

X-ray back scatter techniques for additive manufacturing

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Abstract

X-ray back scatter imaging is rarely applied compared to classical X-ray projection imaging. 20 years ago the company Philips developed “COMSCAN”, a first application case in the aircraft industry, which allowed even a depth resolution using back scatter imaging. The company AS&E in Boston offers back scatter imaging solutions for the security market. Their principle is to scan the object with a highly collimated X-ray needle beam from one side only and detect the backscattered radiation by a large area detector side by side with the collimation wheel. A new prototype is investigated at BAM for application and optimization in non-destructive testing. As modern industrial application field in-situ testing in additive manufacturing is targeted. The accessibility of the printed part during the production process is very limited. This prevent the application of a two sided X-ray inspection or Computed Tomography, were an rotation of the object is required to acquire projections from 360 degrees. An important advantage for the X-ray back scatter technique are also the materials used in additive manufacturing (polymers, ceramics, light metals like Aluminum or Titanium). These materials with lower density and lower Z values give better scatter signals than metals with higher densities and Z values. The back scatter intensity decreases with increasing density and Z value of the material. But the requirements on spatial resolution and contrast sensitivity are more stringent for non-destructive testing of additive manufactured parts compared to the security area. In NDT sizes of indications smaller than 1 mm have to be detected clearly. The investigation of these limits on a state-of-the-art prototype for X-ray back scattering using rotating collimated X-ray needle beams is a part of the BAM project “ProMoAM”. The contribution shows first results of the optimization for NDT and the achieved application limits for several example cases.



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X-RAY BACK SCATTER TECHNIQUES FOR ADDITIVE MANUFACTURING

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BAM

Introduction

X-ray back scatter techniques

- Starting point: Applications for security
- Various detection principles

Prototype „ModBx“ of AS&E, Boston

- Construction and conditions for work
- Example images and optimization of image quality

Applications for additive manufacturing

- First results
- Additional test objects
- Integration into AM equipment?

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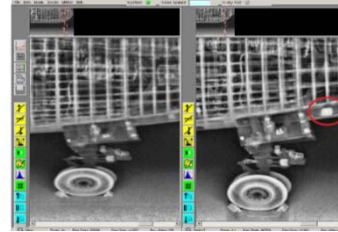
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Applications for Security



Historical Compare Tool with Threat in Front Fuselage
Can be used to compare images of known "clean" aircraft



Aims of imaging by X-ray back scattering:

- Mobile application with **one-sided** measurement access only
- Detection of weapons, explosive materials and contraband in baggage and freight containers
- Identification of dangerous liquids in complex environment

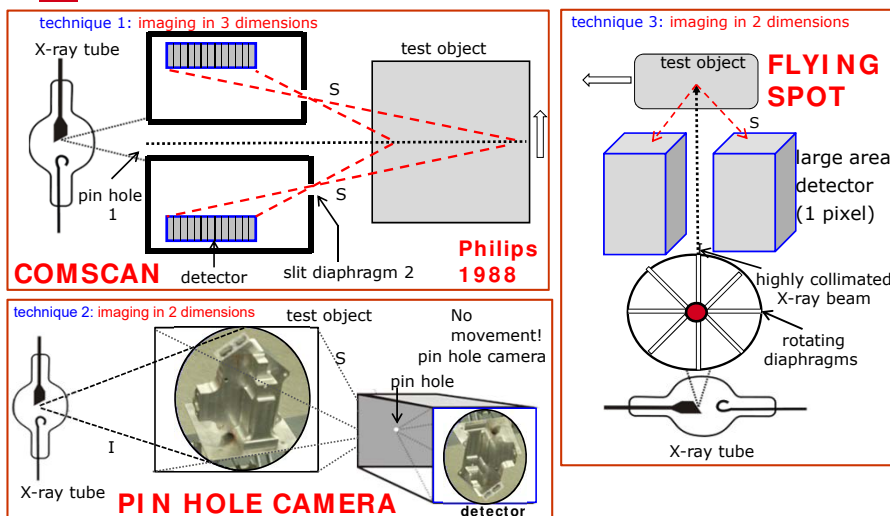
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X-ray back scatter techniques: various principles



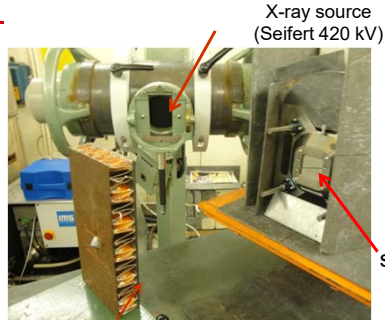
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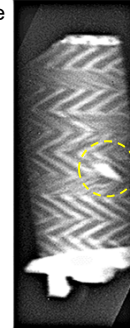
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Example image by single slit diaphragm



back scatter image



CFK sandwich plate
(10 cm x 20 cm x 3.3 cm)

Experimental parameters:

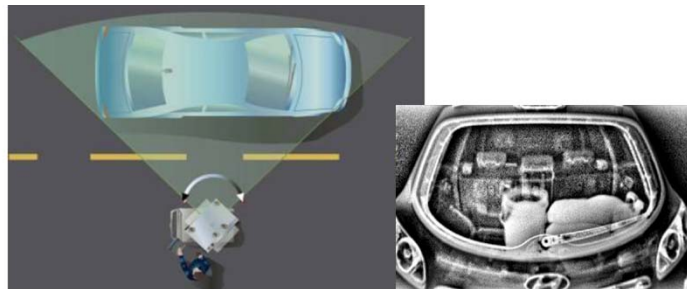
- 420 kV, 10mA, 3 min
- Diaphragm slit opening: 0.9 mm
- Source object distance: 61cm
- Object diaphragm distance: 47 cm
- Diaphragm detector distance: 22 cm

- Damages in the plate can be identified
- Intruded water between surface and core can be visualized
- Structural integrity can be displayed, **but only limited field of view**

AXISS: mobil X-ray back scatter technique by American Science & Engineering



X-ray source: 140 kV, rotating anode with 600 W continuous power
Mobile system with 2D scanning: rotating collimator & horizontal sweep



Field of view: vertical 42°, source adjustable by +/- 22° top/bottom:

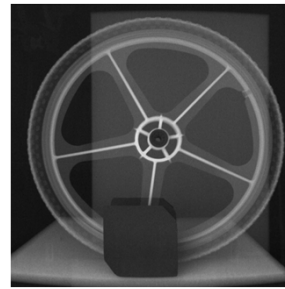
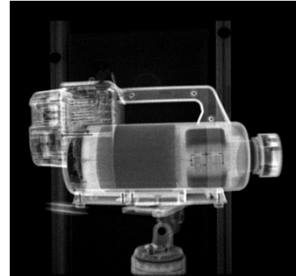
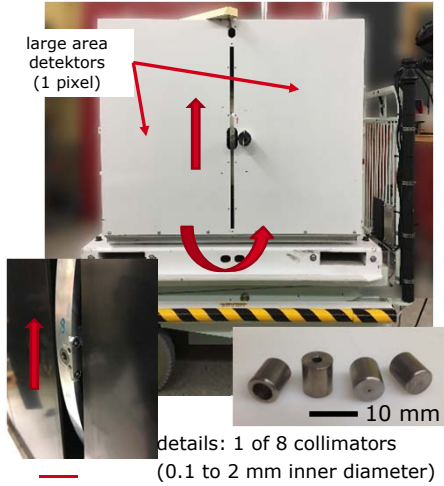


Back scatter prototype "ModBx" by AS&E in BAM 8.3



0.1 mSv/h in beam in 1m distance

Front view on collimator wheel:

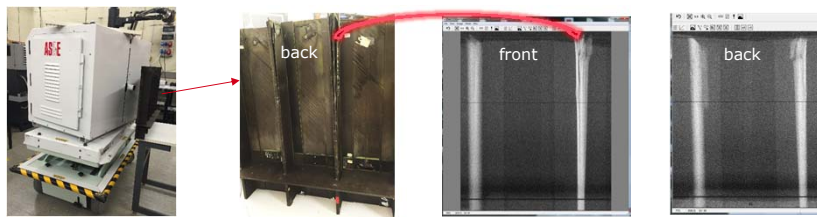


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Example images: flying spot back scattering, back scatter pin hole camera & penetration image with flash tube

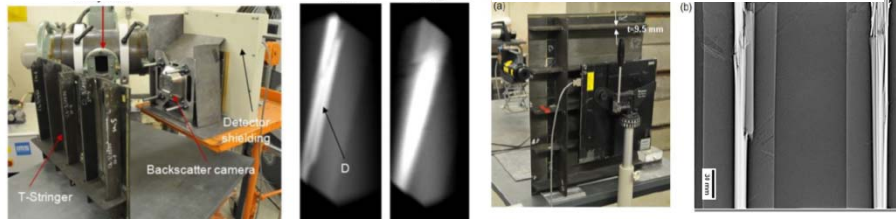


Back scattering with flying spot collimator: 0.5 mm needle beam diameter




Back scatter camera with single slit: 0.5 mm

Penetration with flash tube: pixel 0.15 mm




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Optimization of back scatter prototype “ModBx”:  **stack of Aluminum plates with hole IQIs**

side view

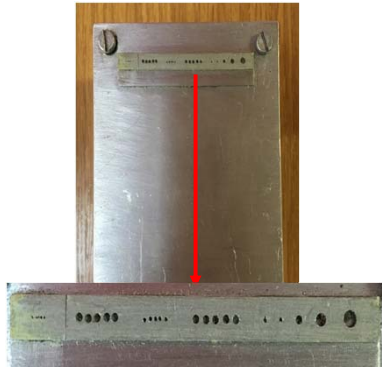
7.7 mm



IQIs stacked on 8 plates


front view

76.8 × 100 × 1.8 mm³




IQI hole \varnothing : 0.15 – 2 mm

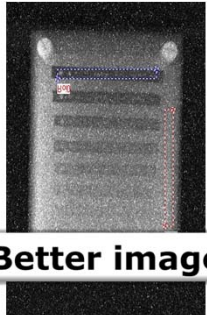
back view



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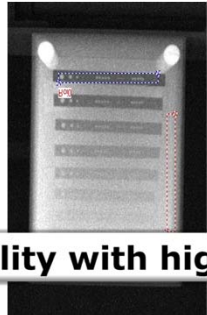
Optimization:  **higher X-ray energy → higher scatter signal**

70 kV



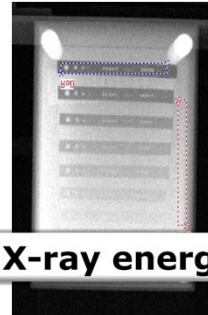
- SNR= 6
- GV= 282
- $SR_b = 0.4$ mm
- CNR=3.5

100 kV



- SNR= 15
- GV= 2062
- $SR_b = 0.4$ mm
- CNR=11

140 kV



- SNR= 35
- GV= 6902
- $SR_b = 0.4$ mm
- CNR=18

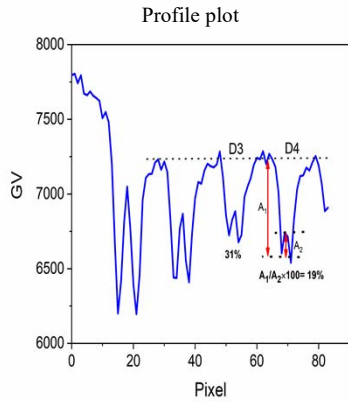
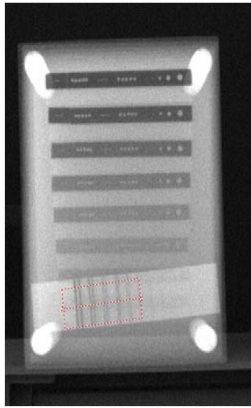
Better image quality with higher X-ray energy

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**Basic spatial resolution SR_b :
Duplex wire IQI according to ISO 19232-5**



X-ray voltage 140 kV, 0.5 mm Collimators
D = 130 mm



Basic spatial resolution
ISO 19232-5
D4
↓
 $SR_b = 0.4 \text{ mm}$
at
0.3 mm pixel size

0.1 mm collimators: SR_b better, but signal too low!
0.25 mm collimators: built, testing in progress...
Wolframet drilled, not eroded!

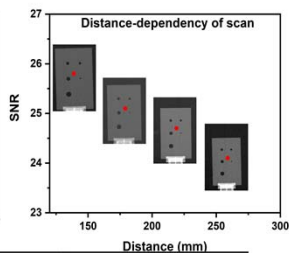
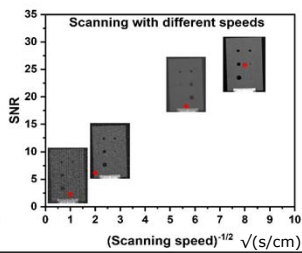
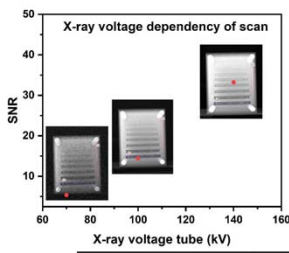
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**Optimization:
SNR & spatial resolution with Duplex IQI**



| | | | |
|---|--|--|--|
| <p>Pixel 0,3mm Koll. 0,5mm BPK D4 SR_b 0,4mm</p> | <p>Pixel 0,12mm Koll. 0,5mm BPK D4 SR_b 0,4mm</p> | <p>Pixel 0,11mm Koll. 0,1mm BPK D7 SR_b 0,2mm</p> | <p>Pixel 0,09mm Koll. 0,1mm BPK D4 SR_b 0,2mm</p> |
| <p>large pixels</p> <p>0.5 mm & 23 us</p> | <p>0.5 mm & 8 us</p> | <p>0.1 mm & 8 us</p> | <p>0.1 mm & 6 us</p> |

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Enhancement of basic spatial resolution by reduced collimator holes and higher sampling frequency but reduction of SNR



140 kV, 4.2 mA, 600 W

Collimator hole: 0.5 mm

Collimator hole: 0.1 mm

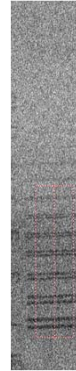


ISO 19232-5

D4

$SR_b = 0.4 \text{ mm}$

• Pixel size = 0.12 mm



ISO 19232-5

D7

$SR_b = 0.2 \text{ mm}$

• Pixel size = 0.09 mm



Mechanical tolerances limit SR_b to 0.2 mm!

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Acceptance levels in the aircraft industry for parts manufactured by AM



- Inner inhomogenities or defects -

| Imperfection or defect | Acceptance criteria for internal characteristics for metallic 3D printed parts | | | |
|------------------------|--|---------------------|---|---------------------|
| | Level | A | B | C |
| Cracks | Not permitted | | | |
| Gas cavities | No line porosity is accepted | | | |
| | | < 200 μm | | < 500 μm |
| Solid inclusions | | < 200 μm | | < 500 μm |
| Lack of fusion | Not permitted | | | |

[3] Airbus Spec: AIPS 01-04-020 „Additive Manufacturing –Powder Bed Fusion

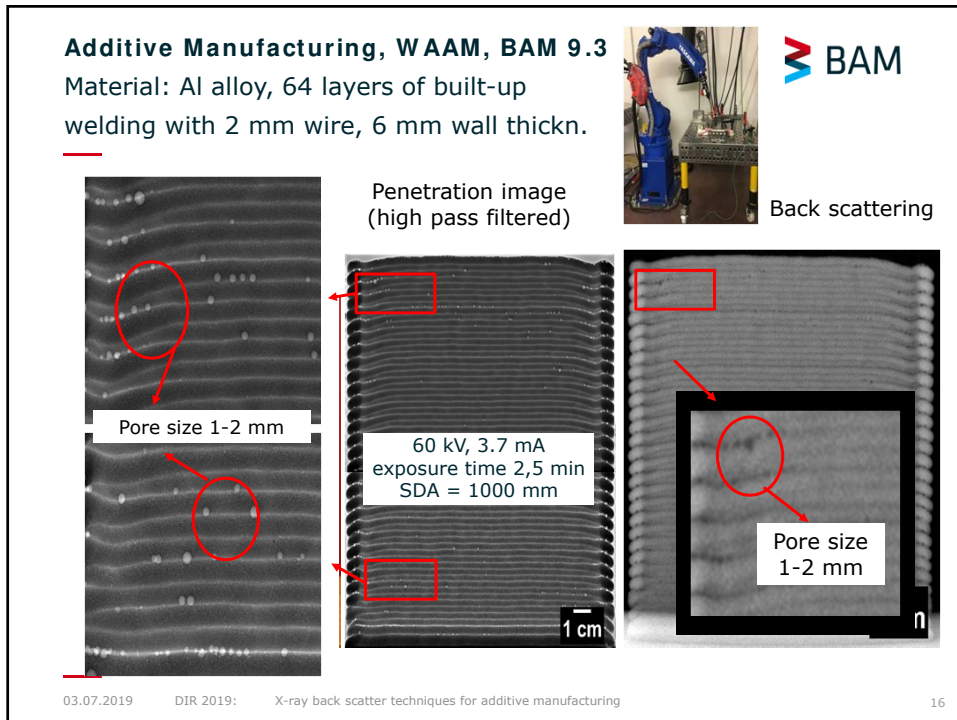
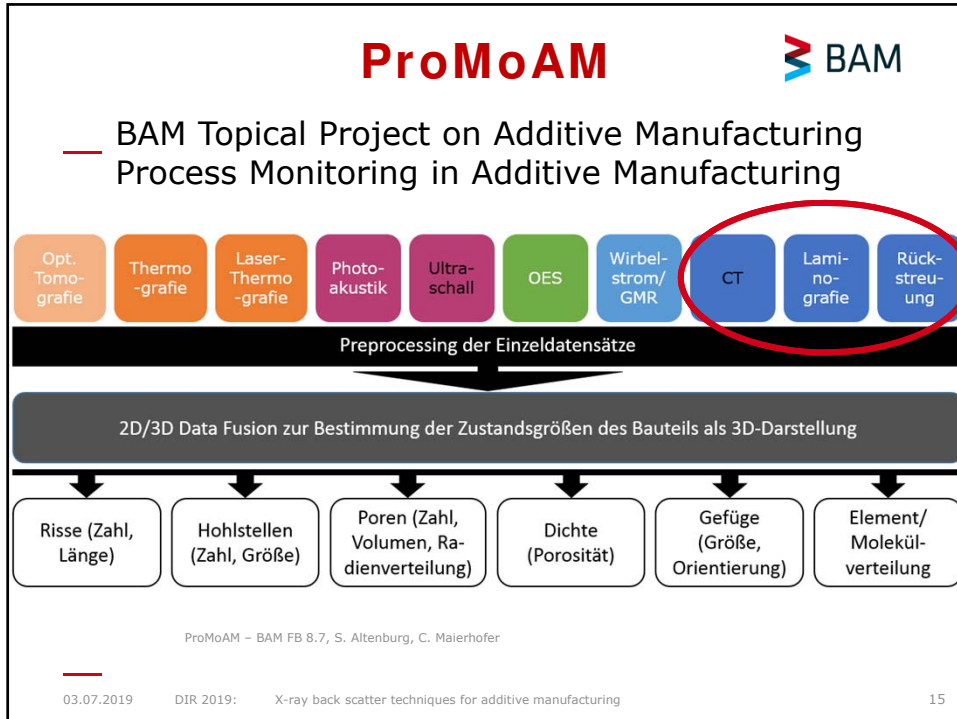
See talk by Testia: <http://www.spacetecheexpo.eu/site/presentations/non-destructive-testing-on-metal-am-parts-and-structures.pdf>

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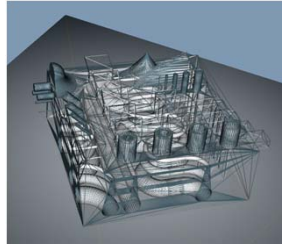


Test samples of Fraunhofer IWS

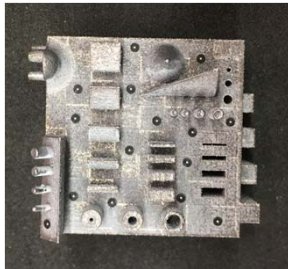
Starting point STL-File:

length: 40 mm
width: 40 mm
height: 25 mm

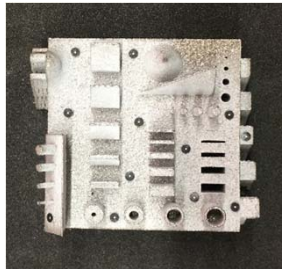
SLM 3D prints from powder
of different materials:



Contact at IWS: Samira Gruber



AISi10Mg



Ti-6Al-4V



IN718

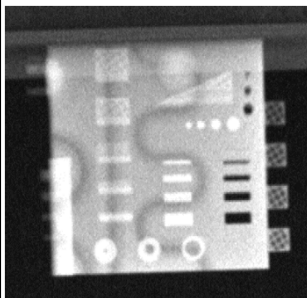
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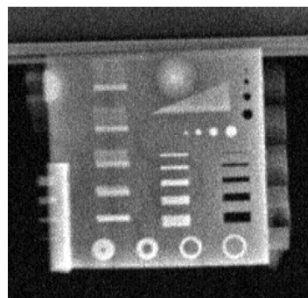
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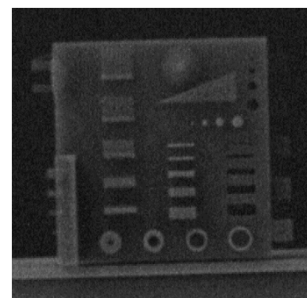
Test samples of Fraunhofer IWS Results of inspection by back scatter technique



AISi10Mg



Ti-6Al-4V



IN718

- Best results with light metals (Compton scattering highest)
- Detection inner structures depending on material (attenuation by steel requires higher X-ray energy)
- "Flying spot" technique allows defect detection in real time above 0.2 mm

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Conclusions



AS&E prototype



- Image quality in back scattering:
 - long scanning time (down to 1 min/cm)
 - small Object Collimator Distance
 - high X-ray voltage (max. 140 kV)
 - low material attenuation, light materials are the best scatterer
- Basic spatial resolution limited by mechanical tolerances of collimator wheel, if collimator holes too small, only signal loss. Optimum for ModBX: 0.25 mm
- Integration into AM set-up? Place in front of open printer!
- Further investigations within "ProMoAM" of BAM

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OUTLOOK: further miniaturization

2016: test of mobile X-ray back scatter technique



Limitation up to 70 kV (10W), **today 120 kV reached!**



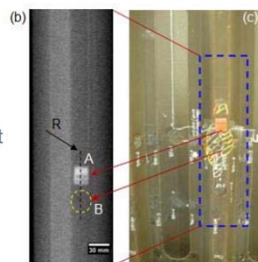
AS&E Mini-Z



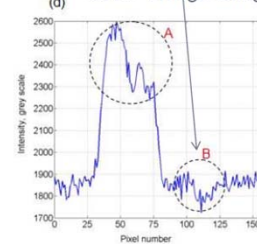
LuFo IPrO 2016
Project with Airbus



Tests at
BAM




B:
Impact damage in
CFRP omega stringer




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The END



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Next steps:

- Test of ModBx prototype for in-situ measurements
 - External detector panels
 - Optimization of Collimator size (Contrast – Resolution)
- Investigation of identical AM test objects from Al, Ti and Inconel (Fraunhofer IKS Dresden)
- Ex-situ measurements of ProMoAM test objects
- Development of scenarios for combination of ModBx prototype direct in the AM printers of BAM 9.3 / 9.4

externe
Detector panels

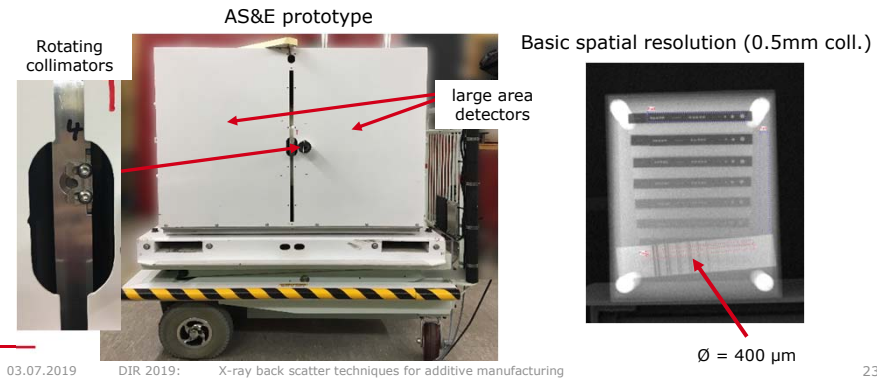
INTRODUCING MINI Z™

The world's first handheld Z Backscatter™ screening system that provides fast, portable, real-time imaging to detect drugs, contraband, and explosives in hard-to-reach locations.

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X-ray back scatter techniques

- Nomovement of object necessary
- One-sided access to object sufficient
- Suitable for typical AM materials (plastics, ceramics, metals)
- In-situ measurements possible!



Aluminum plate

size: $60 \times 100 \times 3 \text{ mm}^3$
 hole $\varnothing = 8, 6, 5, 4, 2, 1 \text{ mm}$



scans with different scanning speeds (pixel size 0.29 mm):

Speed: fast
 SNR= 2
 GV= 3376
 CNR=0.8

Speed: 1/4×
 SNR= 6
 GV= 3607
 CNR=1.8

Speed: 1/32×
 SNR= 18
 GV= 3631
 CNR=5.5

Speed: 1/64×
 SNR= 26
 GV= 3651
 CNR=7.6

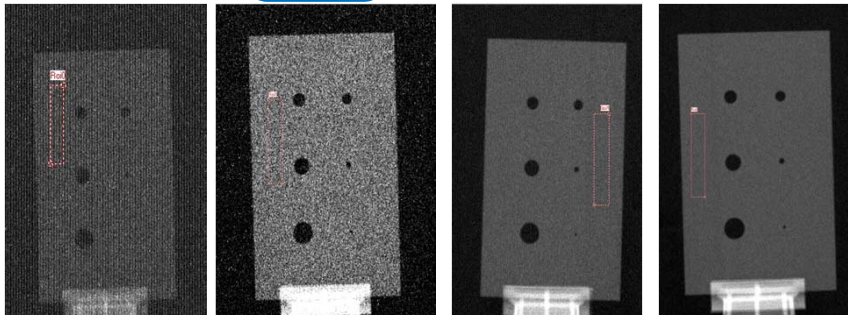


Image quality increases with scanning time