AMiquam

In-situ inspection for Advanced Manufacturing

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Quality management in AM, OPI
HEPIA Genève
Bernard Revaz

Bernard Revaz, CEO

Jonatan Wicht, Appl. Eng.
Alain Berthoud, Mech. Eng.
Yannick Bianchi, Data Scientist
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info@amiquam.ch
AMiquam SA
2, route Cité Ouest
CH-1196 Gland, Switzerland
www.amiquam.ch
https://www.linkedin.com/company/amiquam

+41 77 401 17 48

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Who we are

AMiquam

- Company developing in situ inspection for advanced manufacturing (metal PBF-LB)
- To reduce inspection costs and delays
- Founded in 2020 as a spin-off from ETH and Sensima, an NDT company
- Project with inspire, Fraunhofer, ETH, ESA, MTC, + other research centers
- Active commercial projects in Aerospace, Medtech, and Energy sectors
- Contribute to new industry standards ASTM/ISO, SAE ARP
- Designs approved by machine manufacturers, with full product integration achieved with GFMS (DMP350)
- Pre-approved for F-35 offset program (LPBF heat exchanger + blade repair)

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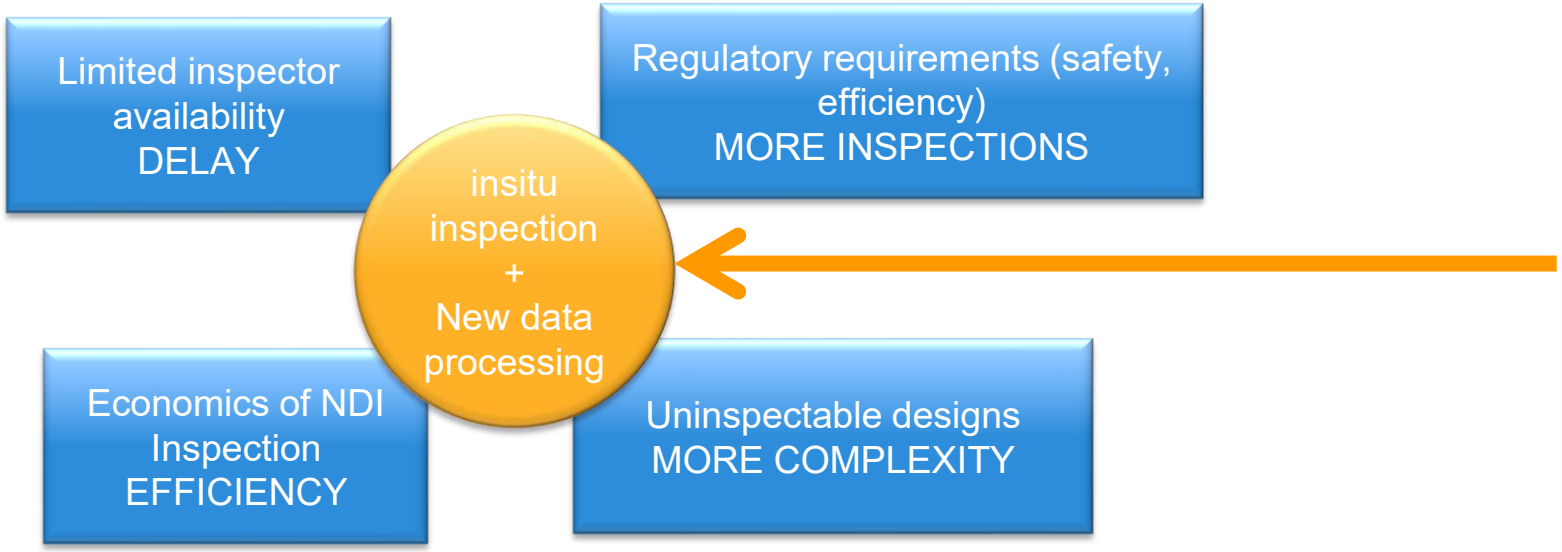
AMIQUAM: Solving the bottleneck of inspection for safety critical metal parts

AMiquam



EASA
European Union Aviation Safety Agency

This project has received funding from the European Union's Horizon Europe Programme

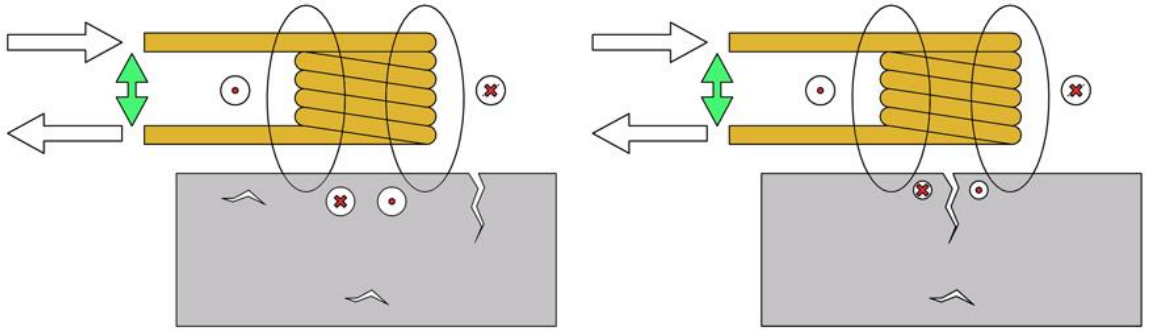
Machine Learning Application Approval

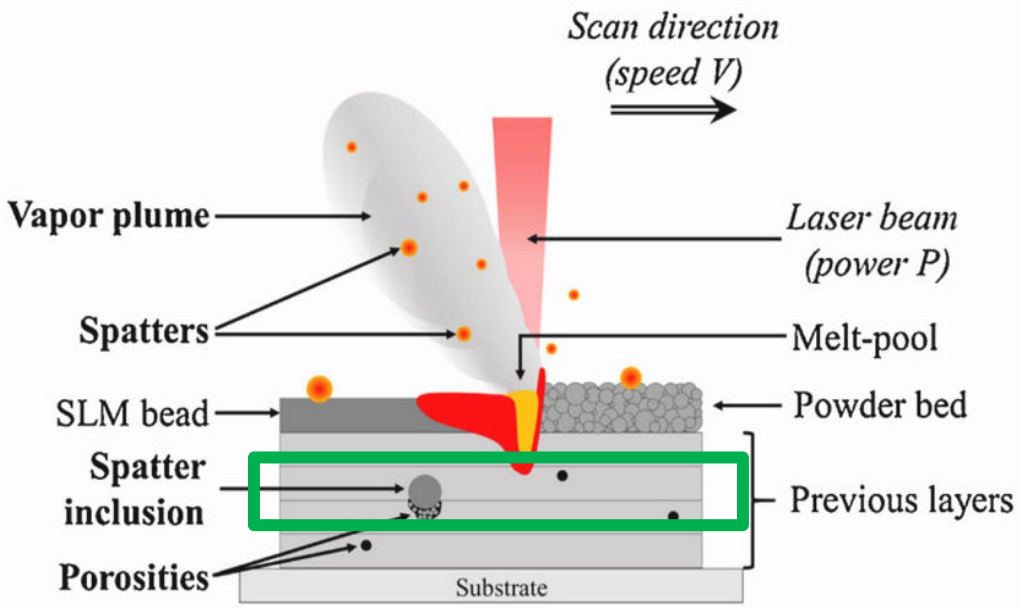
in situ inspection for Advanced Manufacturing

- **Projects in LPBF, DED, WAAM, grinding rectification, EDM**
- **AMiquam supplier of ARIANE 6 (in situ NDT for shot peening + FSW) and other major organisations**
- **Platform for Advanced Manufacturing in situ inspection: reduce production waste/resources + delivery delays**
- **Key components: miniaturized NDT electronics (ECT) – integration/interfacing solutions – automated inspection analysis**

Eddy Currents

- Principles: ac magnetic fields generate currents in the part
- Advantages of EC for metal LPBF: non contact, integration, subsurface
- Purpose of examination: discontinuities and more
- Standardisation efforts for AM: ASTM/ISO, SAE ARP
- Detection limits: PoD





AMIQUAM: Product objectives

Expedite part certification	NDT data available at the end of the process, certification process can start immediately (remotely if necessary)
Reduce human effort required for part certification	Using pre-processing and assisted defect recognition tool a table of indications is generated that is reviewed by the inspector
Reduce costs for NDT	From $1’000-2’000 with CT to $250-500 with in situ inspection
Adhere to existing standard	Compliant with established standards of the space/aviation/defense industry MIL-HDBK-1823A2009, ISO15548, ISO 77.040.20, ISO 9712:2021
Reduce use of CT scans	Complement or replace CT scans
Enable inspection of “uninspectable” parts	In-situ inspection enable the inspection of parts that are not accessible to inspection after the fabrication

Scope of EC inspection

ISO 15549, purpose of examination	Application to metal PBF-LB	Project example
to reveal discontinuities in the product which could affect its fitness for purpose;	See ASTM 3166 (cracks, pores, lack of fusion, inclusions, etc..), rogue flaws	Inspire, DILAPRO, MTC, ESA,…
to measure the thickness of coatings or layers;	Monitoring of process, SPC	Software development
to measure other geometric characteristics;	Detection of cold cracking, prevent part failure, lattice integrity, heat exchangers, hybrid manufacturing	Volum-e, HESSO-VS, TH Rosenheim
to measure metallurgical or mechanical properties of the product+sort products	In situ monitoring of mechanical performance, reduce coupon mechanical tests	Fieldmade
to measure the conductivity and/or permeability of the product;	Measure porosity	EOS, Zeiss, Constellium, Rosswag
+ to measure residual stress	Prevent part failure, reduce HIP	Uni Pavia

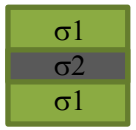
Existing standards + new standard

EC NDT standards

ISO 15548:2013 15549:2008

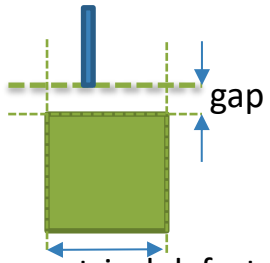
General applications of EC for NDT

ASTM E1004-17



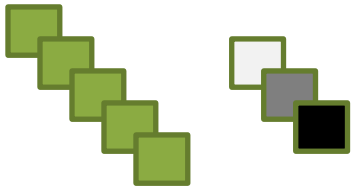
Electrical conductivity measurements

ASTM E376-19



geometrical defects
stress induced deformation

ASTM E1476
E556



Metals Identification, Grade Verification, and Sorting

AM specific requirements

- Positioning the sensors as required by the inspection procedure
- Verifications needed: No impact on fabrication process, No spurious signals caused by cable motion and recoater vibrations
- Lift-off – frequency calibration procedure
- Additional calibration samples for subsurface pores
- Impact of the residual stress on the defect assessment
- Features of the software used to analyse the data and generate the report
- Cancelation of powder signal, when powder is over the sample
- [illegible]ction of pore/defect healing

In-process inspection standard for AM

ASTM 3166, 52930, 52906, 52905

AM guides, practice, standards

Existing standards

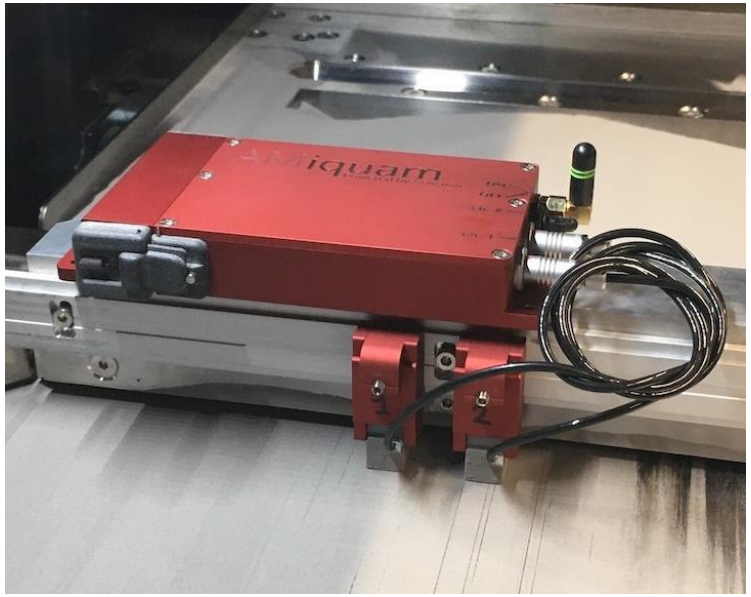
ASTM 3166: Standard Guide for Nondestructive Examination of Metal Additively Manufactured Aerospace Parts After Build:

52930:Additive manufacturing — Qualification principles — Installation, operation and performance (IQ/OQ/PQ) of PBF-LB equipment

52906: Non-destructive testing — Intentionally seeding flaws in metallic parts

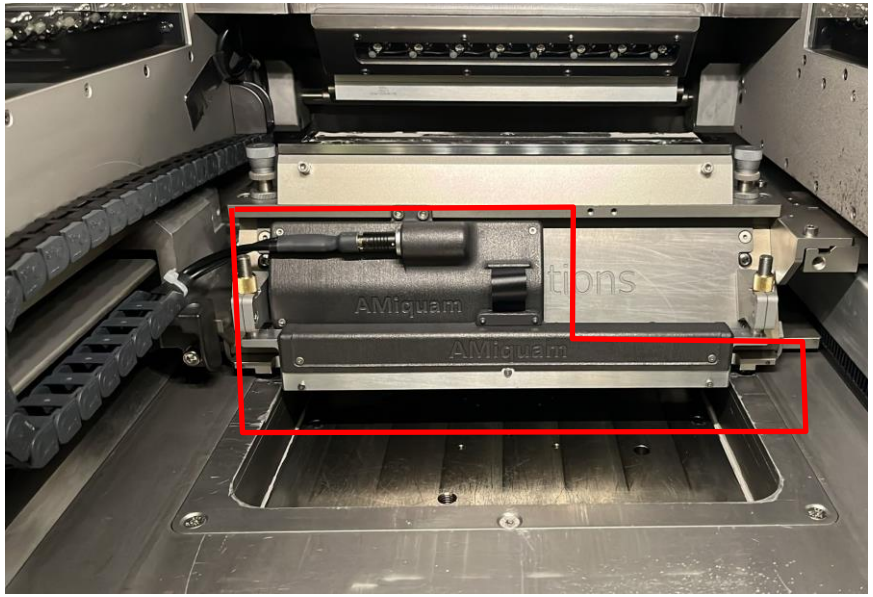
52905: Non-destructive testing and evaluation — Defect detection in parts

In situ ECT for LPBF



W1-2/4 sensors

Validation, screening

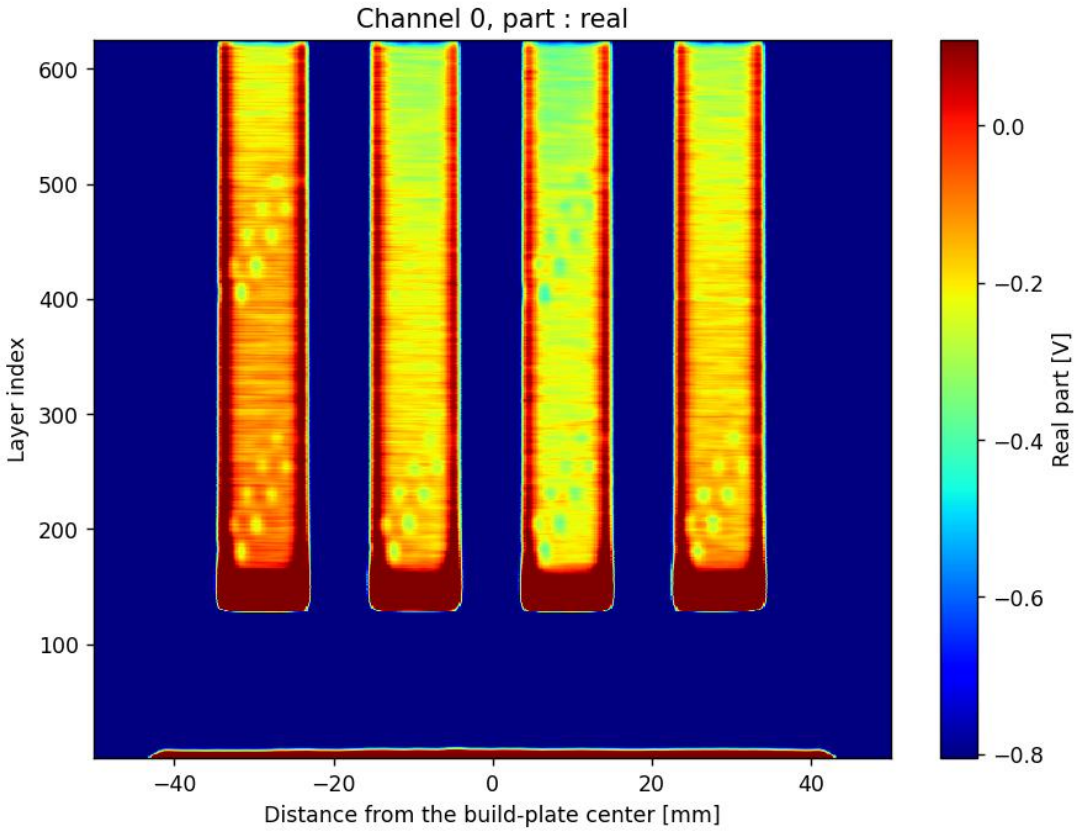


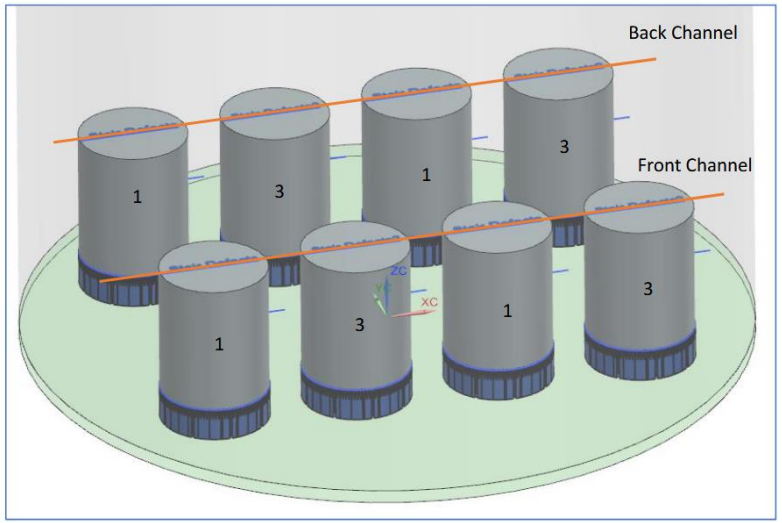
W2-ECA

Machine agnostic
Fully reversible installation
No penalty on process
Compatible with multilaser
Modular design (n x 240mm)

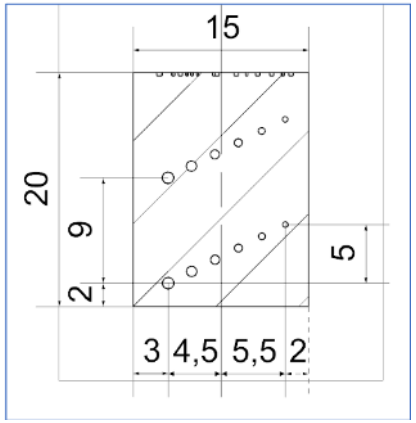
Conservative design
Focus on integration

Defect detection



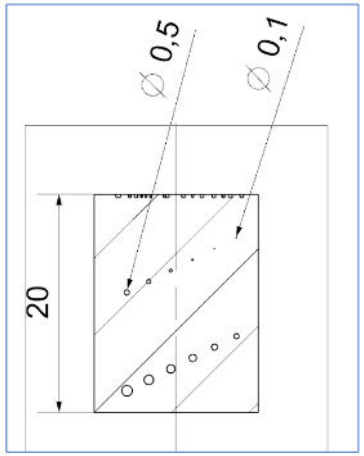


Type 1



Defects from 1mm to 0.5mm

Type 3



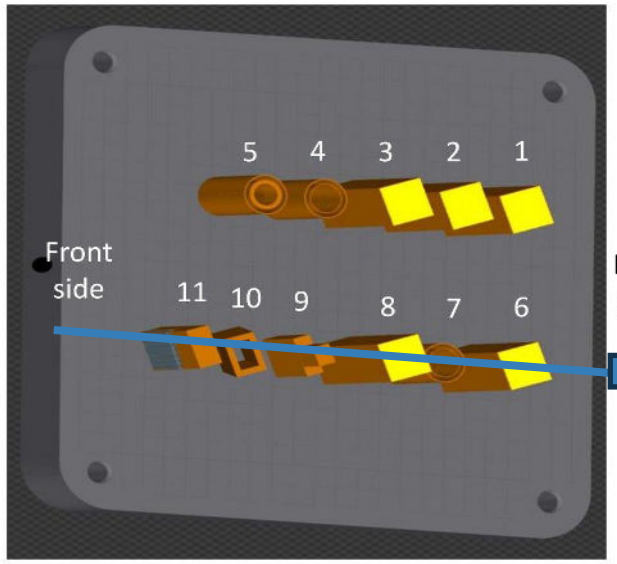
Defects from 1mm to 0.1mm

Results: Defect detection

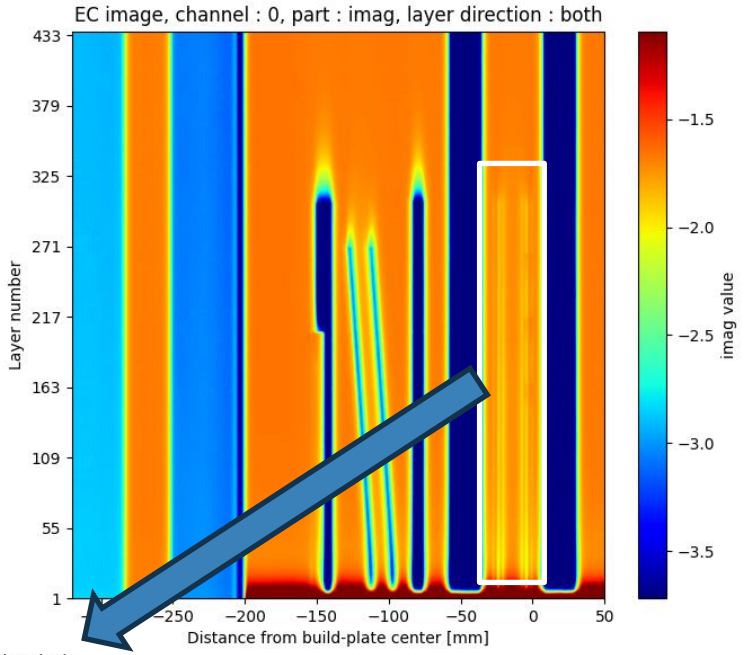
LPBF process based on digital information

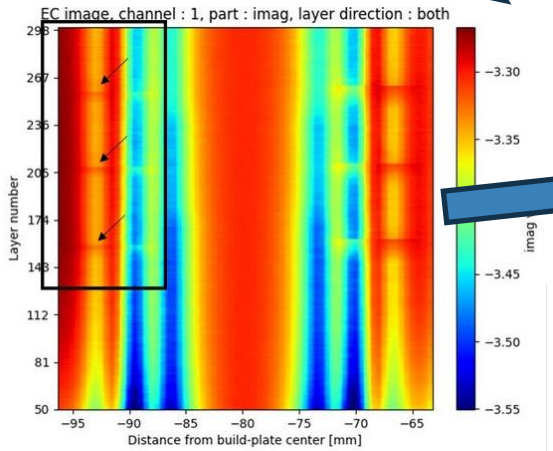
ECT images are strongly redundant

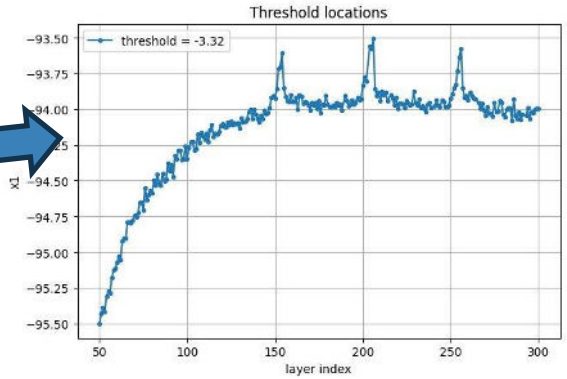
Indications can be selected with algorithms



Design of the full fabrication





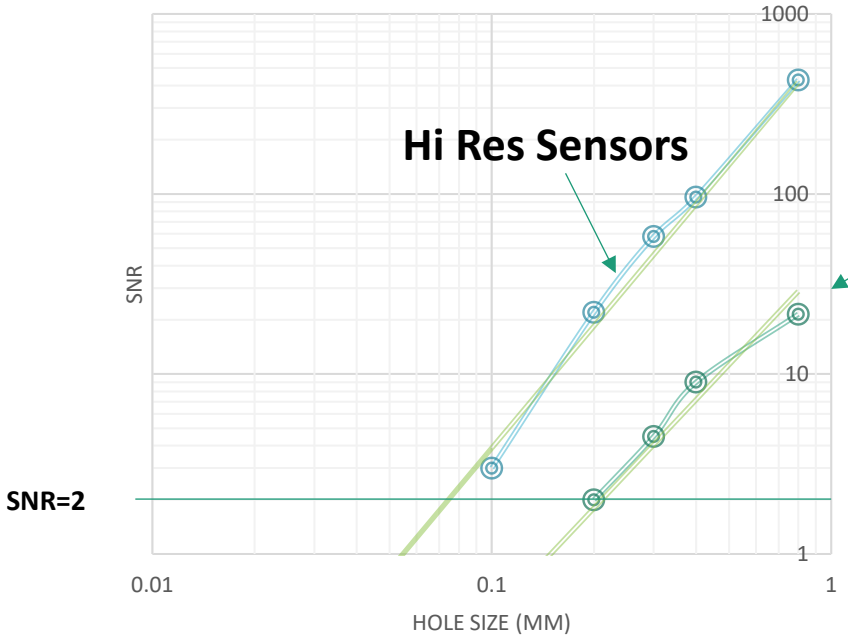


Sensitivity

AMiquam sensors/electronics sensitivity to pore (mm), conditions: milled/casted samples

- 0.2mm (sensor: ABS56)
- <0.1mm (sensor: SR25) pore detection

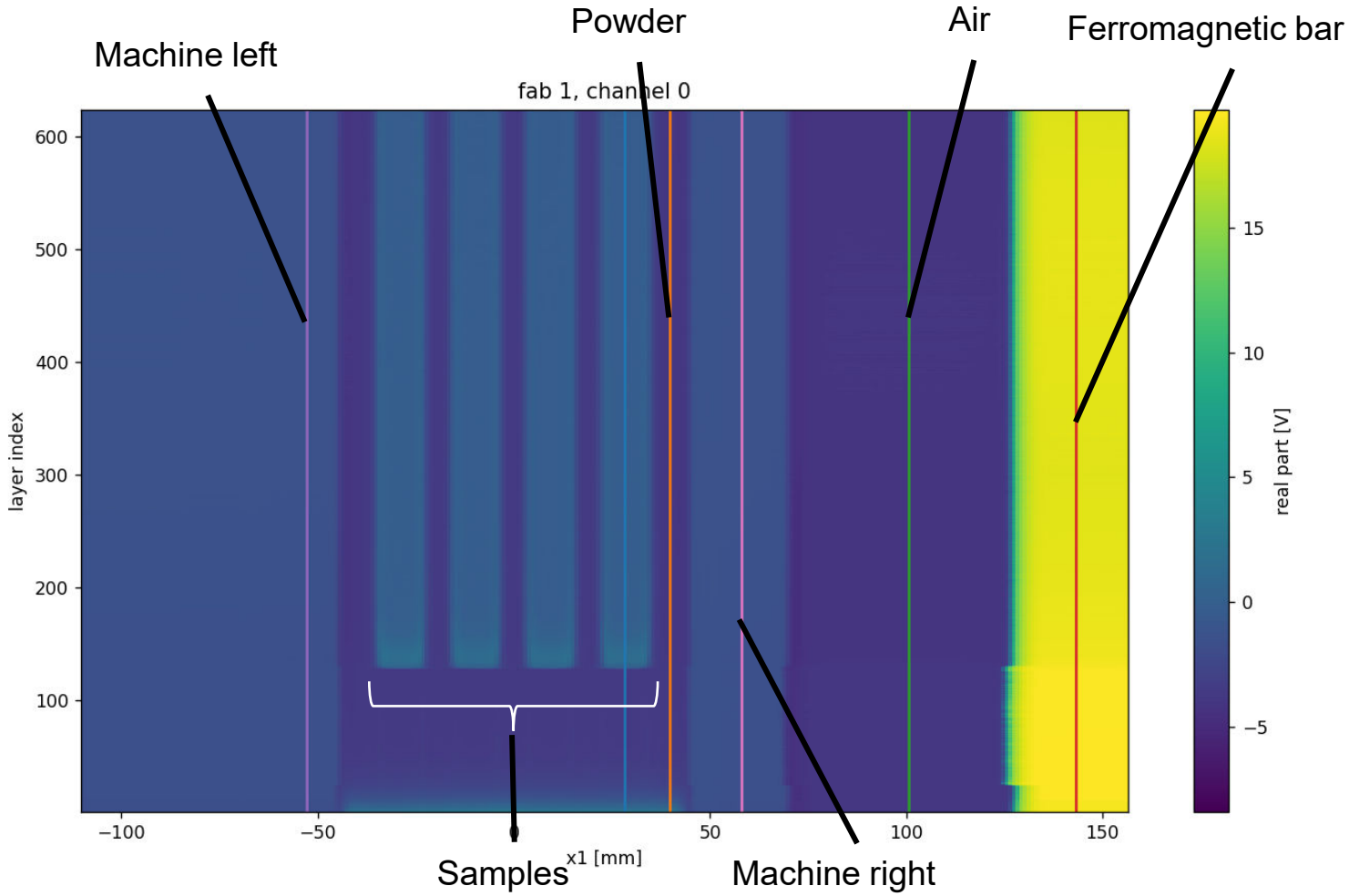
Sensitivity (Signal to noise Ratio) in ideal case:



Sensors used in products W1/W2

Sensitivity (SNR = 2)	Sensor used in product W1/W2	High res sensors (not in products yet)
Sensitivity (flat homogeneous samples)	0,2 mm	0,07 mm
Sensitivity (in situ inspection)	0,4 mm	?

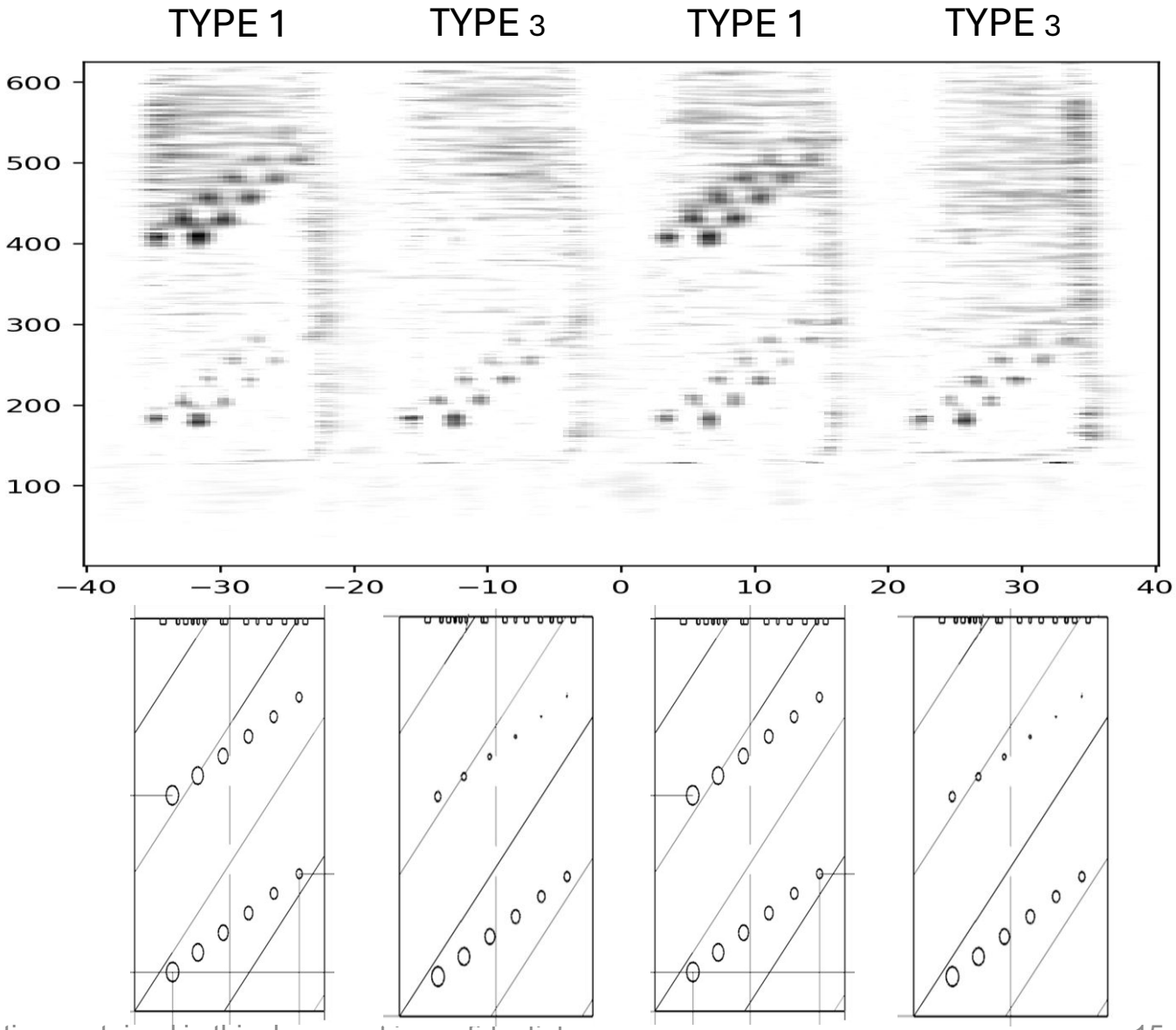
EC cross section view (channel 0)



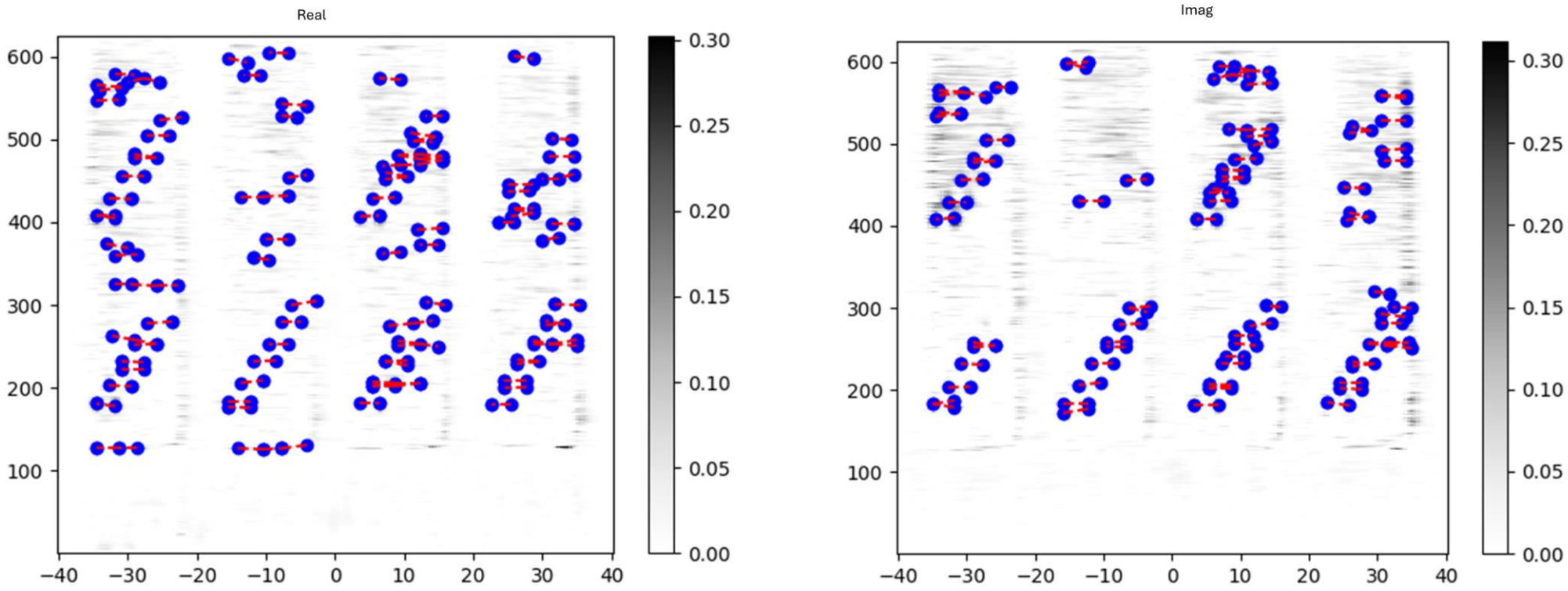
Feature analysis and detection

Algorithms transform the complex EC signals into:

1. relevant features
   dark dots
2. process variations
   thin horizontal lines



Spatial correlation of detected features



Each pore causes a double dot structure related to the "point spread function" of the sensor.
This structure can be used to separate the defect from the process variations ("background noise").

Detection limits

Some 0.2mm pores show the double peak structure

Further work

- Improvement of measurement parameters
  - Frequency, data acquisition rate, sensor design
- Data processing
  - Phase optimisation, deconvolution
- CT scans to assess the "quality" of the pores

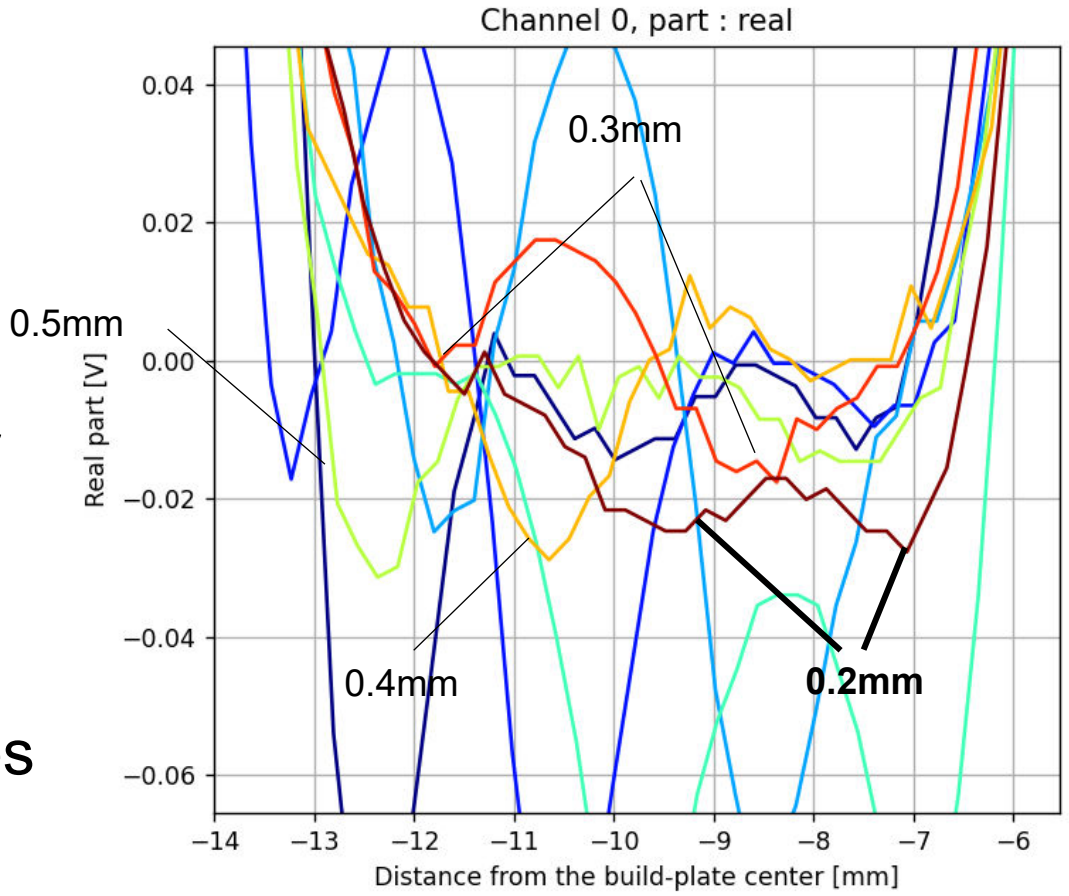
Pore diameter [mm]	Feature size [mV]
1	96
0.9	94.6
0.8	80
0.7	86.7
0.5	29.3
0.4	36.4
0.3	17.1
0.2	10

Detection limits

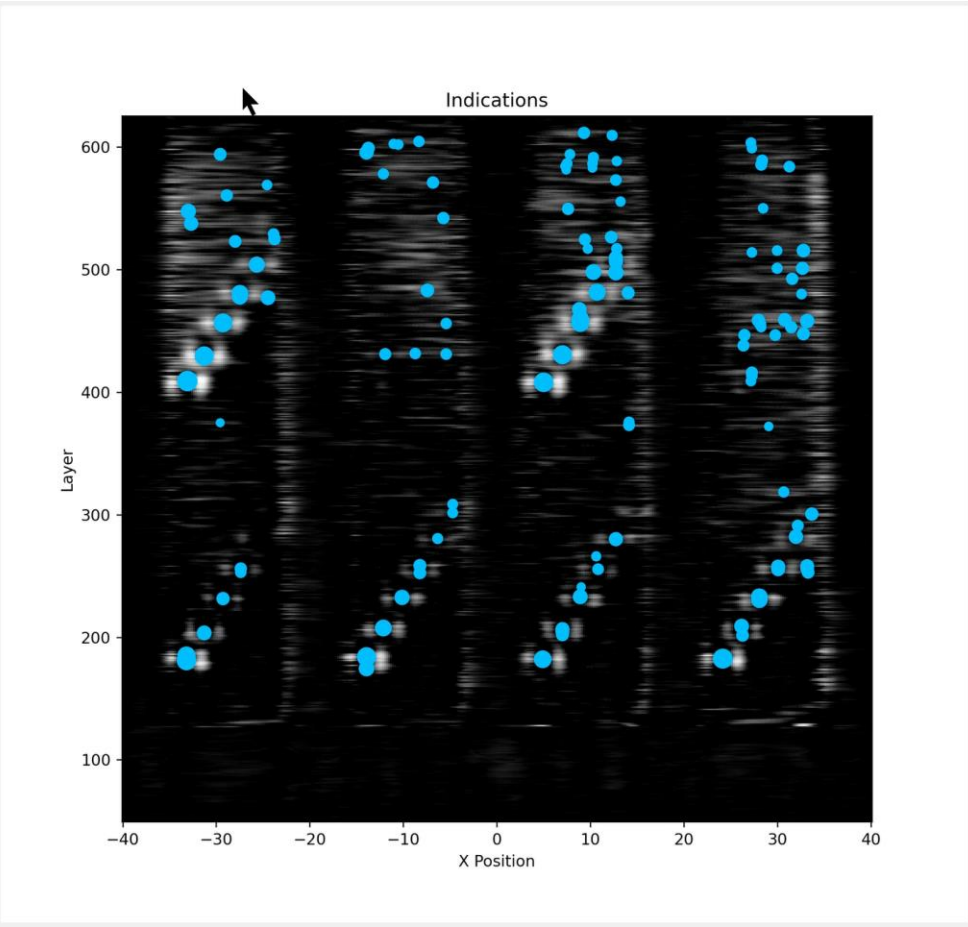
the double peak structure of 0.2mm pores is detected in the spatial EC traces

Further work

- Improvement of measurement parameters
  - Frequency, data acquisition rate, sensor design
- Data processing
  - Phase optimisation, deconvolution
- CT scans to assess the "quality" of the pores



Indications with size estimation



x	Layer	Value	Size Estimation
-33.08	409.0	0.2895	1.0
24.16	182.5	0.273	0.943
-33.18	181.0	0.2625	0.9067
5.01	408.0	0.262	0.905
-31.28	429.5	0.252	0.8705
-13.93	184.0	0.251	0.867
7.02	430.5	0.246	0.8497
-29.27	456.5	0.2415	0.8342
-33.18	185.0	0.2235	0.772
8.92	456.5	0.2205	0.7617
4.91	182.0	0.212	0.7323
8.92	459.5	0.2075	0.7168
10.73	481.5	0.196	0.677
-27.47	480.5	0.1955	0.6753
-12.13	207.5	0.188	0.6494
28.07	233.0	0.1865	0.6442
28.07	230.5	0.1805	0.6235
-27.47	478.0	0.173	0.5976
-25.66	504.0	0.1725	0.5959
10.33	498.0	0.1655	0.5717
-13.93	174.5	0.163	0.563
12.73	497.5	0.1585	0.5475
-10.13	232.5	0.1545	0.5337
-32.98	547.5	0.154	0.532
8.92	233.0	0.1455	0.5026
26.17	209.0	0.144	0.4974
-31.28	203.5	0.144	0.4974
-24.46	477.0	0.142	0.4905
8.82	467.5	0.1385	0.4784
31.98	282.0	0.135	0.4663
-32.68	537.5	0.1345	0.4646
33.18	458.0	0.134	0.4629
12.73	509.5	0.133	0.4594
-13.93	595.5	0.133	0.4594
30.08	257.5	0.1325	0.4577
7.02	206.5	0.1315	0.4542
12.73	506.5	0.131	0.4525
12.73	280.0	0.13	0.4491
30.08	255.5	0.1275	0.4404
7.02	204.5	0.1275	0.4404
33.18	258.0	0.126	0.4352
33.18	256.0	0.121	0.418
30.78	459.0	0.12	0.4145
-7.42	483.0	0.119	0.4111
32.78	515.5	0.1175	0.4059
33.68	300.5	0.114	0.3938
27.97	458.5	0.114	0.3938
-29.27	231.5	0.1135	0.3921

A list of indication is automatically generated to be reviewed by a certified inspector
The blue dots correspond to the location of the defects based on the deconvolution of the white dot pairs

Thanks!

AMiquam SA
2, route Cité Ouest
1196 Gland, Switzerland