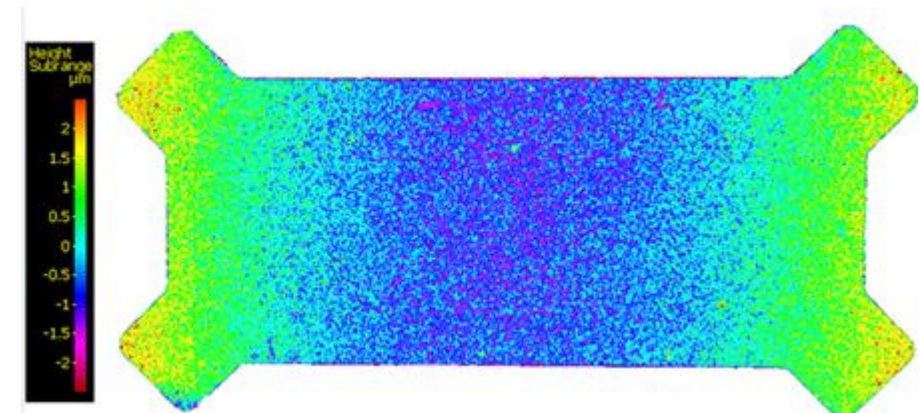


<https://www.edmdept.com/3d-metrology-systems-full-details/metrology-system-capabilities/>



Metrology ensures that AM components:

- ☐ Meet design intent and functional requirements
- ☐ Are suitable for critical applications
- ☐ Can be certified for use in regulated environments

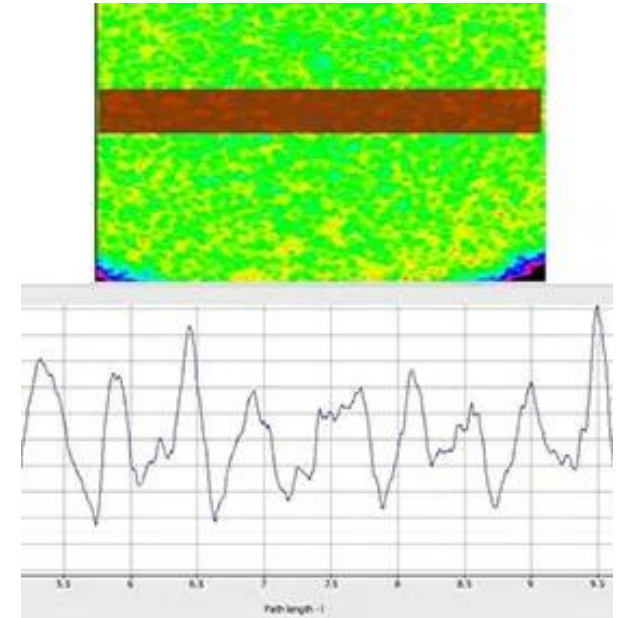




Metrology Systems Used in Additive Manufacturing:

Different metrology systems are applied depending on the material, geometry, and required accuracy.

- ☐ Dimensional measurement systems
- ☐ Surface measurement systems



Metrology in Additive Manufacturing for metals/polymers

These systems allow the evaluation of:

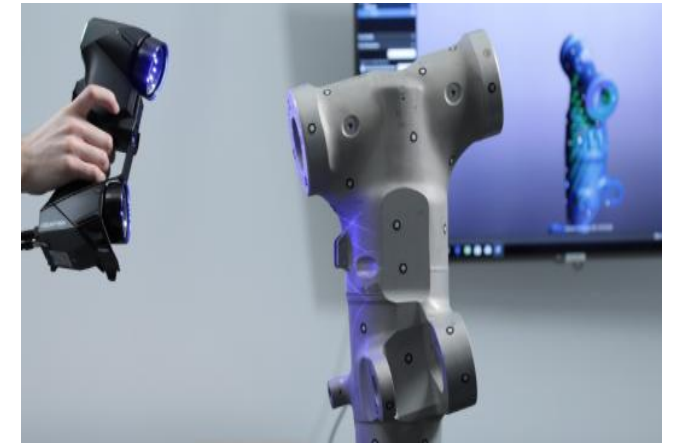
- ☐ Surface roughness and texture
- ☐ Dimensional deviations
- ☐ Warping and distortion common in AM parts



<https://www.keyence.com/products/3d-measure/3d-scanner/vl-800/>

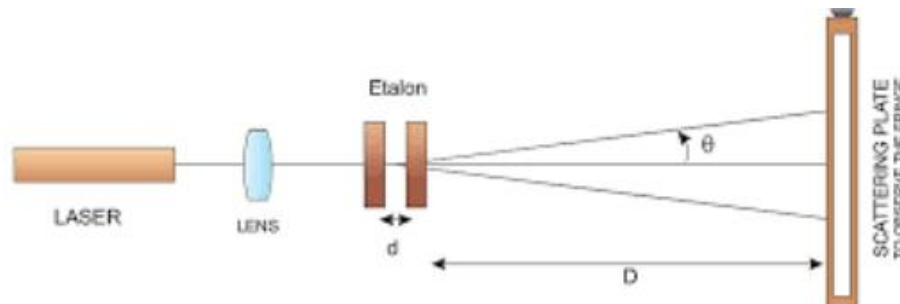
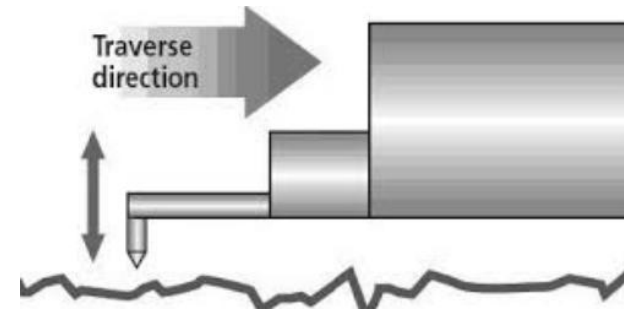
Dimensional measurement systems:

- ☐ Coordinate Measuring Machines (CMM)
- ☐ Optical and laser scanners
- ☐ Structured light systems
- ☐ Computed Tomography (CT) for internal geometries



Surface measurement systems:

- ☐ Contact profilometers
- ☐ Optical profilometers



<https://www.keyence.com/products/3d-measure/roughness-measure/>



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Metrology in Additive Manufacturing for metals/polymers

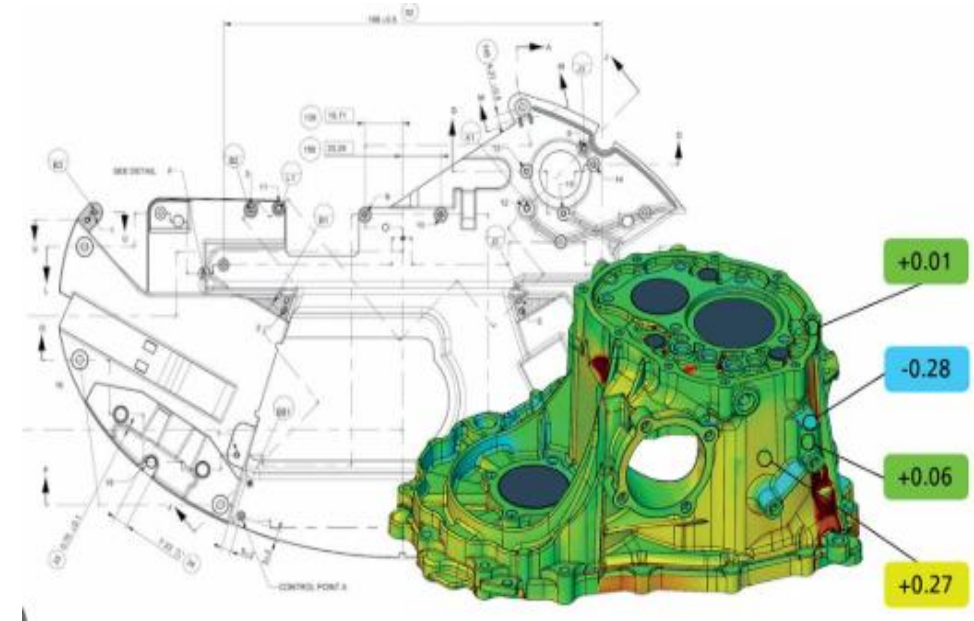
Role of Metrology in Geometric Product Specification (GPS)

Geometric Product Specification (GPS) defines how part geometry and tolerances are specified and verified.

How does Metrology ensure compliance?

- ❑ Verifying form, orientation, location, and profile tolerances
- ❑ Checking dimensional chains and functional features
- ❑ Supporting the interpretation of complex geometries typical of AM designs

Proper application of GPS principles ensures consistency between design, manufacturing, and inspection.





Regulatory Standards for Metrology in AM

- ❑ **ISO 8015, 1101 and 14405** : Standards that define the fundamental framework of Geometrical Product Specification (GPS), including principles, symbols, and rules for geometric dimensioning and tolerancing of parts.
 - ❑ ISO 8015 – Fundamental principles of GPS
 - ❑ ISO 1101 – Geometrical tolerancing
 - ❑ ISO 14405 – Dimensional tolerancing

International Standard



INTERNATIONAL ORGANIZATION FOR STANDARDIZATION INTERNATIONAL ORGANIZATION OF STANDARDS ISO 8015, 1101 and 14405

Metrology in Additive Manufacturing for metals/polymers



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Regulatory Standards for Metrology in AM

- ❑ **ISO 17025** : Specifies the general requirements for the competence, impartiality, and consistent operation of laboratories performing testing and calibration, including metrology inspections.
- ❑ **ISO 10360** : A series of standards that define acceptance and reverification tests for Coordinate Measuring Machines (CMMs), including contact and optical systems, to ensure dimensional measurement accuracy.
- ❑ **ISO 25178 and ISO 21920** : Standards that cover surface texture metrology, addressing parameters, measurement methods, and evaluation of both areal (3D) and profile (2D) surface roughness.



Regulatory Standards for Metrology in AM

- ❑ **AS9102** : Defines the requirements for First Article Inspection (FAI) in the aerospace industry, ensuring that manufactured parts conform to engineering design, drawing, and quality requirements.
- ❑ Validation of AM components against design requirements

Metrology in Additive Manufacturing for metals/polymers



(Module 1) Activity

Selecting the Appropriate Metrology System

Objective:

Apply technical criteria to select the most appropriate measurement system for Additive Manufacturing components.

Scenario:

Each group receives a different case study.

- A** – Metal part with complex internal channels
- B** – Polymer component with critical functional surfaces
- C** – Lightweight lattice structure
- D** – Geometrically optimized bracket

Metrology in Additive Manufacturing for metals/polymers



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1- Select the most appropriate measurement system:

- CMM (contact)
- Laser scanner
- Structured light system
- Computed Tomography (CT)
- Profilometer

2- Technically justify your selection considering:

- Part geometry
- Accessibility
- Required accuracy
- Measurement time

3- Identify:

- Critical parameters to measure
- Potential measurement risks
- Impact on aerospace certification



Learning Objectives (Module 1)



- ☐ Understand the role of metrology in meeting aerospace and defense standards
- ☐ Ensure dimensional and surface texture compliance for safety-critical AM parts



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Dimensional Metrology Techniques in Additive Manufacturing

Module 2



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2 - Dimensional Metrology Techniques in Additive Manufacturing

Module Overview

- ❑ Measurement techniques for AM components
- ❑ Advantages and challenges of AM metrology



Classification of Metrology Systems

- ❑ Contact vs non-contact systems
- ❑ Dimensional vs surface metrology



Classification of Metrology Systems

Contact CMM: Principles

- ☐ Coordinate Measuring Machines (CMM)
- ☐ High accuracy point-based measurement
- ☐ Suitable for critical dimensional features



Classification of Metrology Systems

Contact CMM: Standards & Application

- ☐ ISO 1101, ISO 14405, ISO 10360
- ☐ Verification of dimensional integrity in AM parts



Classification of Metrology Systems

Contact CMM: Inspection Approaches in AM

- ☐ Post-build inspection
- ☐ In-process inspection
- ☐ Advantages and limitations of each approach?



Classification of Metrology Systems

Optical Dimensional Metrology: Principles

- ☐ Laser scanning and structured light scanning
- ☐ Full-field measurement of complex geometries
- ☐ Fast data acquisition



Classification of Metrology Systems

Surface Metrology: Principles

- ☐ Surface roughness and texture in AM
- ☐ Influence on functional performance



Classification of Metrology Systems

Surface Metrology: Standards & Application

- ☐ ISO 21920 and ISO 25178
- ☐ Profile and areal surface measurements



Emerging Trends in AM Metrology

- ☐ In-situ monitoring systems
- ☐ Automation and digital twins
- ☐ Data-driven quality control



Limitations and Common Errors of AM Metrology techniques

- ☐ Measurement uncertainty
- ☐ Accessibility of complex geometries
- ☐ Misinterpretation of GD&T in AM



(Module 2) Activity

Contact vs Non-Contact: Which One to Choose?

Objective:

Compare dimensional metrology techniques and analyze advantages, limitations, and AM applications.

Metrology in Additive Manufacturing for metals/polymers

Part 1 – Comparative Analysis
Complete the table:



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(Module 2) Activity

Part 1 – Comparative Analysis, complete the table

Criteria	CMM (Contact)	Optical Scanner
Accuracy		
Speed		
Complex geometries		
Surface preparation required		
Aerospace application		

(Module 2) Activity

Group Tasks

Part 2 – Decision Making

Decide which technique to use for:

1. A critical structural component with tight tolerances
2. A part with complex organic geometry
3. Rapid in-process quality inspection

Provide justification for each decision.

Also Discuss

- Sources of measurement uncertainty
- Limitations of each technique
- Impact of incorrect selection on regulatory compliance



Learning Objectives

(Module 1.2)

- ☐ Understand how metrology data is captured and used
- ☐ Assess compliance with regulations





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Measurement Strategies for Additive Manufacturing

Module 3



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There are more and more possibilities for maintaining **control** of our parts while they are **being manufactured**.

Since the beginning of Additive Manufacturing, we have only had the possibility to **visually** inspect the parts.

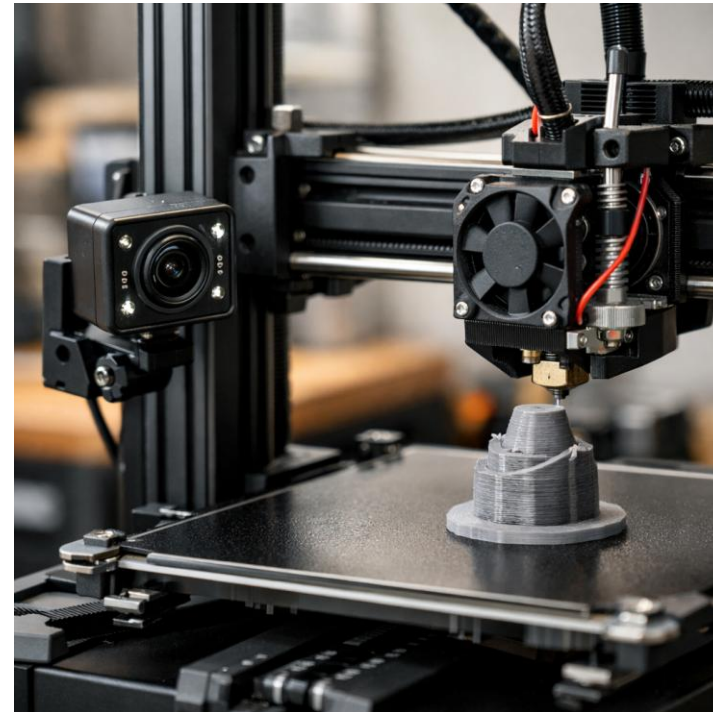
In-process inspection in AM

- ❑ What happens when nobody is watching?
- ❑ No monitoring = no control



In-process inspection in AM

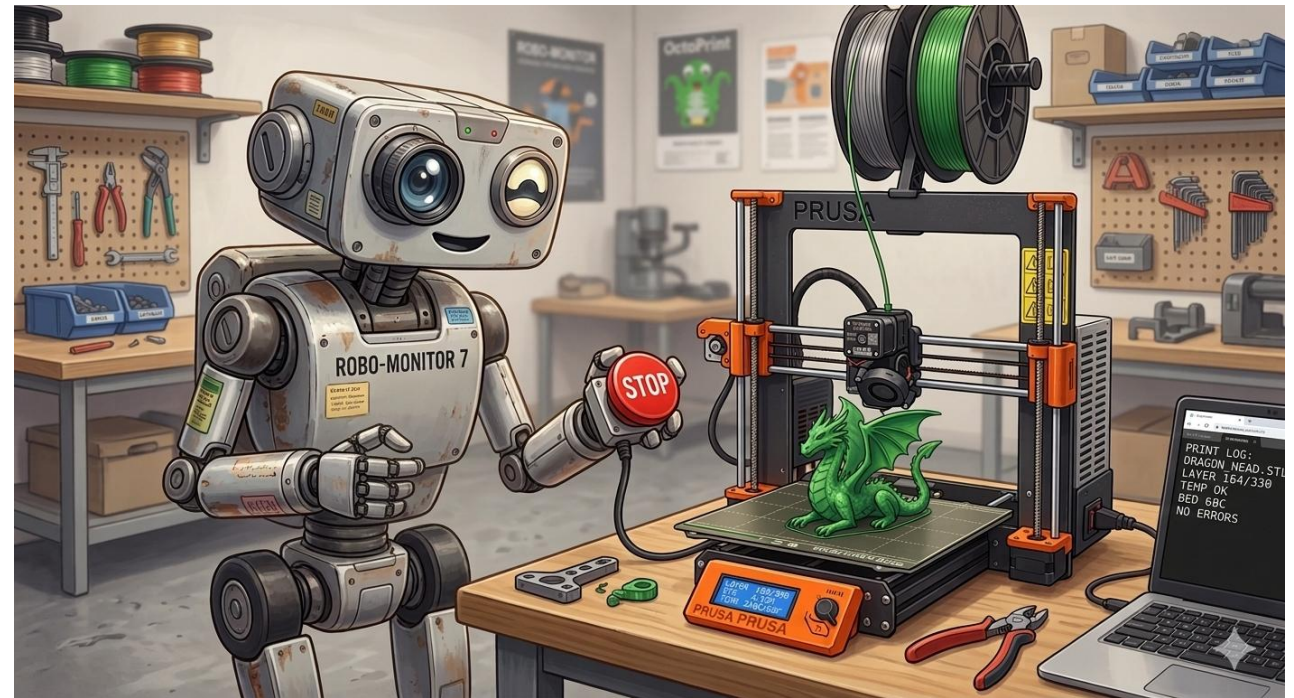
- ❑ Camera added – full visibility, anytime
- ❑ Now someone can always be watching



Illustrative image generated with AI

In-process inspection in AM

- ❑ AI stops the error. The report is still missing.
- ❑ Smarter monitoring – but still not the complete solution

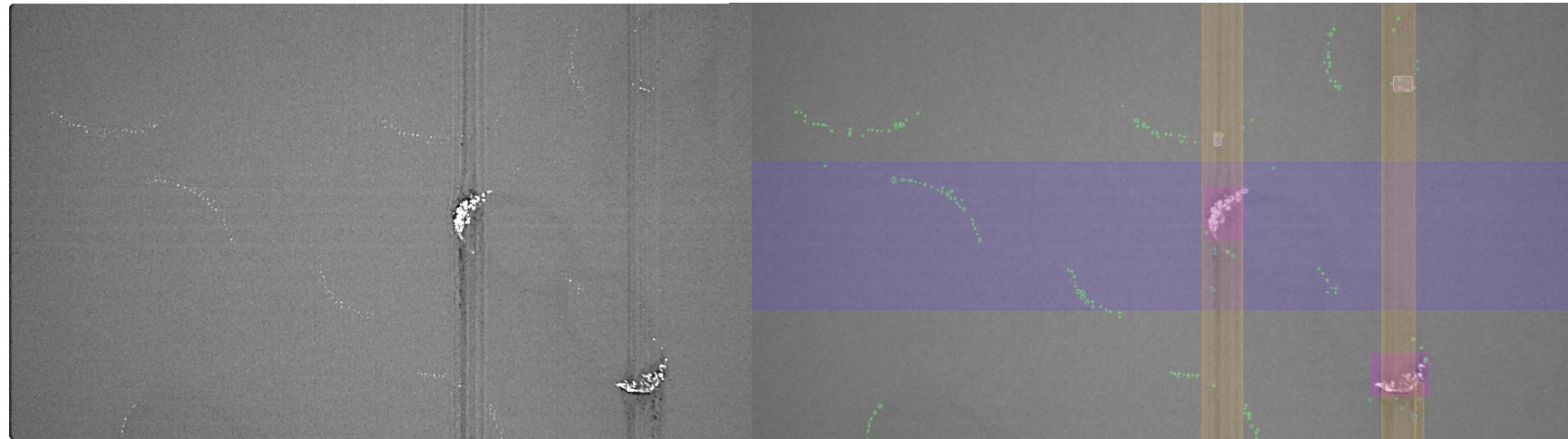


Illustrative image generated with AI

In-process inspection in AM



- ❑ AI sees the defect – before it happens
- ❑ Automatic NDE report. No surprises.
- ❑ Warn. Evaluate. Document.
- ❑ From camera to intelligent monitoring



● Pinning

● Streaking

● Hopping

● Warpage

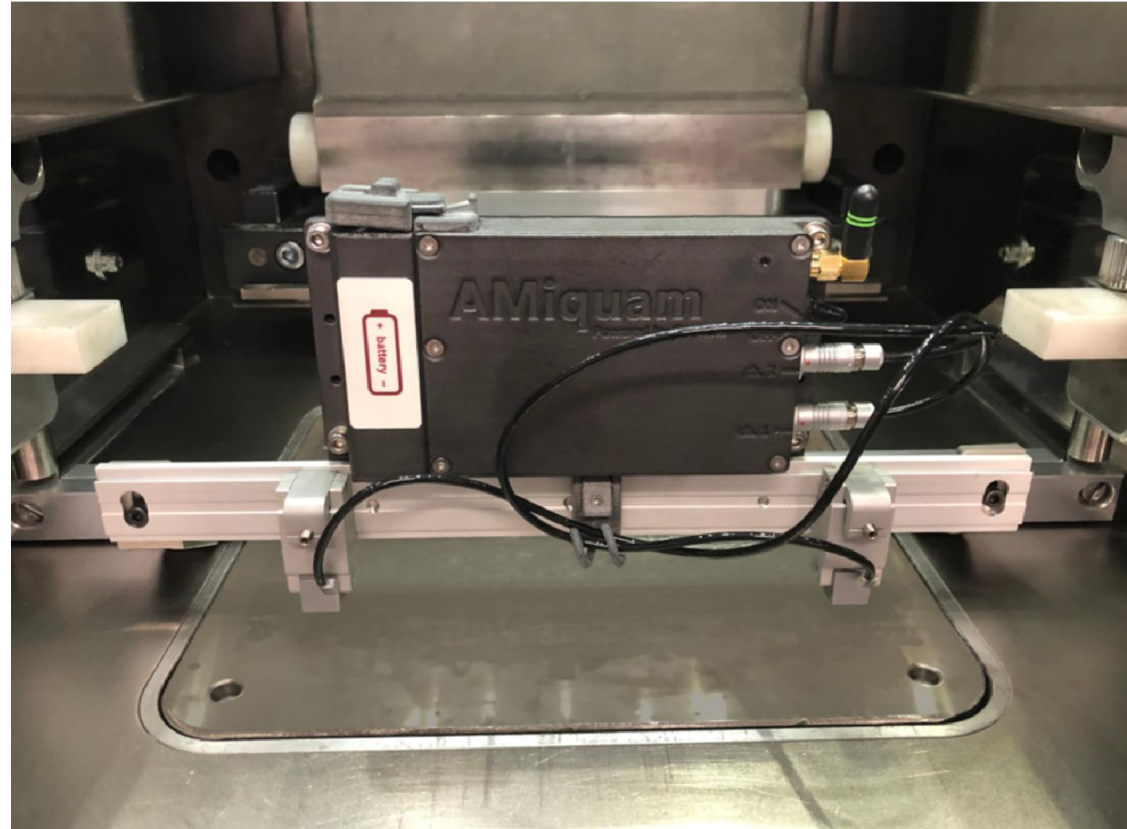
● Obstruction

● Spatter

<https://www.euler3d.com/static/images/landing/comparison/with-defects.png>

In-process inspection in AM

- ❑ Eddy current testing directly in the process
- ❑ Sensor on recoater – inspection in every layer



<https://amiguam.net/wp-content/uploads/2025/01/1-11.png>

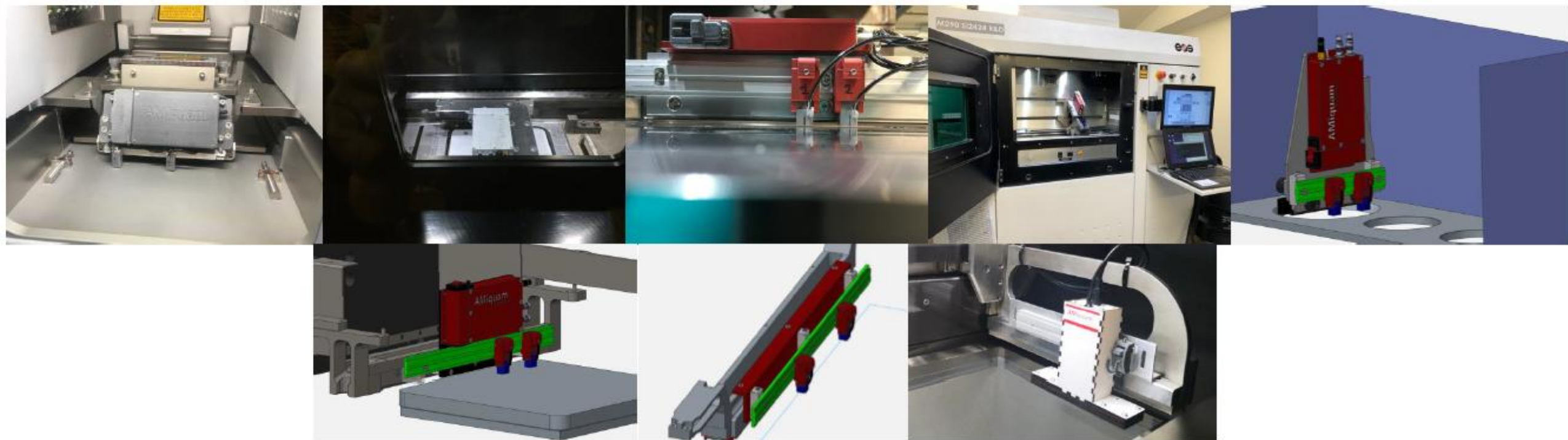


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Example form Amiquam.net



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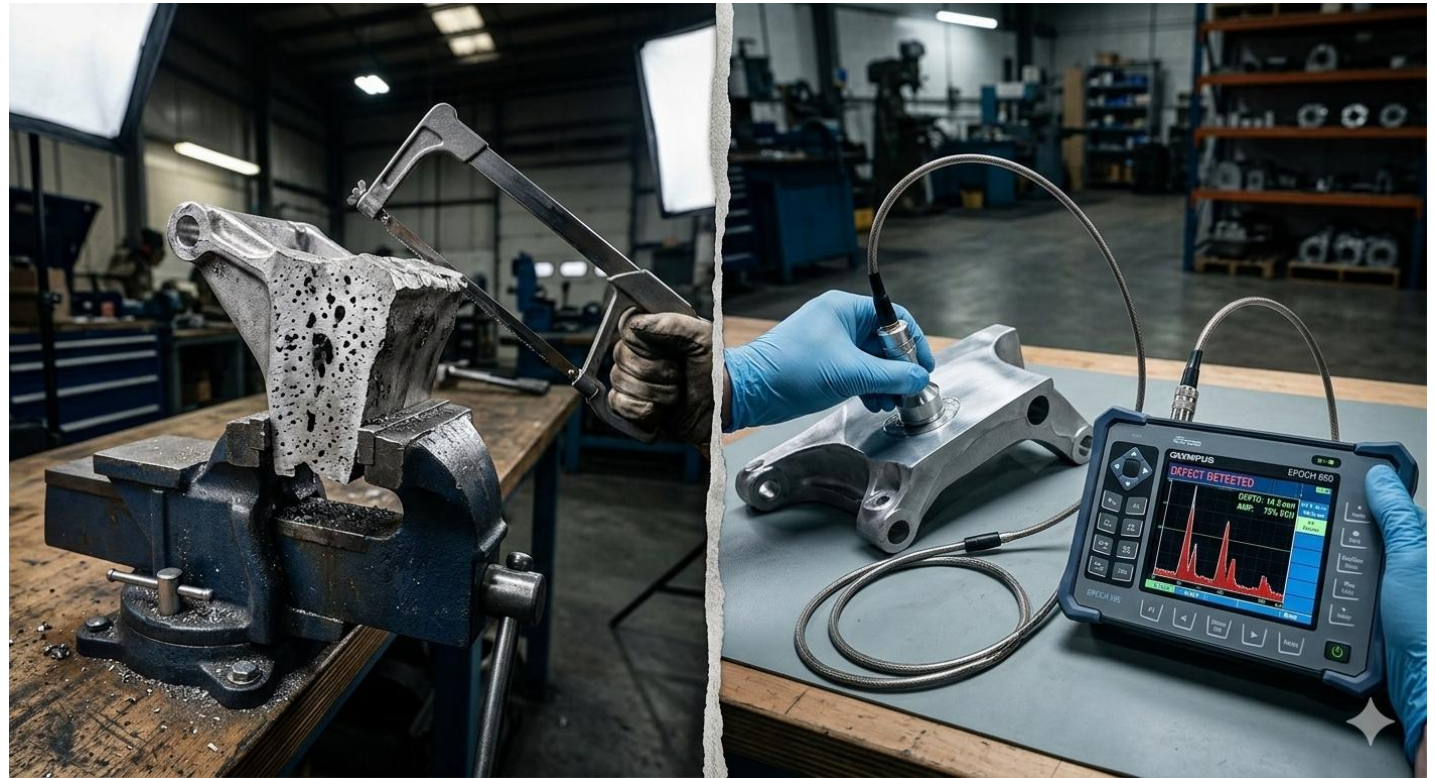
Source: <https://amiquam.net/wp-content/uploads/2025/01/ASTM-ICAM-Diffusion-1.pdf>

Other companies that can provide equipment for in-process inspection include:

Renishaw, Phase3D and FormAlloy, which have integrated it into their DED machines.

Post build inspection in AM

- ❑ Destructive vs. non-destructive testing
- ❑ Two methods: destroy to understand – or understand without destroying

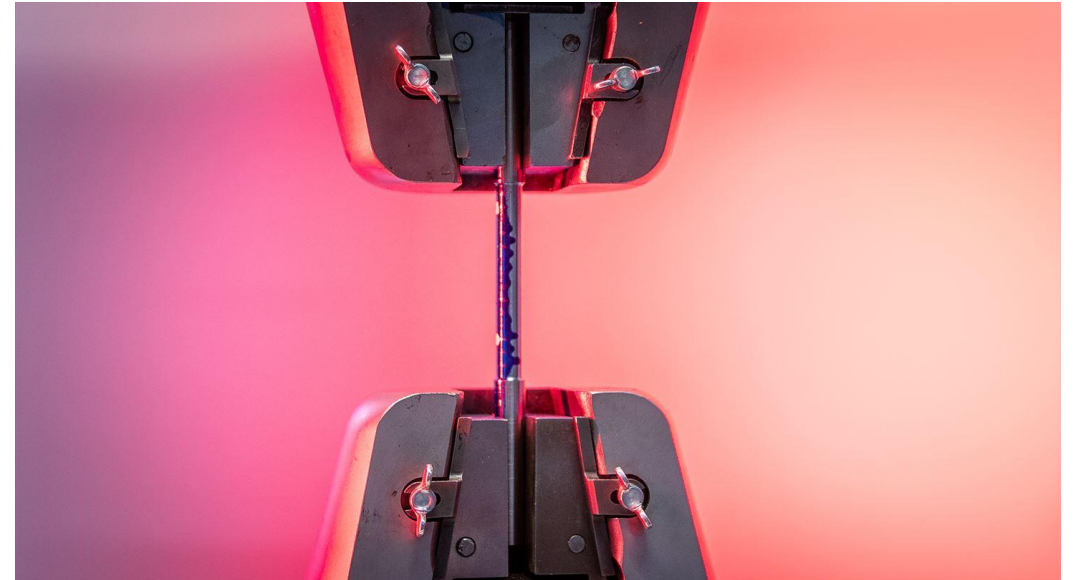


Illustrative image generated with AI

Post build inspection in AM



- ❑ ASTM F3122 & ISO/ASTM 52904 – standardised quality assurance
- ❑ Same plate. Same parameters. Same batch. Full representativeness.



<https://www.teknologisk.dk/ydelser/akkrediteret-proevning-af-metal/vi-staar-klar-til-at-hjaelpe-dig/42023>

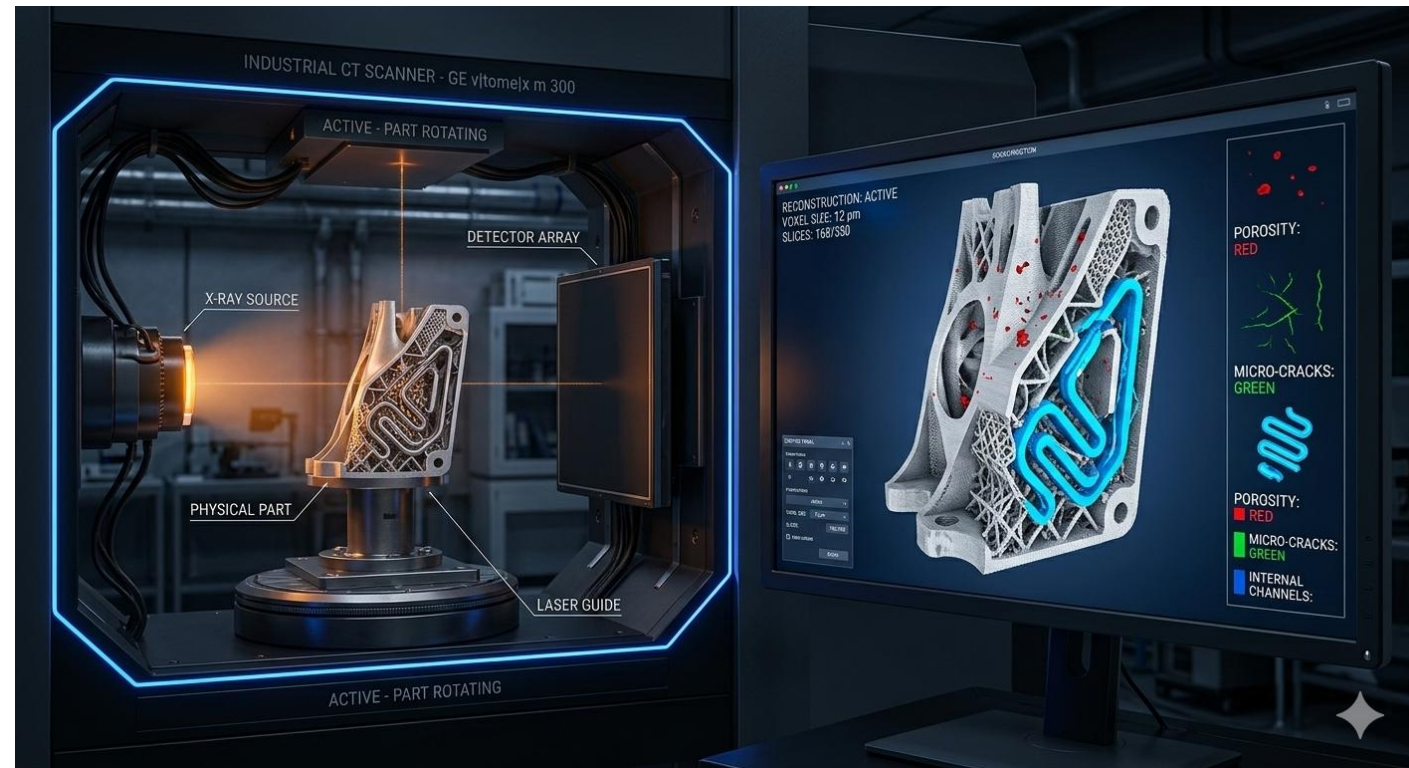
Practical test specimen strategy for AM

The image to the right shows an AI-generated illustration of how test specimens for destructive testing are produced in the same production run as the part that should not be destroyed. With these specimens, it is possible to perform tensile, compression, bending and cross-section analyses.



CT Scanning in Additive Manufacturing: What and Why

- ❑ The only method with full 3D insight into the part's interior
- ❑ CT sees everything – gas porosity, cracks, inclusions. Nothing hides.
- ❑ $\pm 10 \mu\text{m}$ accuracy. Directly against the CAD model.

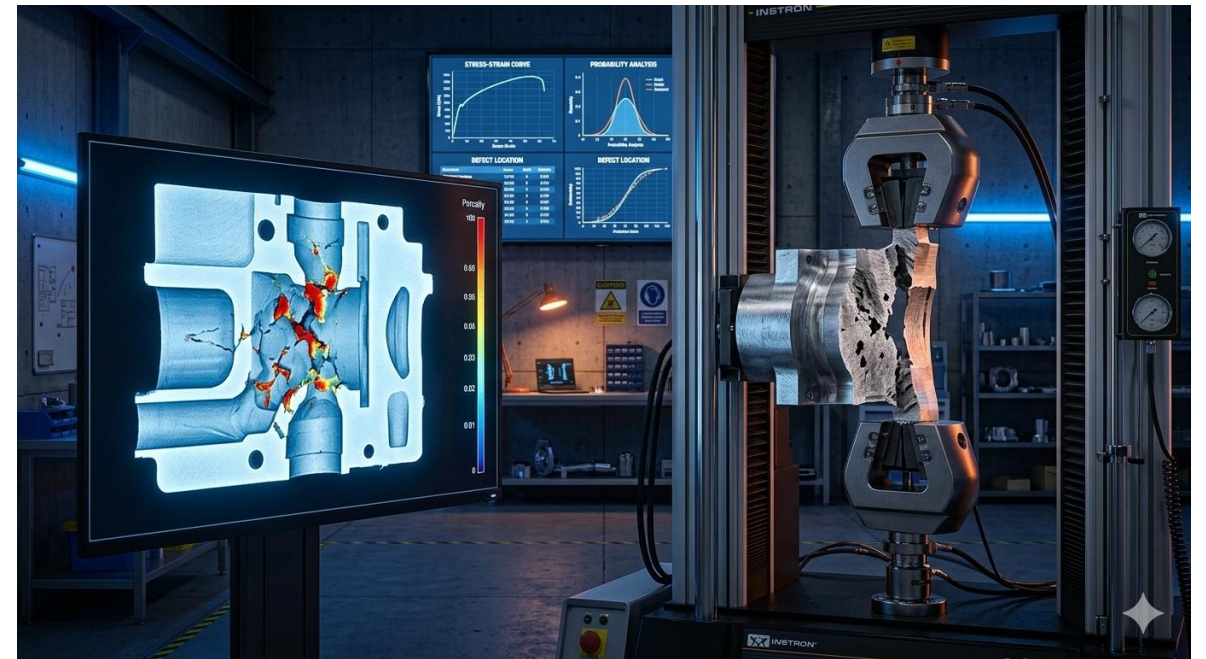


Illustrative image generated with AI

Post build inspection in AM

CT Combined with Destructive Testing: The Complete Strategy

- ❑ CT maps the defect – destructive testing explains the consequence
- ❑ From worst-case assumption to actual defect population



Illustrative image generated with AI

CMM – Coordinate Measuring Machine

- ❑ CMM – precision measurement in three dimensions
- ❑ Contact or optical – same goal: geometrical truth



<https://www.zeiss.com/metrology/en/systems/cmms/bridge-type-cmms/zeiss-spectrum-family/zeiss-spectrum.html>

Design and operating principle

- ❑ X, Y and Z – one point at a time, high precision
- ❑ CNC-controlled measurement program – reproducible every time



<https://metrology.news/measurement-interface-standard-boosts-cmm-automation/>

Measurement Strategies for Additive Manufacturing, CMM



There are generally three types of CMM:

- ☐ Bridge
- ☐ Gantry
- ☐ Arm



<https://groupsynergy.com/synergy-group-insights/faro-8-axis-max-scanning-probing>

Probe types

- ☐ Right probe = right data
- ☐ Hard surface? Contact.
Complex shape? Scanning. Fragile? Optical.
- ☐ Three probe types – contact, scanning or optical



https://hexagon.com/-/media/project/one-web/master-site/altudo/l1184-mi/cmm-probes-and-sensors_c100_01.jpg

Accuracy and measurement uncertainty

- ❑ ± 1 to $\pm 5 \mu\text{m}$ – but only under the right conditions
- ❑ AM surfaces up to $R_a 20 \mu\text{m}$ – a challenge for probe contact



Illustrative image generated with AI



CMM for measuring AM parts

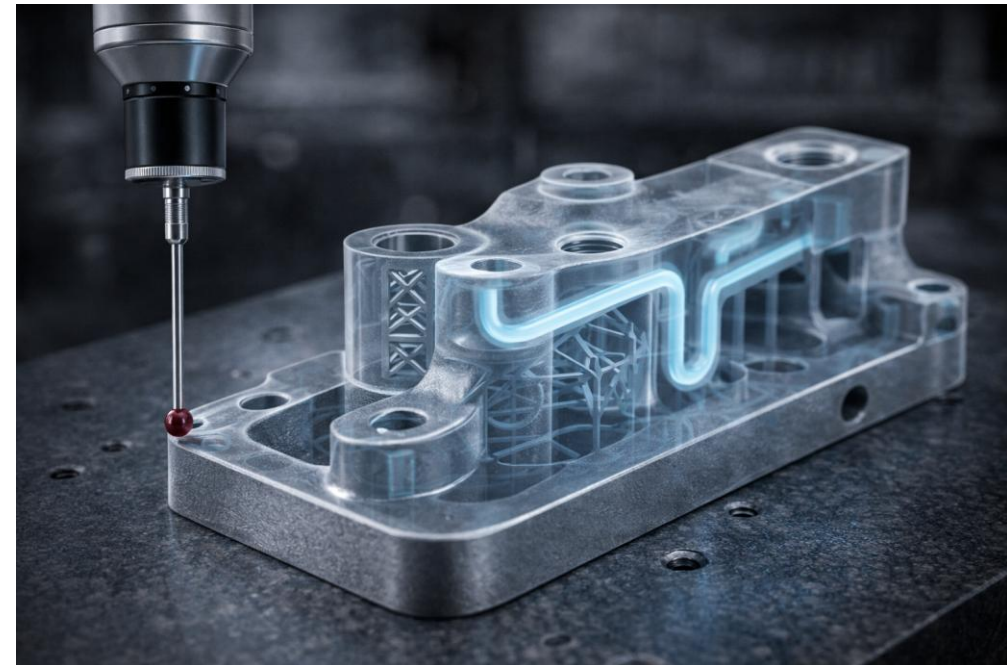
- ❑ Mating surfaces. Bearing housings. Sealing surfaces. CMM finds the truth.
- ❑ Traceable results directly against drawing and GD&T
- ❑ CMM verifies the critical – precise and traceable



Illustrative image generated with AI

CMM for measuring AM parts

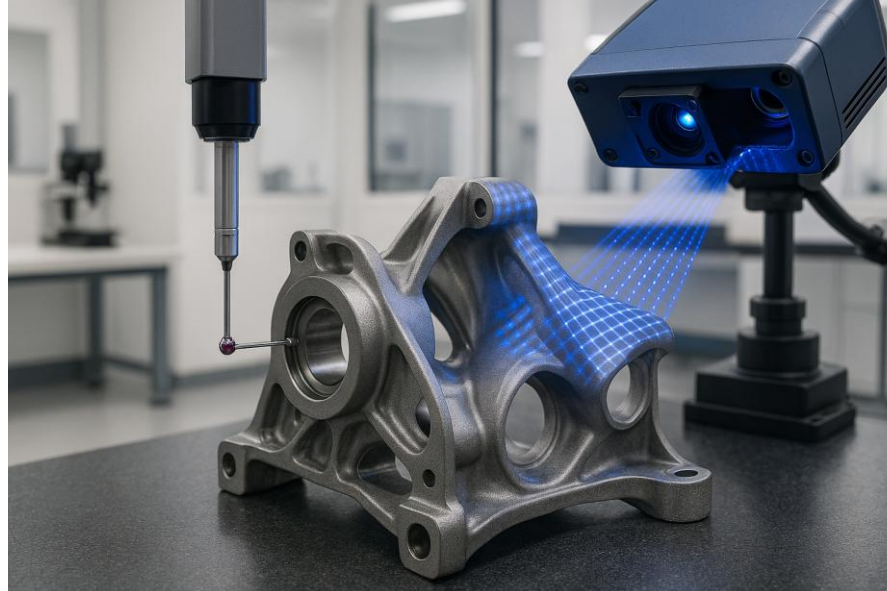
- ❑ CMM only measures what it can reach – and what it is programmed to
- ❑ Internal channels and lattice structures are invisible to the probe
- ❑ Complex AM geometry requires CT or 3D scanning as a supplement
- ❑ Point-based measurement has blind spots



Illustrative image generated with AI

Summary

- ❑ CMM verifies the critical measurements
- ❑ No single method beats the combination



Illustrative image generated with AI

3D Scanning – Non-Contact Surface Measurement

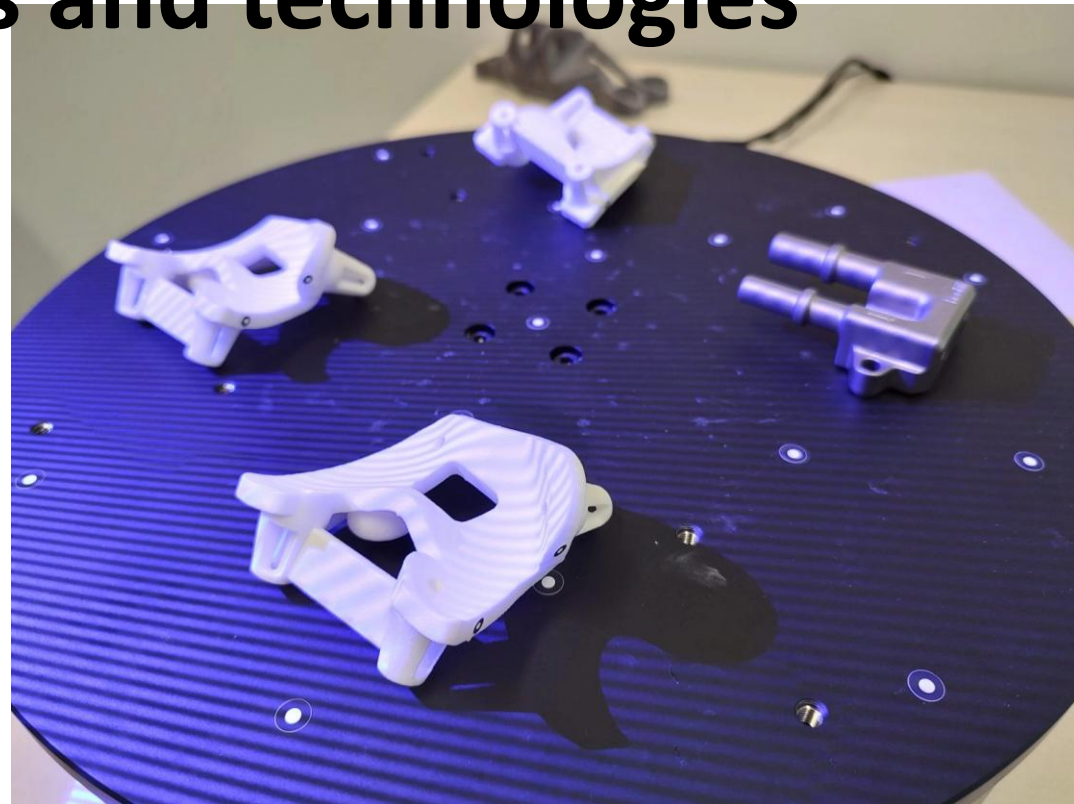
- ☐ No probe. No contact. Full surface data.
- ☐ Freeform surfaces and organic geometries



Illustrative image generated with AI

Measurement principles and technologies

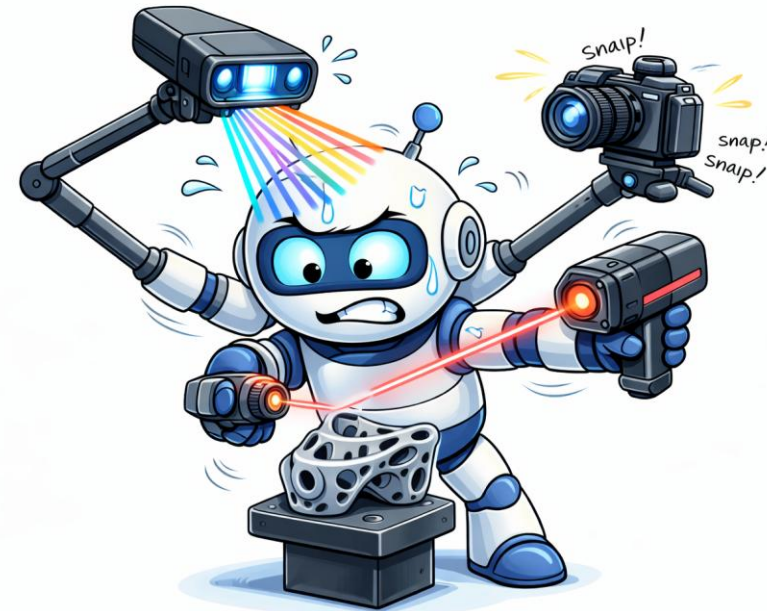
- ❑ Project stripes. Measure deformation. Calculate geometry.
- ❑ $\pm 20\text{--}50\text{ }\mu\text{m}$ – from a few millimetres to one metre
- ❑ Fast. Precise. Non-contact.



<https://www.aniwaa.com/review/3d-scanners/gom-scan-1-review-gom-inspect-professional/>

Measurement principles and technologies

- ☐ Photographs from all angles
– global accuracy on large parts
- ☐ Three principles
 - ☐ Structured light
 - ☐ Laser
 - ☐ Photogrammetry

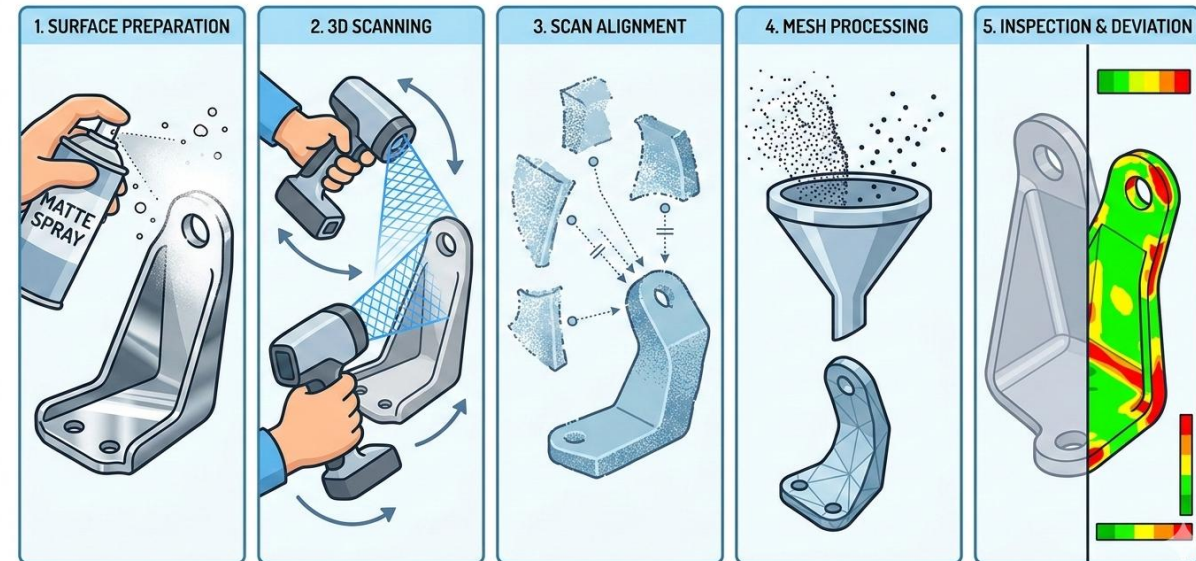


Illustrative image generated with AI

Workflow from scanning to analysis

- ❑ Prepare. Scan. Register. Clean. Compare.
- ❑ Matting spray first – metal surfaces reflect too much
- ❑ From raw point cloud to nominal/actual analysis against CAD

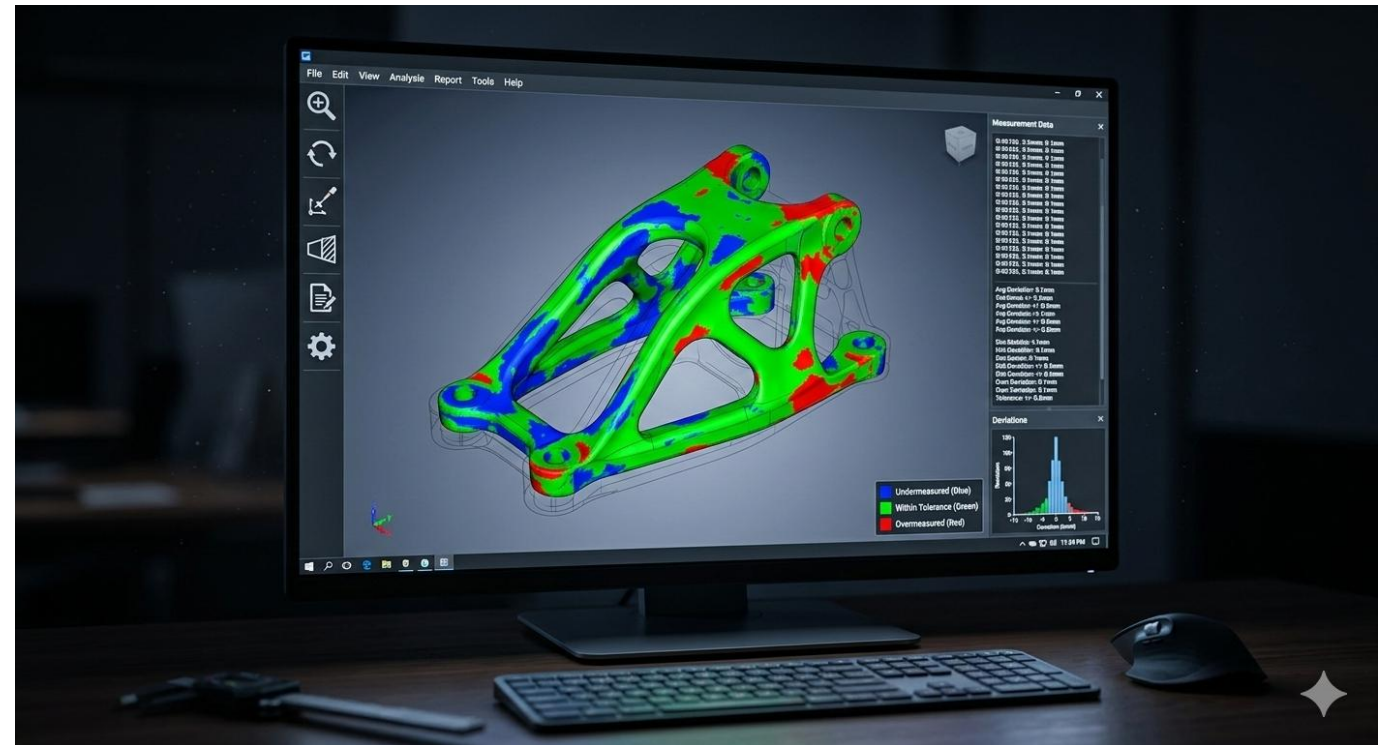
3D SCANNING WORKFLOW: FROM PHYSICAL PART TO DIGITAL MODEL



Illustrative image generated with AI

Nominal/actual analysis and colour mapping

- ❑ GOM, PolyWorks, Geomagic – mesh meets CAD
- ❑ Hundreds of deviations – one colour map reveals them all



Illustrative image generated with AI

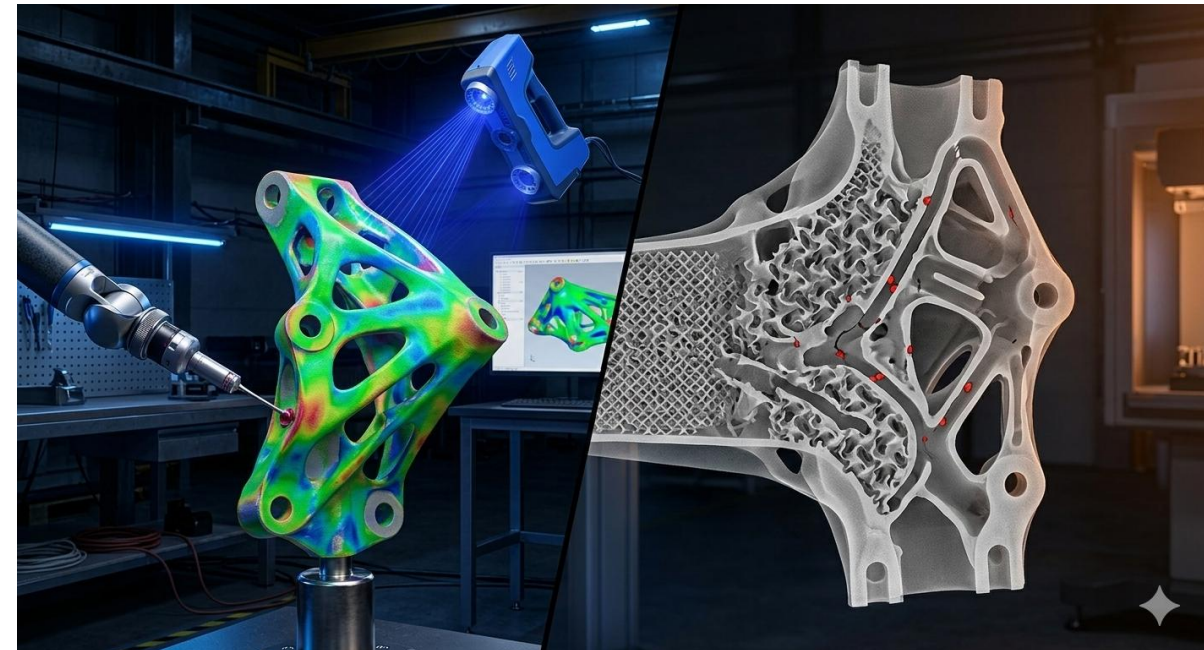


Accuracy and limitations

- ❑ Rough metal surface = noise in the point cloud
- ❑ $\pm 20 \mu\text{m}$ under optimal conditions – reality is rarely optimal
- ❑ 3D scanning captures the shape – CMM captures the tolerance

Accuracy and limitations

- ❑ 3D scanning and CMM stop at the surface – internal structures are invisible
- ❑ Internal channels and lattice structures – only CT can go inside and reveal pores, cracks and unmelted powder



Illustrative image generated with AI



Summary

3D scanning is an indispensable technology in the **quality assurance** of AM parts, because it can quickly and **non-contactly** document **complex geometries** and visualise **shape deviations** across the entire part surface. The technology **complements CMM** rather than replacing it, and the most robust inspection strategy for AM parts combines 3D scanning for surface analysis and shape control with CMM for verification of critical tolerances, and industrial CT where internal structures need to be inspected.

White Light Interferometry (WLI) – Introduction



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WLI is a **non-contact optical technique** that uses broadband light to reconstruct surface topography via interference fringes.

- ❑ **Vertical resolution:** $<0.1 \text{ nm}$ (independent of magnification)
- ❑ **Lateral resolution:** $\sim 0.3 \text{ }\mu\text{m}$
- ❑ **Strengths:** Large field of view, compatible with smooth, rough, transparent and reflective surfaces
- ❑ **Limitations:** Steep slopes and highly scattering surfaces

Well suited for **semiconductor, optics, coatings** – in both R&D and production.



<https://www.bruker.com/en/products-and-solutions/test-and-measurement/3d-optical-profilers/contourx-500.html>

WLI – Advances & Measurement Modes



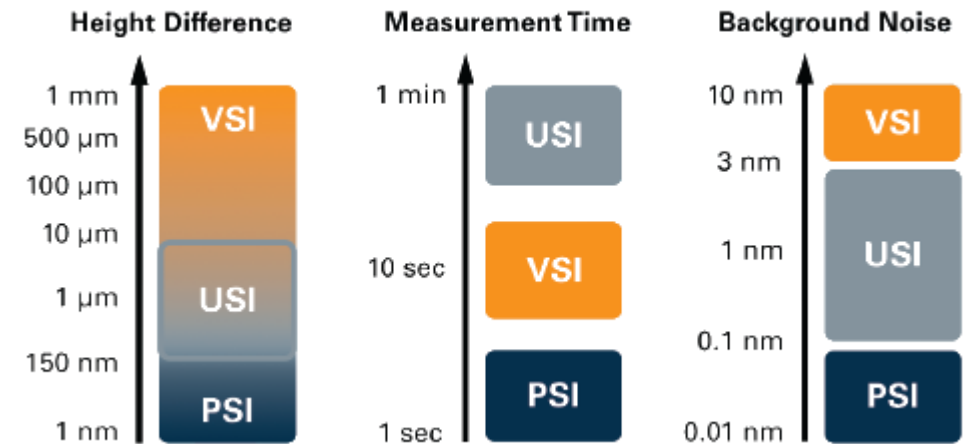
From lab to production

Modern WLI systems feature internal laser calibration, vibration isolation and recipe-based workflows for production environments.

Three measurement modes

- ☐ **PSI:** Highest resolution – ultra-smooth, reflective surfaces
- ☐ **VSI:** Moderate to high roughness – semiconductor, MEMS, precision machining
- ☐ **USI:** Hybrid PSI+VSI – adaptive per pixel for mixed surfaces

Through-film: Measures through transparent films – captures top surface and buried interfaces.



WLI – Objectives, Filtering & Software

Objectives

- ☐ Start with **10x/20x** for general characterization
- ☐ **LWD objectives** for deep recesses and transparent layers
- ☐ Higher **NA** for steep slopes; **mirror objectives** for sidewalls

Filtering (ISO 25178)

- ☐ **Gaussian:** Separates roughness and waviness
- ☐ **Cutoff (λ_s , λ_c , λ_f):** Correct selection is critical for reliable results

Vision64: All-in-one analysis and visualization with ISO-compliant parameters (R_a , S_a , R_z , S_z , S_k).



WLI – Practical Considerations & Error Sources



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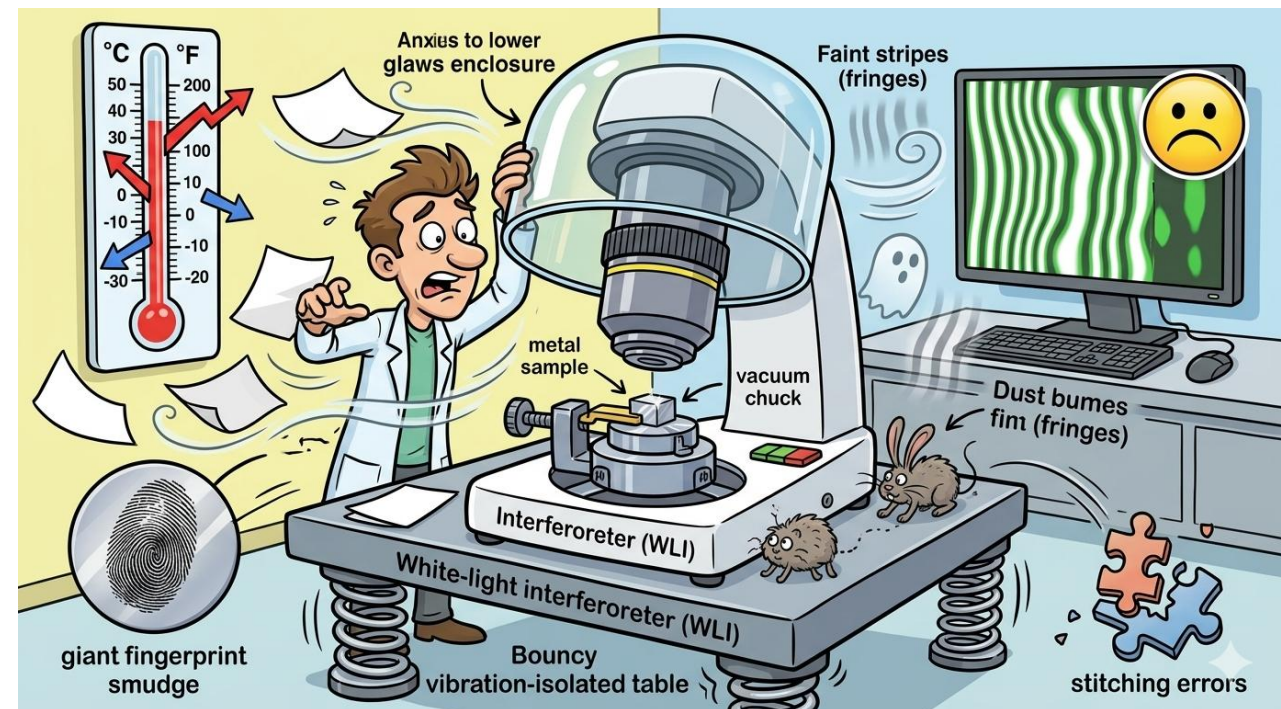
Environmental factors

- ❑ **Vibration:** Phase noise – use vibration-isolated tables
- ❑ **Air currents:** Turbulence distorts fringes – use enclosures
- ❑ **Temperature:** Thermal drift – temperature-controlled rooms recommended

Sample preparation

- ❑ Secure fixation (magnetic bases, vacuum chucks, custom fixtures)
- ❑ Cleaning for dust, oil and contamination
- ❑ Typical artifacts: **stitching errors, phase unwrapping, speckle noise, ghost fringes**

Operator variability is minimized through training, protocols and automated workflows.



Measurement Strategies for Additive Manufacturing



	CMM	3D Scanning	WLI
Measurement Principle	Contact-based, one point at a time	Non-contact, millions of points simultaneously	Interferometry, optical phase measurement
Accuracy	$\pm 1\text{--}5\ \mu\text{m}$	$\pm 20\text{--}100\ \mu\text{m}$	Sub-nm (vertical), $\sim 0.5\ \mu\text{m}$ (lateral)
Speed	Slow (hours)	Fast (minutes)	Seconds per field of view
Data Type	Single points on selected features	Full point cloud of the entire surface	3D surface topography, height maps
Complex Geometries	Limited – does not undercut	Good – captures freeform surfaces	Limited to small field of view
Internal Structures	No	No (requires CT scanning)	No
Surface Roughness (AM)	Affects probe contact	Requires matting spray	Specialized – measures Ra/Sa directly
Documentation	Traceable numerical values, pass/fail	Color maps, visual shape analysis	ISO 25178 parameters, 3D maps
Best For	Critical tolerances and mating surfaces	Overall shape control and freeform surfaces	Surface roughness, microtopography and finish quality



Key points for CMM / 3D-SCAN:

- CMM is precise but slow – used for **critical features with tight tolerances**
- 3D scanning is fast and provides **full surface data** – used for shape control and deviation analysis
- AM parts' rough surfaces and complex geometries challenge **both** methods in different ways
- The two methods are **complementary**, not competing
- **Best practice:** Combine CMM + 3D scanning, and add CT scanning for internal structures



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Case Study: CADskills

*Improved Quality for Customized Medical Implants
Using 3D Scanning*



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Case: CADskills – Improved Quality for Customized Implants



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About CADskills

- Belgian company specialising in patient-specific implants
- Designs and develops biofunctionalised implants for dysfunctional joints and bones
- Works from CT data and surgeon preferences
- Uses ATOS Q 3D scanner for quality control

Challenge

- Ensuring high implant quality for durability, compatibility, and reliability
- Reducing risk of complications, infections, and implant failure

Source: handsonmetrology.com/blog/improved-quality-for-customized-implants-at-cadskills/

CADskills – Implant Manufacturing Process

From CT data to finished implant

- **1. Design:** The implant is designed from CT data and surgeon preferences
- **2. 3D printing:** The implant is 3D-printed with a porous structure resembling human bone
- **3. Post-processing:** Micro-shot peening, acid etching, ultrasonic cleaning, and polishing
- **4. Quality control:** Scanning with ATOS Q to verify no deformations
- All implants are scanned before being shipped to hospitals and implanted in patients

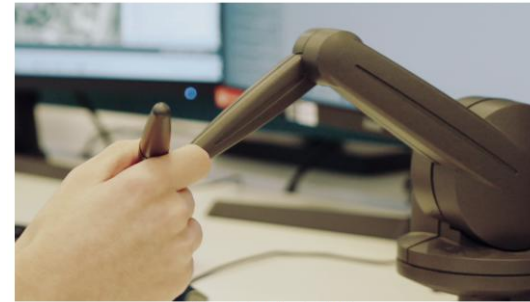


Fig. 1: Implant design

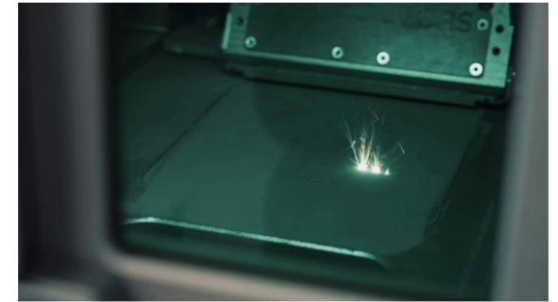


Fig. 2: 3D printing of the implants



Fig. 3: Manual post processing



Fig. 4: Quality control with ATOS Q

Image: handsonmetrology.com – Fig. 1-4: Implant design, 3D printing, Post processing, Quality control

Source: handsonmetrology.com/blog/improved-quality-for-customized-implants-at-cadskills/

CADskills – Quality Control with ATOS Q 3D Scanner

Why ATOS Q?

- Fast data acquisition with precise results
- **Blue Light Equalizer** – ideal for scanning reflective surfaces
- **Triple Scan Principle** – handles porous structures on the implants

Scanning and inspection

- Comparison of scanned implant with the original design
- Deviations visualised directly in colour (colour map)
- Verifies that no deformations occurred after printing and post-processing

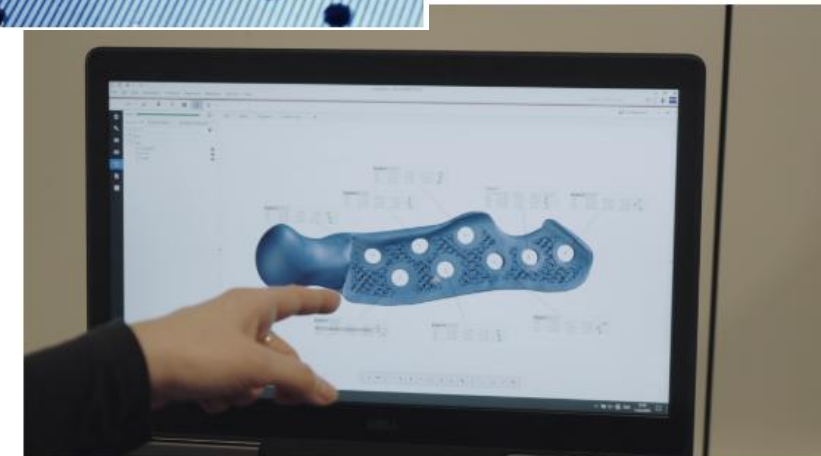
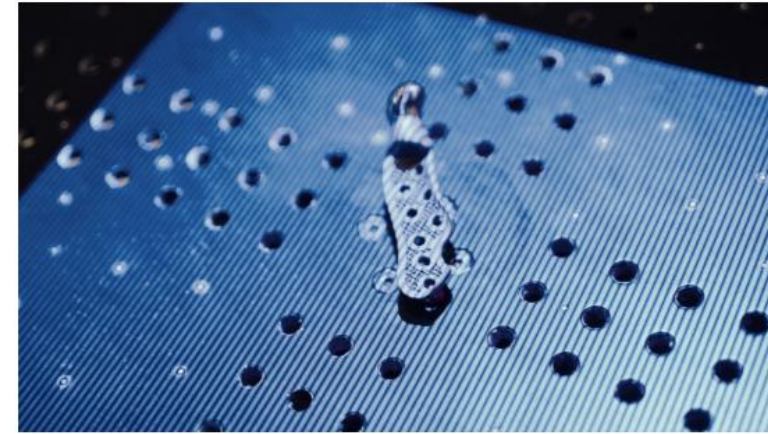


Image: handsonmetrology.com – Fig. 5: Implant scanning, Fig. 6: Scan vs. design comparison

Source: handsonmetrology.com/blog/improved-quality-for-customized-implants-at-cadskills/

CADskills – Results and Key Takeaways



Results with ATOS Q

- Improved quality control of all patient-specific implants
- Direct visual feedback via deviation colour map
- Increased patient safety – all implants verified before delivery

Key Takeaways

- 3D scanning is essential for quality assurance of 3D-printed medical implants
- Porous structures and reflective surfaces require specialised scanning technology
- Metrology solutions enable better patient outcomes and reduced risk

Source: handsonmetrology.com/blog/improved-quality-for-customized-implants-at-cadskills/



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Case Study: Sintavia

*X-Ray CT Verification of 3D Metal Printing for
Aerospace Applications*



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Case: Sintavia – X-ray CT Verifies 3D Metal Printing



About Sintavia

- 3D metal printing company based in Davie, Florida
- Leading supplier of AM components for aerospace & defense
- Full-service provider: design-through-production with metallurgical lab
- Uses Nikon XTH 450 micro-focus CT system for quality control

Challenge

- Full understanding of thousands of process parameters in metal AM
- Detection of random defects (voids, inclusions) in metal powder-bed fusion

Source: aerospacemanufacturinganddesign.com/article/x-ray-computed-tomography-verifies-3d-metal-printing/

Sintavia – CT Inspection of Internal Channels

Internal channels in AM parts

- 3D-printed metal parts often contain complex internal passages and channels
- These are invisible to traditional contact and line-of-sight measurement methods

Why CT is necessary

- CT provides full 3D visualisation of internal geometry
- Verifies density, voids, and dimensions inside the part
- The only non-destructive method for inspecting internal structures

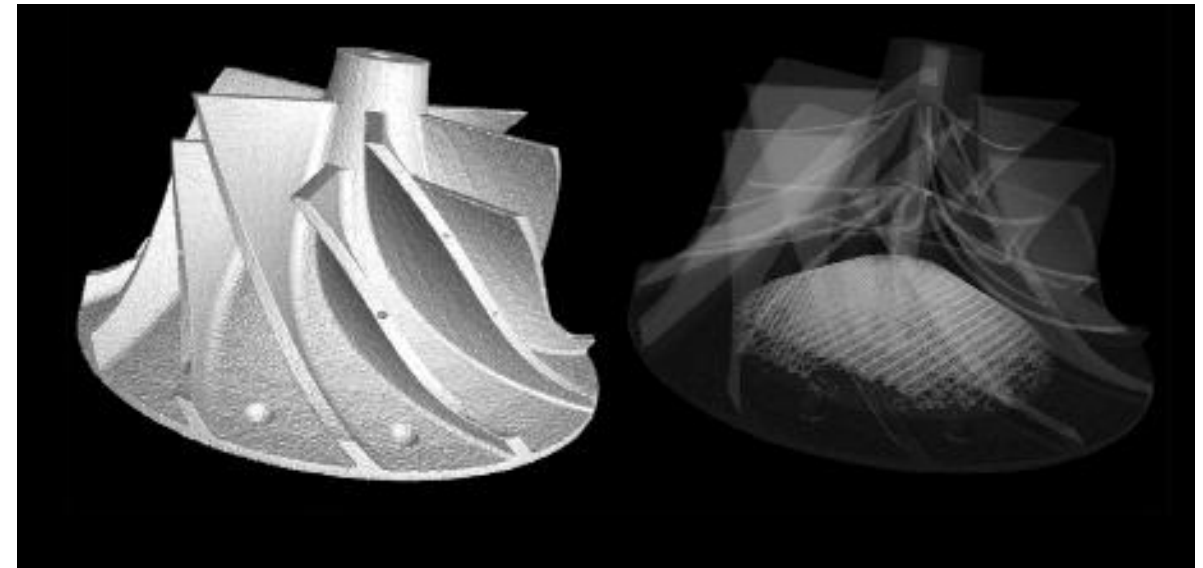


Image: aerospacemanufacturinganddesign.com – Sintavia 3D-printed metal part with internal passages

Source: aerospacemanufacturinganddesign.com/article/x-ray-computed-tomography-verifies-3d-metal-printing/

Sintavia – Micro CT with Nikon XTH 450

Nikon XTH 450 Micro-Focus CT System

- Converts 2D pixels to 3D voxels – full 3D density map
- 450 kV micro-focus X-ray source – the world's only at this energy level
- 25 micron repeatability and accuracy
- Visual format makes data easily readable and interpretable

What is detected?

- Voids, inclusions, and porosity in 3D-printed metal parts
- Geometric and tolerance-based quality control – non-destructive

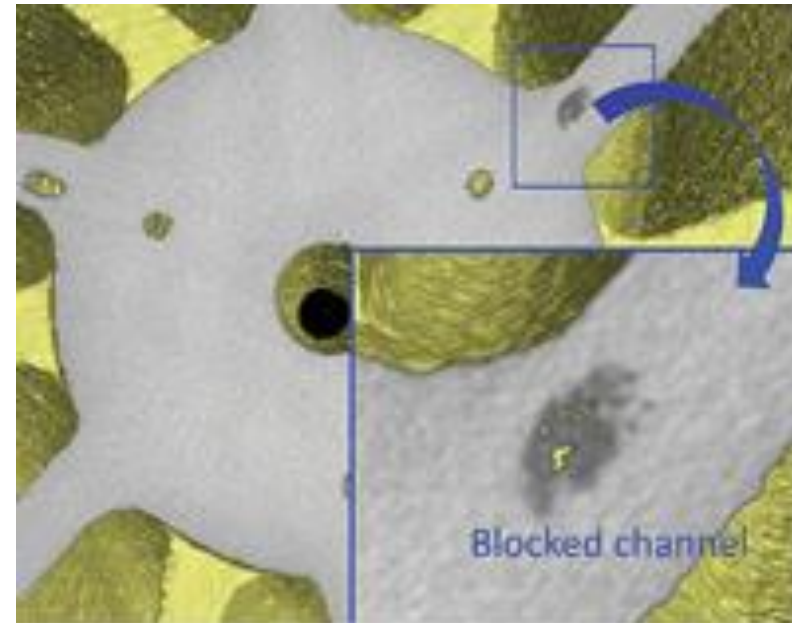


Image: aerospacemanufacturinganddesign.com – Nikon XTH 450 micro CT / 3D density map

Source: aerospacemanufacturinganddesign.com/article/x-ray-computed-tomography-verifies-3d-metal-printing/

Sintavia – Results and Key Takeaways



Results

- Faster parameter optimisation and quality auditing than competitors
- Full non-destructive inspection of complex internal structures
- Positioning as a full-service design-through-production provider

Key Takeaways

- X-ray CT is indispensable for verification of 3D-printed metal parts in aerospace
- Process understanding via Ishikawa approach + CT provides competitive advantage
- Non-destructive 3D scanning replaces traditional 2D radiography for AM

Source: aerospacemanufacturinganddesign.com/article/x-ray-computed-tomography-verifies-3d-metal-printing/



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Case Study: Rocket Combustion Chamber

*Choosing the Right Verification Process for Additively
Manufactured Aerospace Components*



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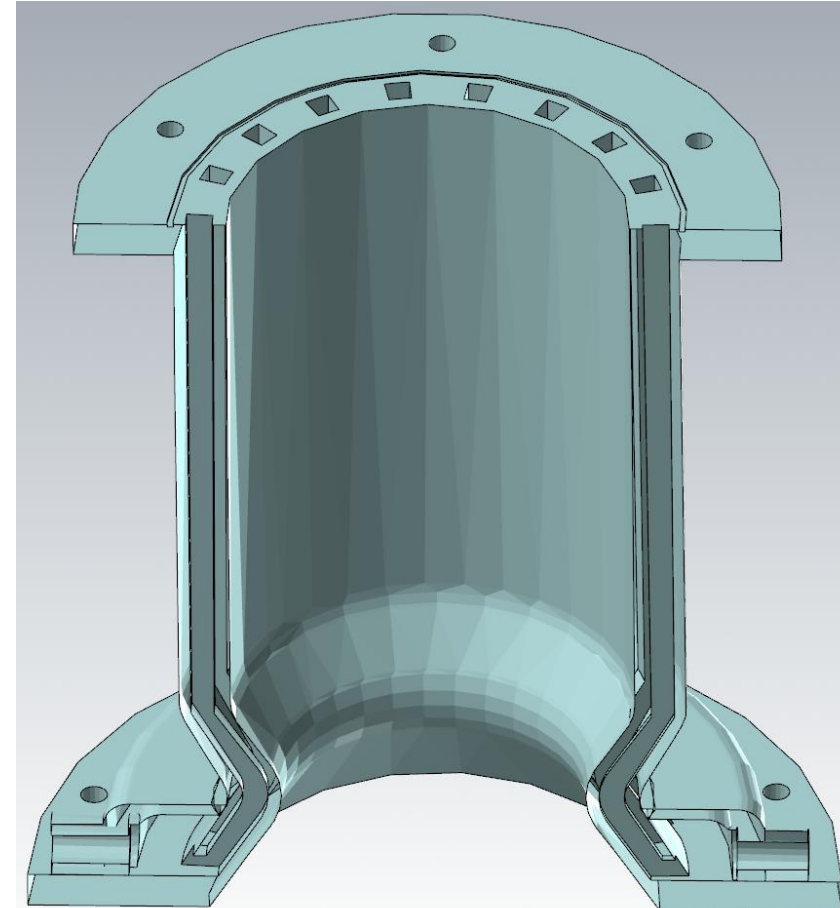
Case: Verification of Regeneratively Cooled Rocket Combustion Chamber

The component

- Regeneratively cooled rocket combustion chamber – 3D-printed in metal
- Cooling channels integrated in the chamber wall route fuel around the chamber
- Safety-critical component in aerospace applications

The questions

- What are the critical features of this part?
- Which verification processes should be selected to ensure part quality?



Component Complexity – Critical Features



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Internal cooling channels

- Axial channels along the chamber wall – fully encapsulated in the metal
- Inaccessible to optical, tactile, and ultrasound-based methods

Thin walls (hot wall)

- Thin wall between combustion gas and coolant – dimensions are critical
- Deviations can cause overheating and catastrophic failure

Porosity and material quality

- Voids and inclusions from powder-bed fusion can weaken the structure
- Requires density verification throughout the entire volume



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Verification Methods – Which Processes Can Be Used?

Optical 3D scanning (e.g. ATOS Q)

-  External geometry, surface deviations, CAD comparison
-  CANNOT see internal channels, porosity, or wall thickness

Tactile measurement (CMM)

-  Precise external dimensions, tolerance control
-  Limited to accessible surfaces – no internal access

Ultrasound (UT)

-  Wall thickness, surface defects
-  Simple geometries only – difficult on porous AM surfaces



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X-ray CT – The Decisive Verification Method

What CT can do that no other method can

- Full 3D visualisation of internal cooling channels and geometry
- Wall thickness measurement between channel and combustion chamber
- Porosity analysis – detection of voids and inclusions throughout the volume
- CAD-to-scan comparison of both external and internal geometry
- Non-destructive – the part remains intact after inspection

Challenges of CT for this component

- High material density requires sufficient kV (e.g. 225–450 kV)
- Part size vs. resolution – trade-off between detail and scan volume

Comparison of Verification Methods



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Feature	Optical 3D	CMM	Ultrasound	X-ray CT
External geometry	✓ Yes	✓ Yes	⚠ Partial	✓ Yes
Internal channels	✗ No	✗ No	✗ No	✓ Yes
Porosity	✗ No	✗ No	⚠ Partial	✓ Yes
Wall thickness	✗ No	✗ No	✓ Yes	✓ Yes
Non-destructive	✓ Yes	✓ Yes	✓ Yes	✓ Yes

Conclusion – Recommended Verification Strategy



Recommendation: Combined approach

- **1. X-ray CT (primary):** Full volumetric inspection – internal channels, porosity, wall thickness, CAD comparison
- **2. Optical 3D scanning (supplementary):** Rapid verification of external geometry and surface quality

Conclusion

- No single method can verify all critical features
- CT is indispensable for internal structures – the only non-destructive solution
- Optical scanning supplements with rapid external geometry control



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Feedback Questionnaire



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Any questions?

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