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Towards an integrated sensor system control for direct laser melting

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University of Pisa Italy Department of Civil and Industrial Engineering

This presentation: www.lanzetta.unipi.it/research/am

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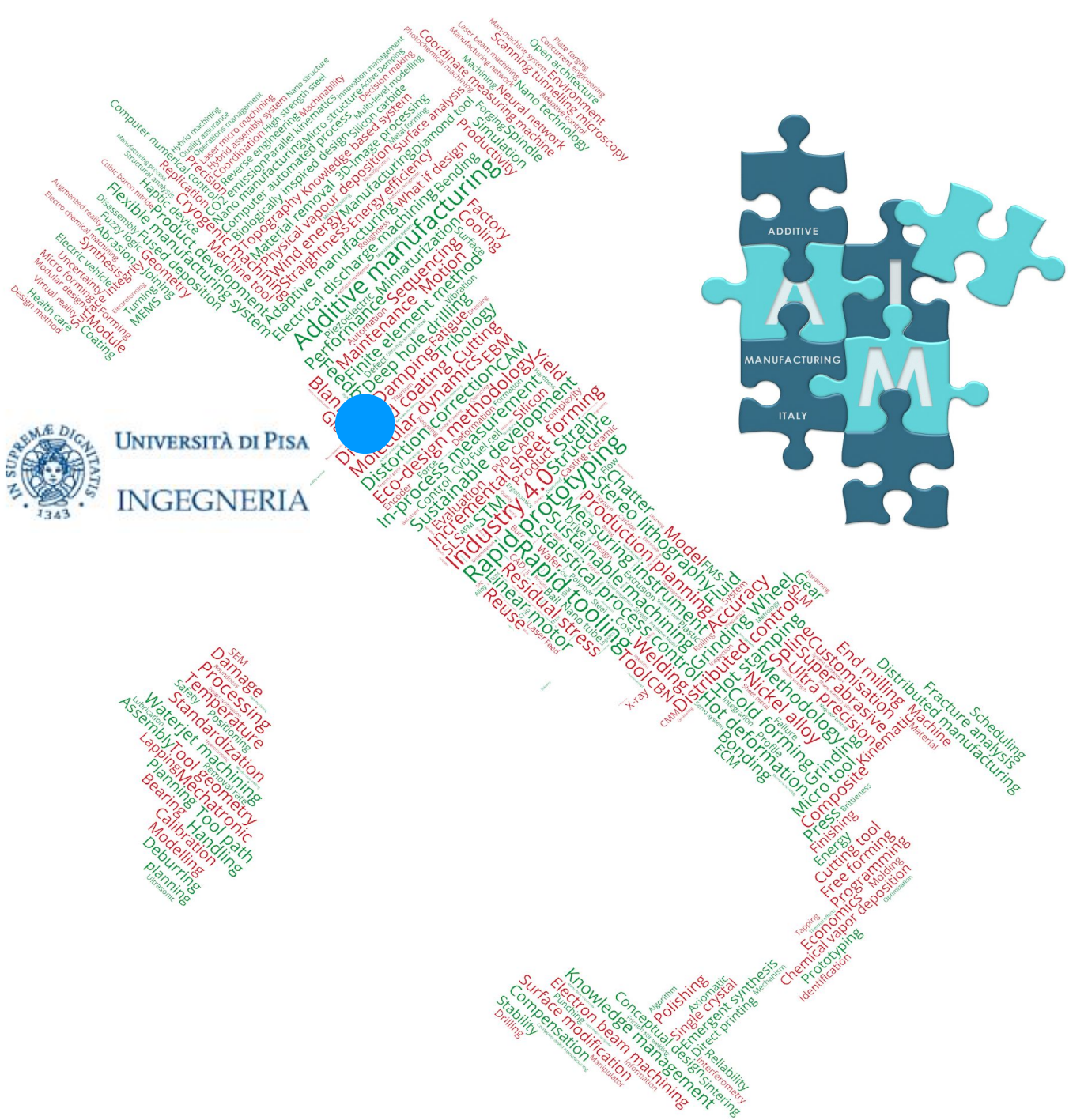
Towards an integrated sensor system control for direct laser melting



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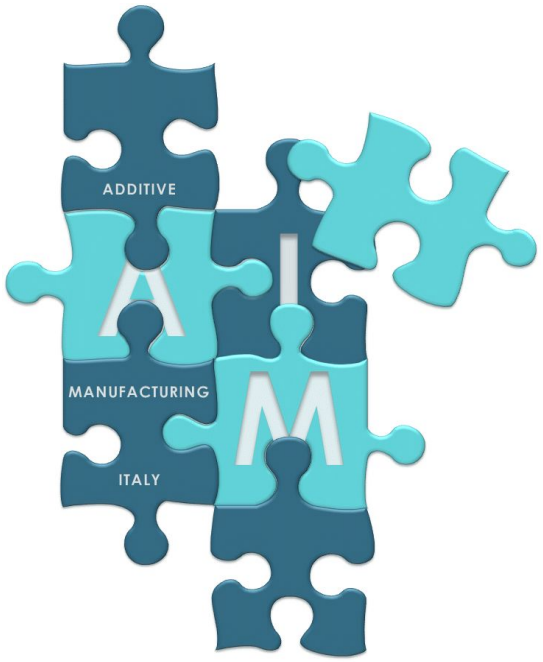

Additive Manufacturing Focus Group

Coordinator: prof. Michele LANZETTA

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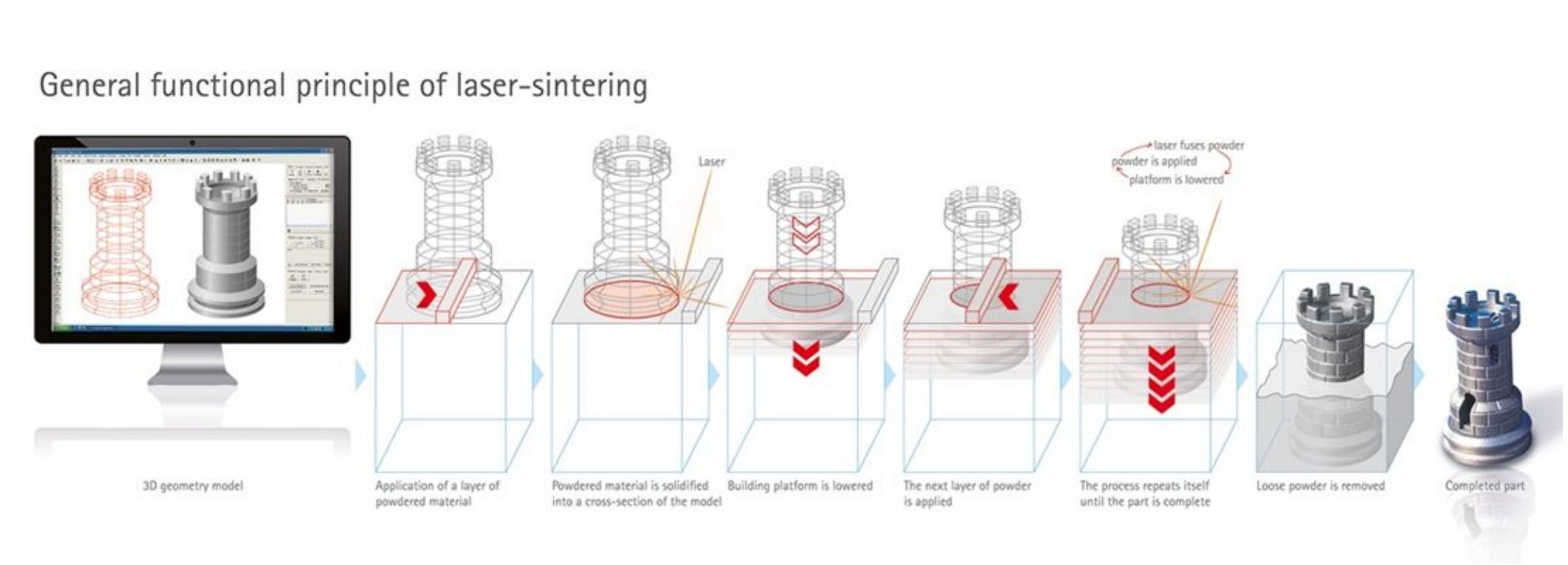
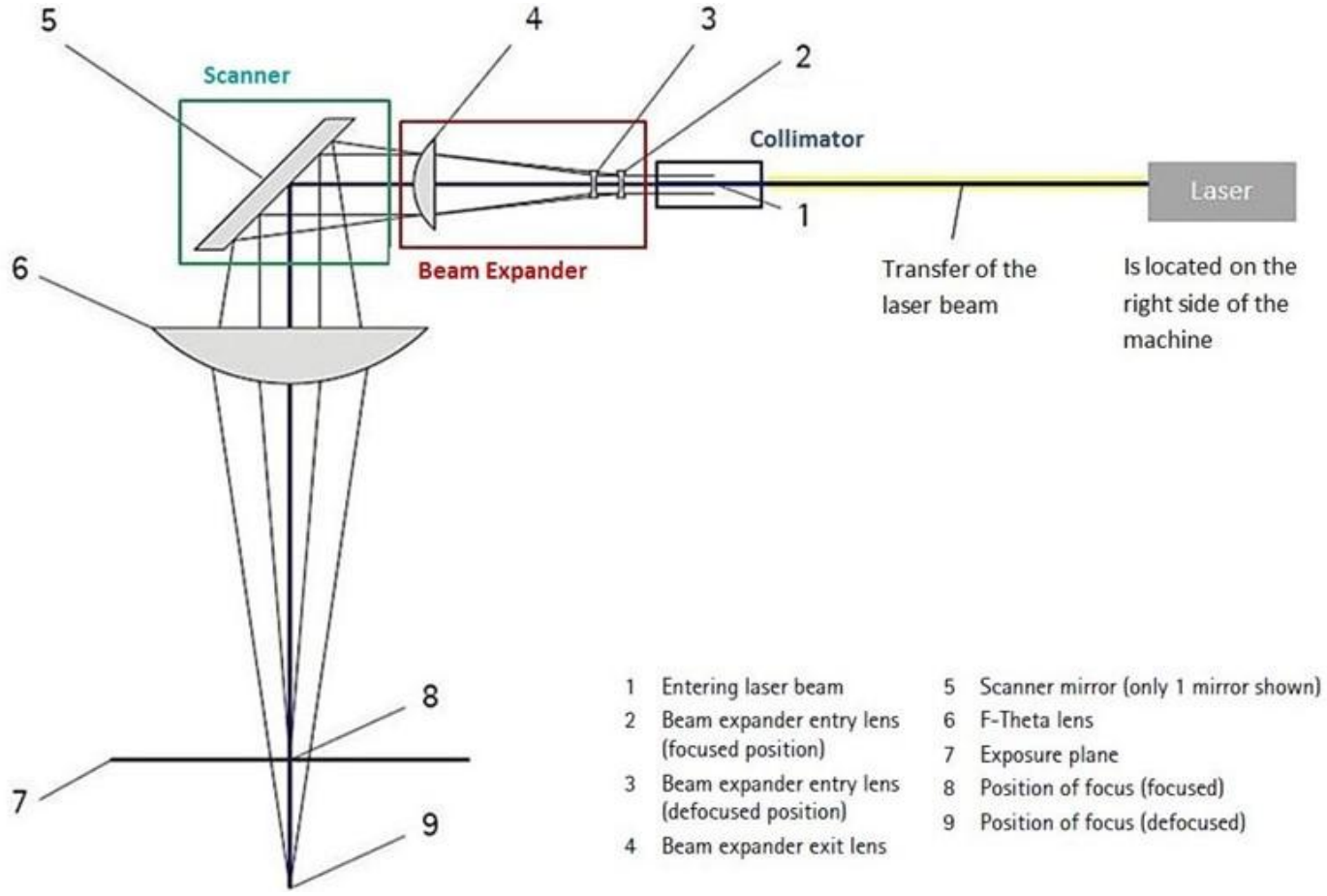
Direct Metal Laser Sintering (DMLS) Process



Direct Metal Laser Sintering (DMLS) Process

Optical system

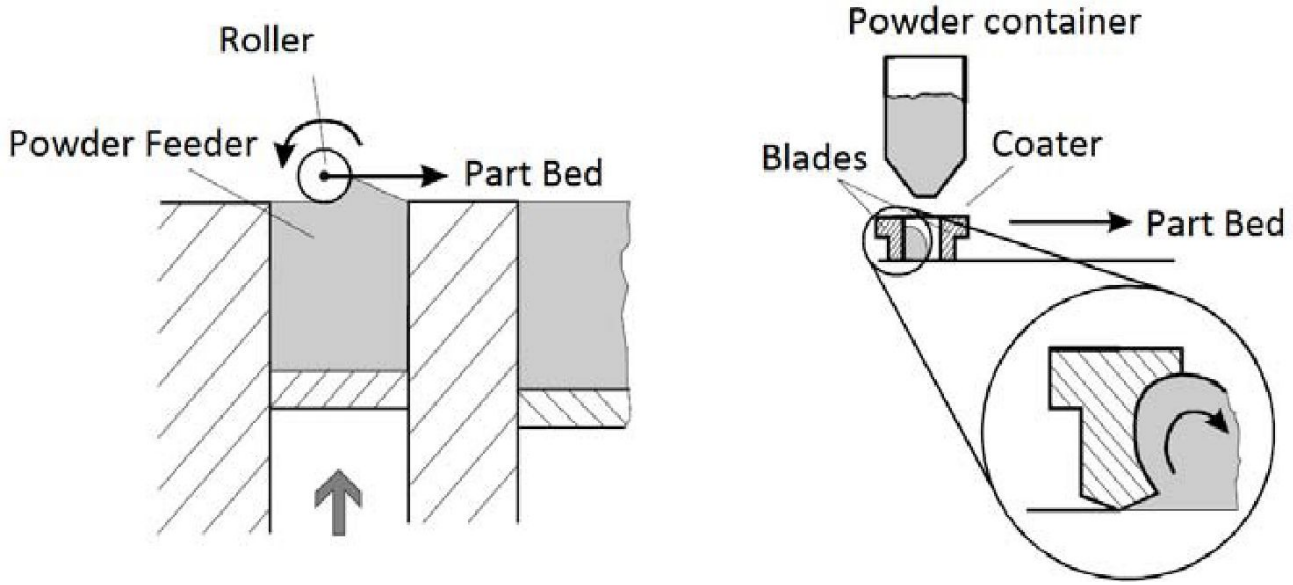
- Laser: Ytterbium 1064 nm
- Optical fiber: bring the radiation from the laser
- Collimator: collimate the laser radiation
- Beam expander: increase the beam diameter
- Scanner: with high dynamic mirrors to direct the beam
- F-Theta lens: focus the beam



Direct Metal Laser Sintering (DMLS) Process

Recoating system

- Today two different spreading system are present on the market
- A roller or a blade spread the powder on the bed

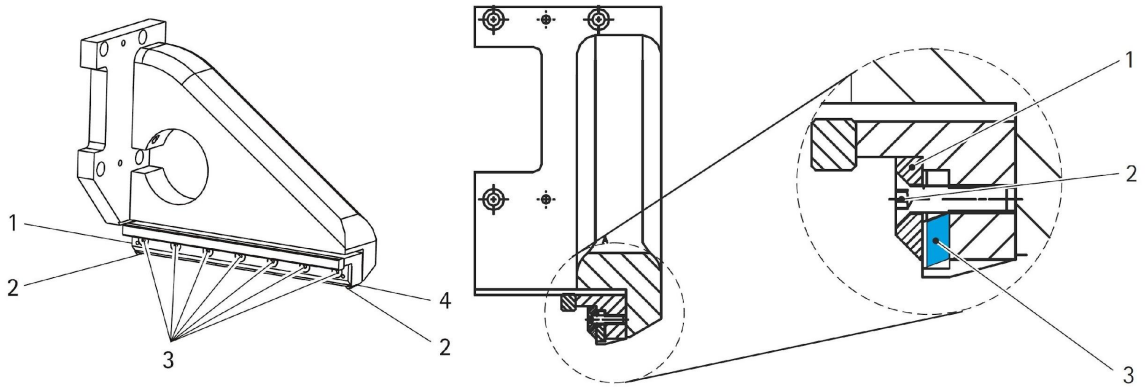


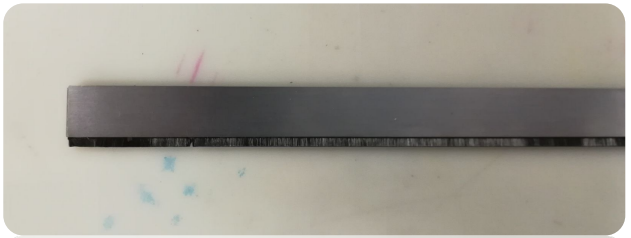
A. Amado et al. 2011

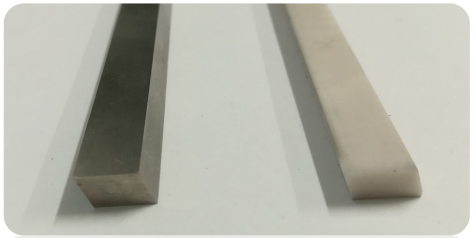
Direct Metal Laser Sintering (DMLS) Process

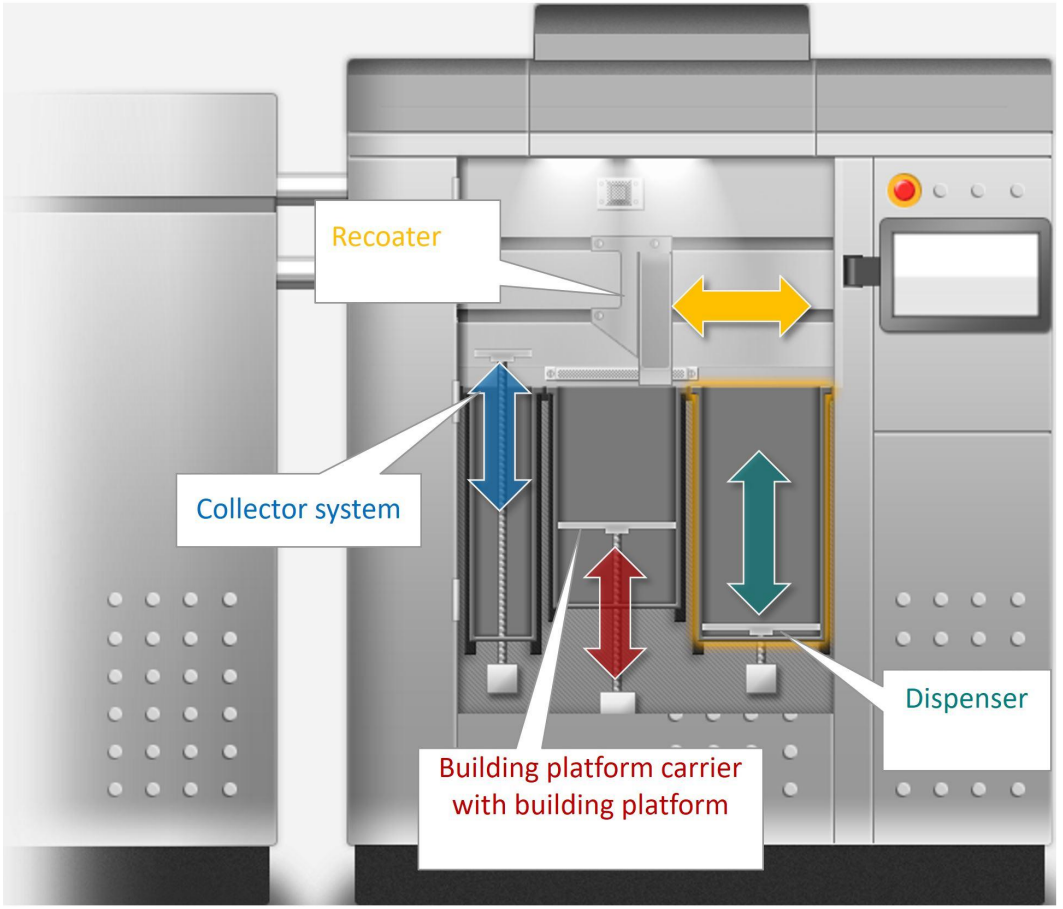
Recoating system

- 3 platform on EOS® M280 e M290
- Recoater with changeable blade





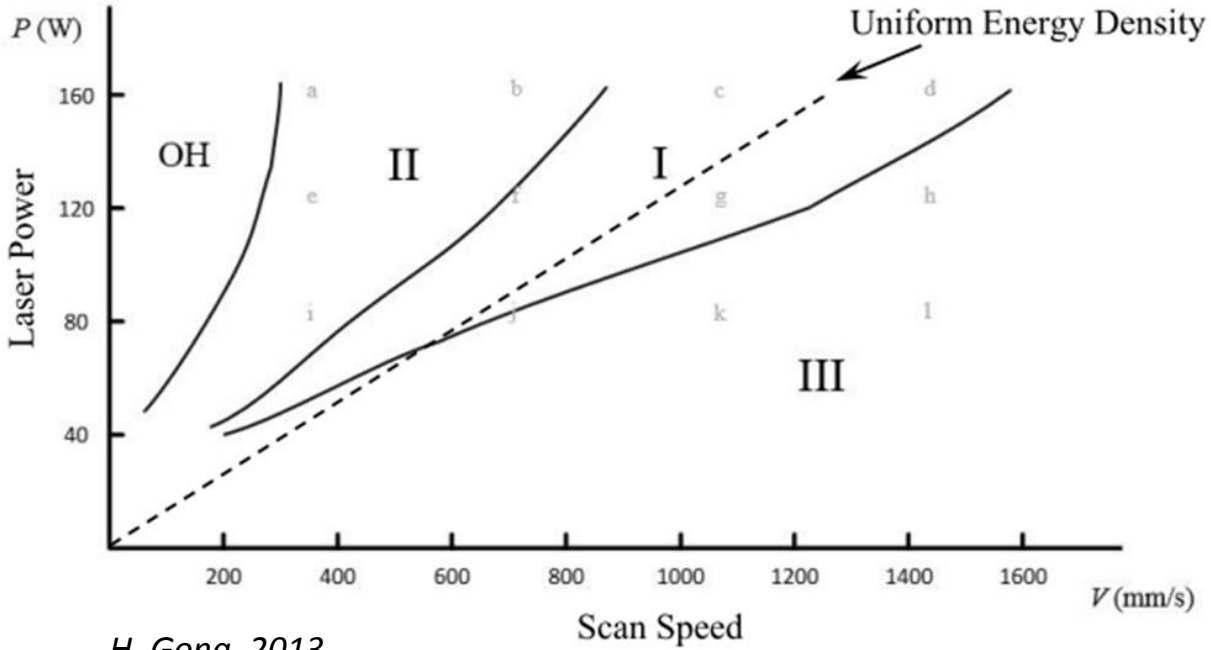




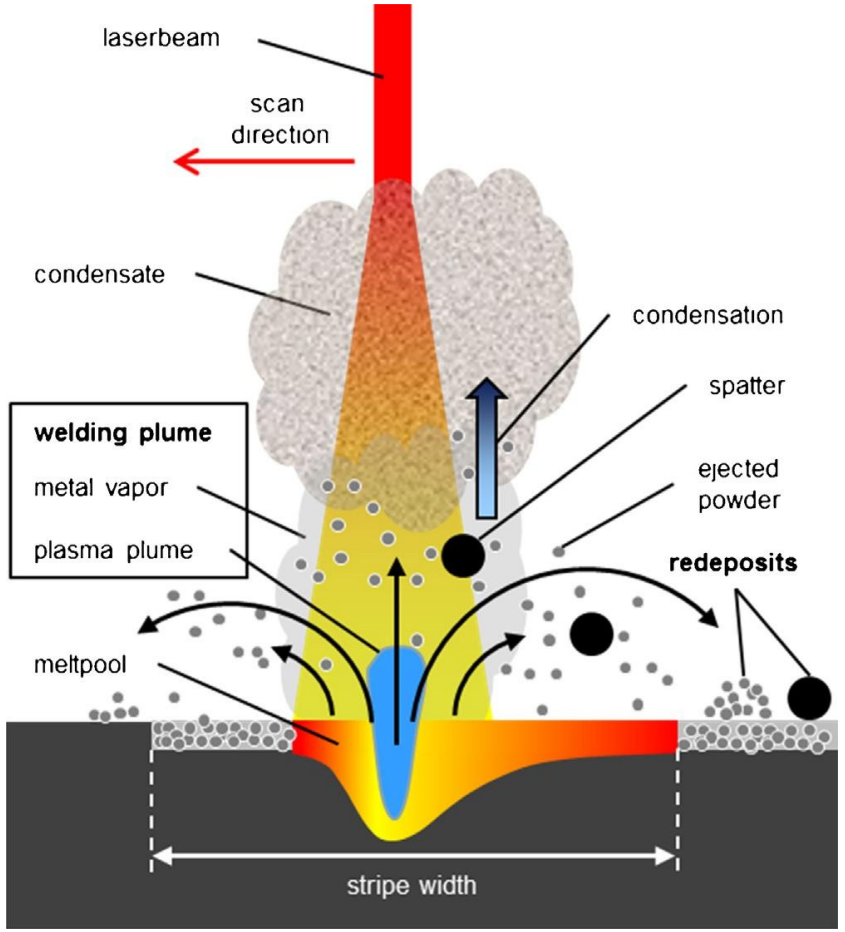
Direct Metal Laser Sintering (DMLS) Process

Key hole process

- Main process parameters: speed, laser power, hatch distance
- Emission of different types of products

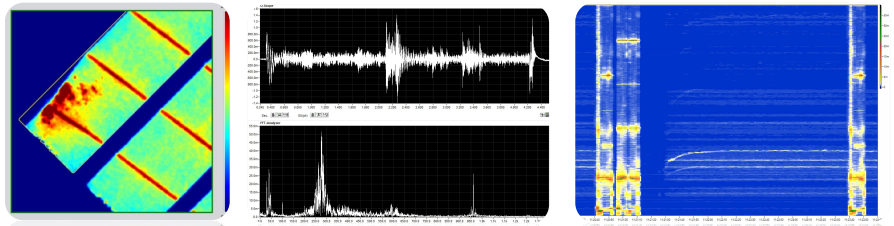


H. Gong, 2013

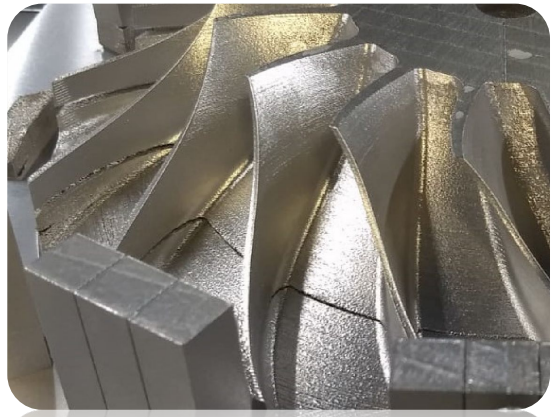


A. Ladewiga et al. 2016

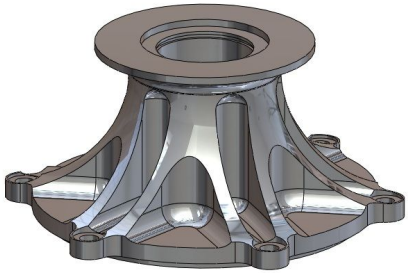
Defects classification

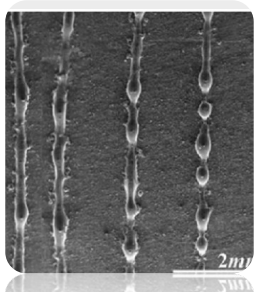


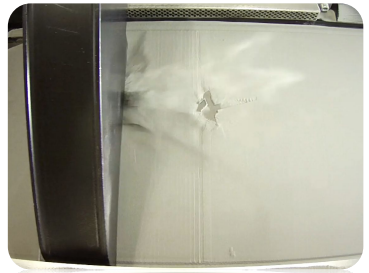
In situ monitoring

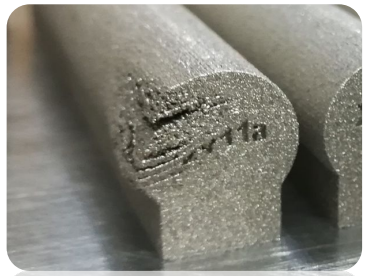


Defect sources → Process defects → Part defects



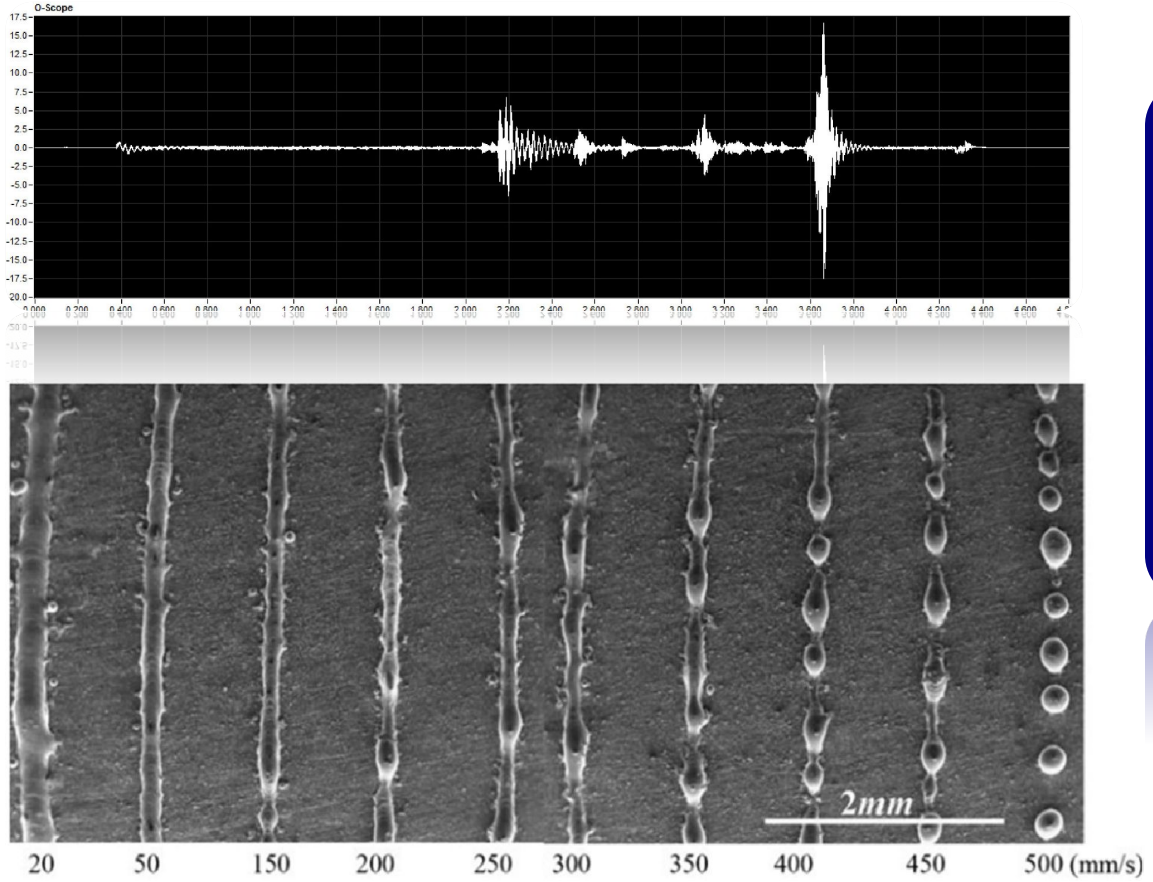




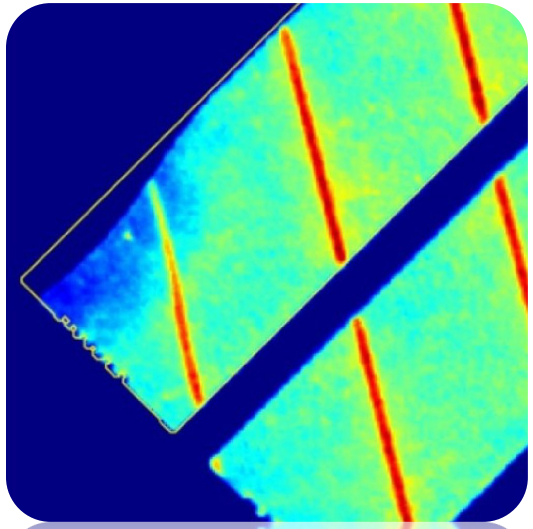


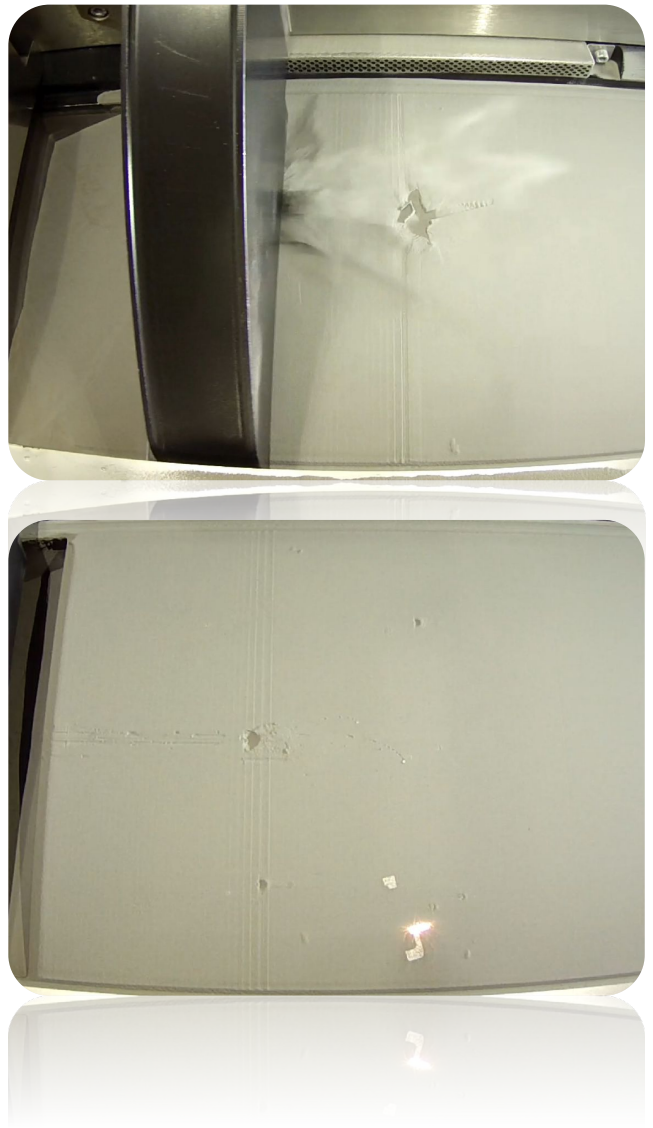
Defects classification

Process defects



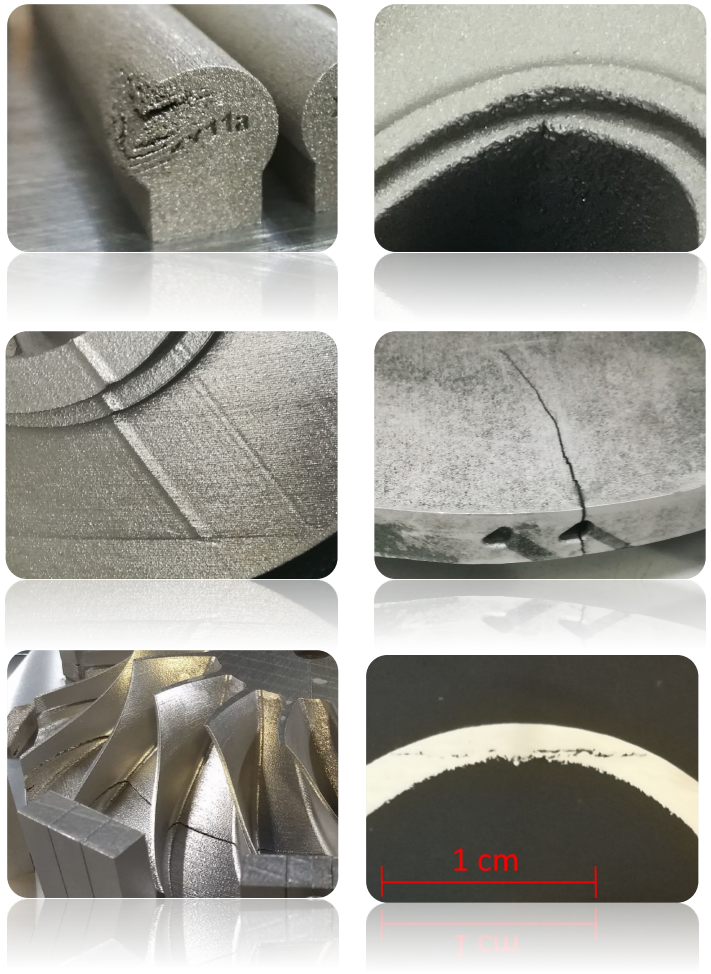
R. LI et al. 2012





Defects classification

Part defects



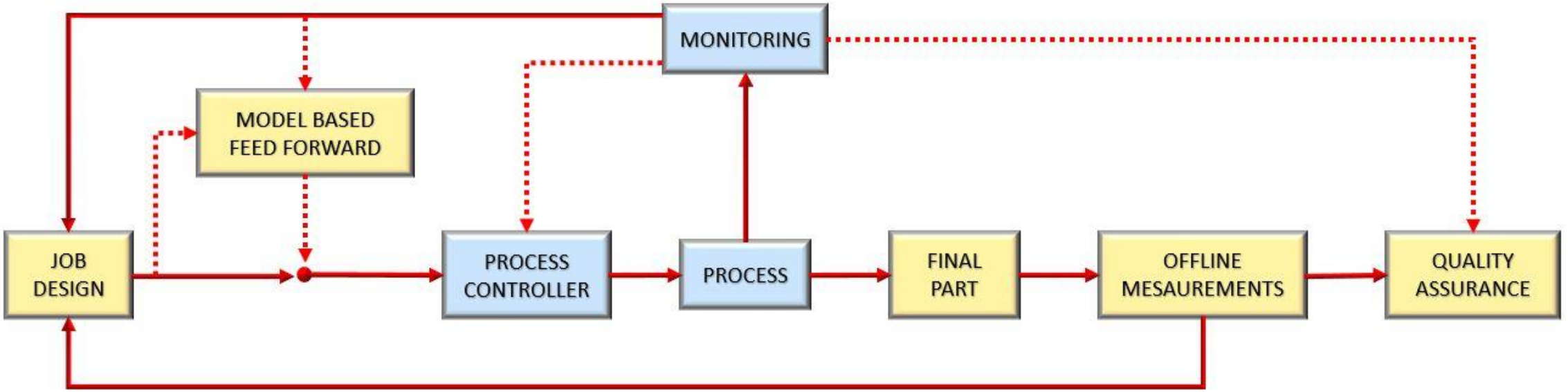
Process defects	Part defects					
	Incompleted parts	Geometric defects	Surface defects	Residual stress, cracks and delamination	Porosity	Microstructural inhomogeneity and impurity
Powder bed						
Lack of powder	●	●	●	●	●	●
Recoater collision	●	●	●		●	●
Recoater vibration			●			
Particle drag		●	●		●	●
Melting						
MeltPool instability			●		●	●
Spatter emission			●		●	●
Hot/Cold spot			●	●	●	●
Balling		●	●		●	●
Gas flow						
Instability			●		●	●
Dishomogeneity			●	●	●	●
Laser scanning						
Geom. deformation		●				
Lack of power			●		●	●
Thermal						
Deformation	●	●		●		

Defects classification

Defect sources

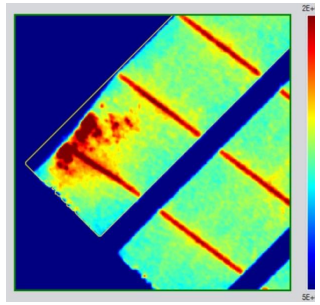
	Defects cause														
	Machine							Design							Powder
Process defects	Optical chain	Building platform	Machine calibration	Laser	Filtration system	Recoating system	Software	Layer thickness	Process parameters	Part orientation	Supports	Part shape	Powder bed parameters	Gas flow parameters	
Powder bed															
Lack of powder						●							●		
Recoater collision		●	●			●		●	●	●	●	●			
Recoater vibration		●				●		●	●		●	●	●		●
Particle drag		●				●		●	●		●	●			●
Melting															
MeltPool instability	●		●	●	●		●	●	●					●	●
Spatter emission			●	●	●		●	●	●					●	●
Hot spot			●	●	●		●		●		●	●		●	
Cold spot	●		●	●			●		●			●		●	
Balling			●	●			●	●	●						
Gas flow															
Instability					●									●	
Dishomogeneity					●									●	
Laser scanning															
Geom. deformation	●		●				●								
Lack of power	●		●	●	●		●								
Thermal															
Deformation		●			●			●	●	●	●	●		●	

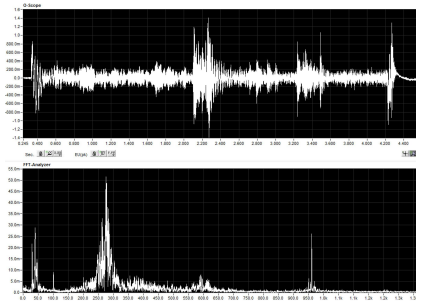
DMLS *in situ* Monitoring

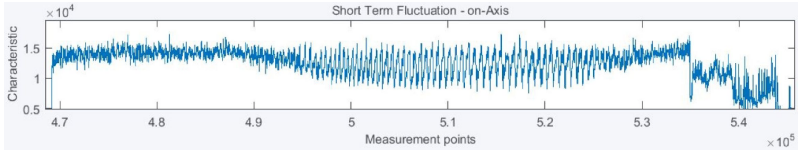


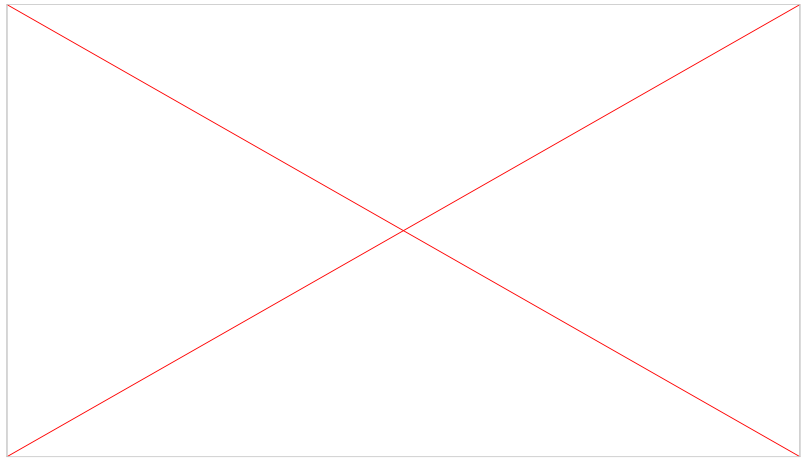
DMLS *in situ* Monitoring

Monitoring sensors





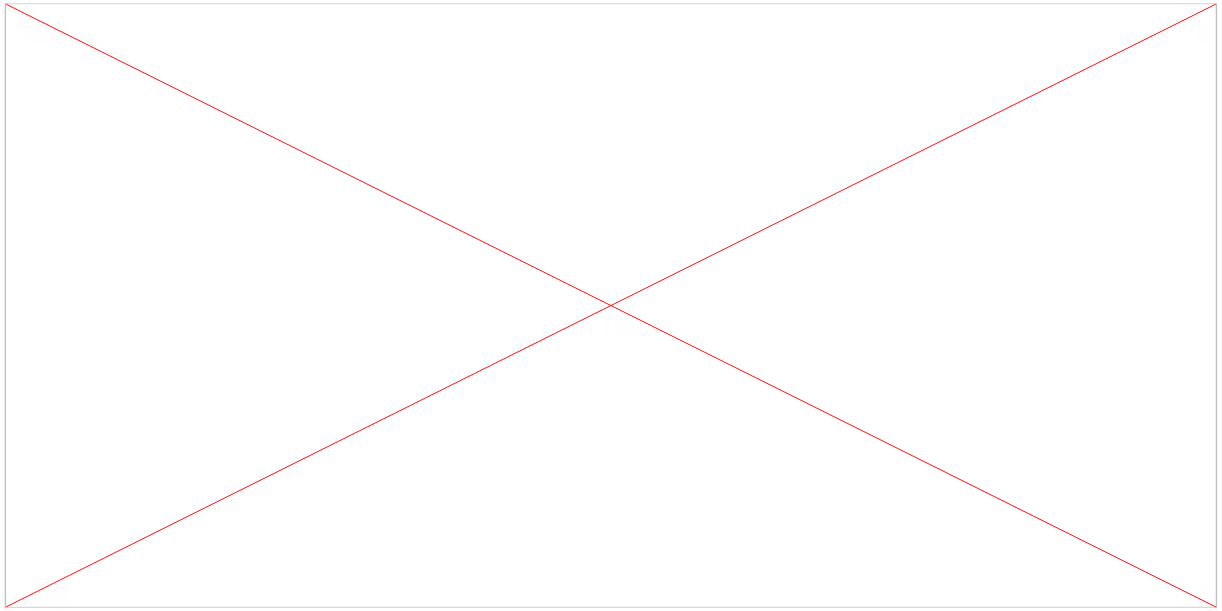


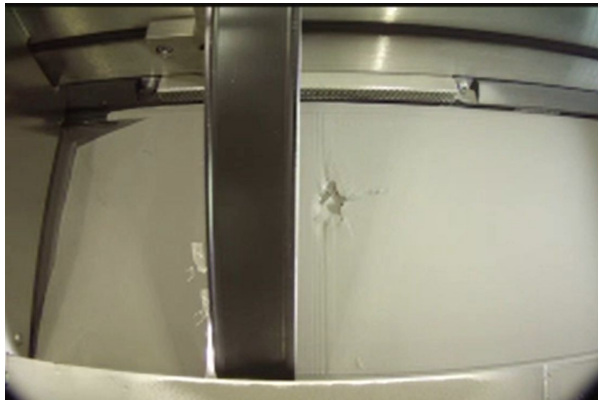


Process defects	Monitoring sensors: Accelerometer	Camera	OT	MeltPool
Powder bed				
Lack of powder	○	●	●	●
Recoater collision	●	●	○	○
Recoater vibration	●	○		
Particle drag		●	○	○
Melting				
MeltPool instability		○	○	●
Spatter emission		○	●	○
Hot/Cold spot		○	●	●
Balling		○	○	●
Gas flow				
Instability		○	○	●
Dishomogeneity		○	●	
Laser scanning				
Geometric deformation		●	○	
Lack of power		○	●	●
Thermal				
Deformation	○	○	○	○

Camera Monitoring

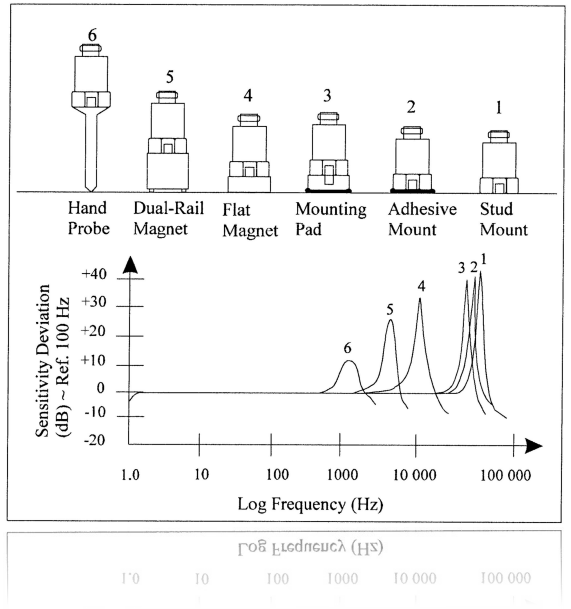
- Remote online visualization
- Recording system

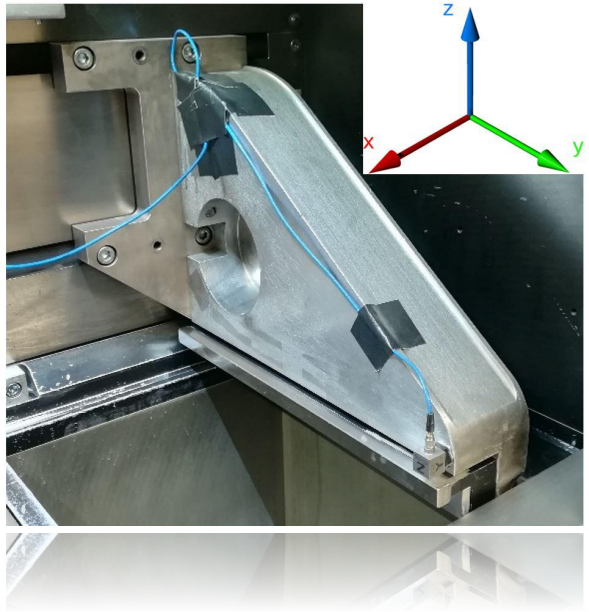


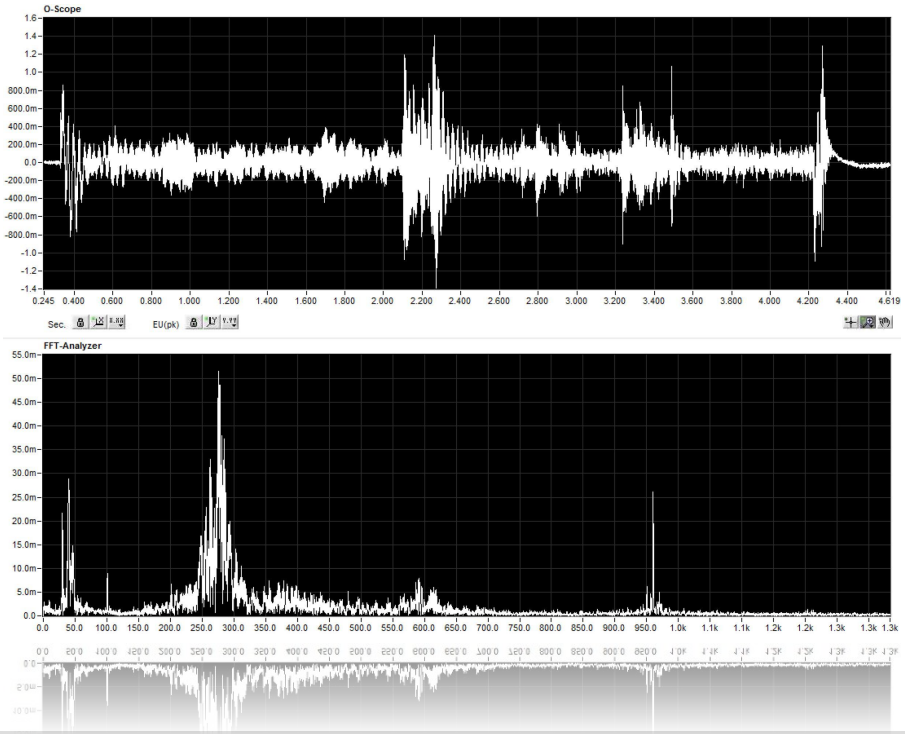


Accelerometer monitoring

- Recoating system vibration
- Powder bed quality analysis
- Threshold alarm setting



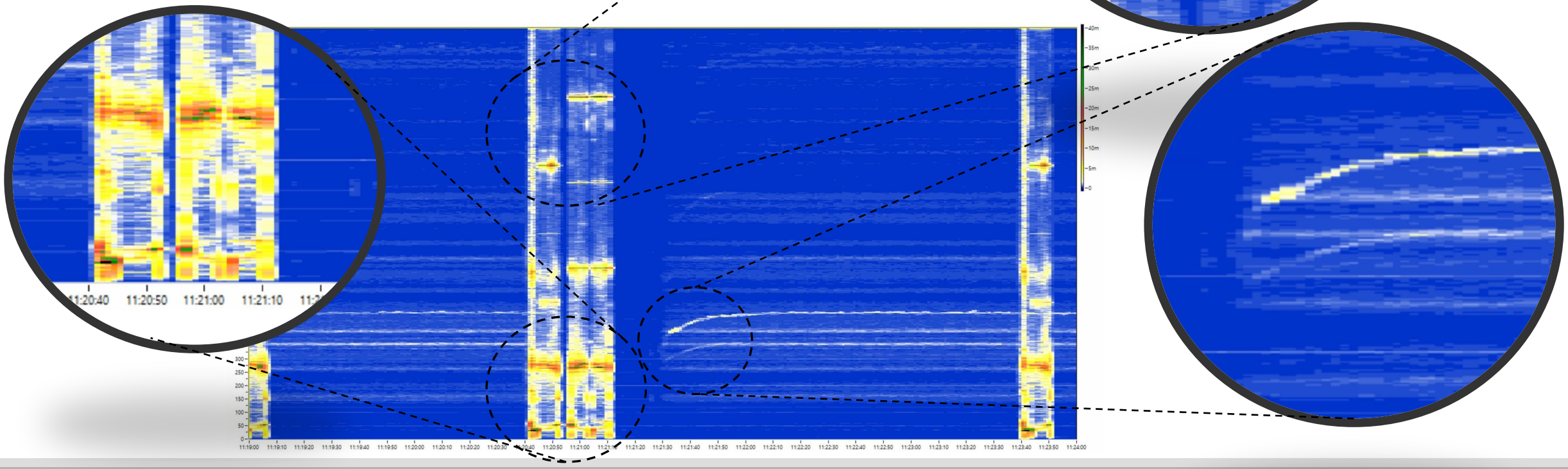




Accelerometer monitoring

Signal analysis

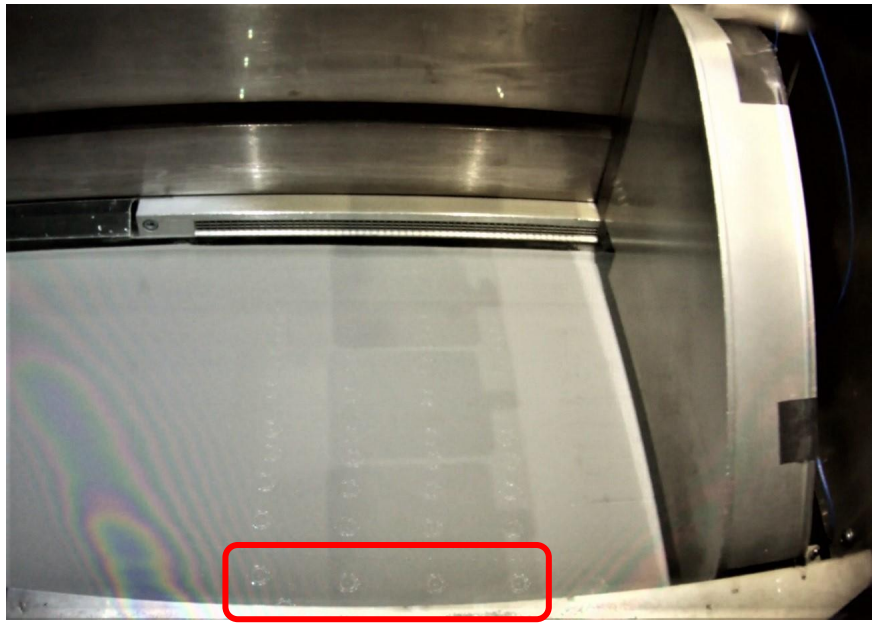
- Frequencies of recirculation fan identification
- Natural frequencies identification
- Engine frequencies identification

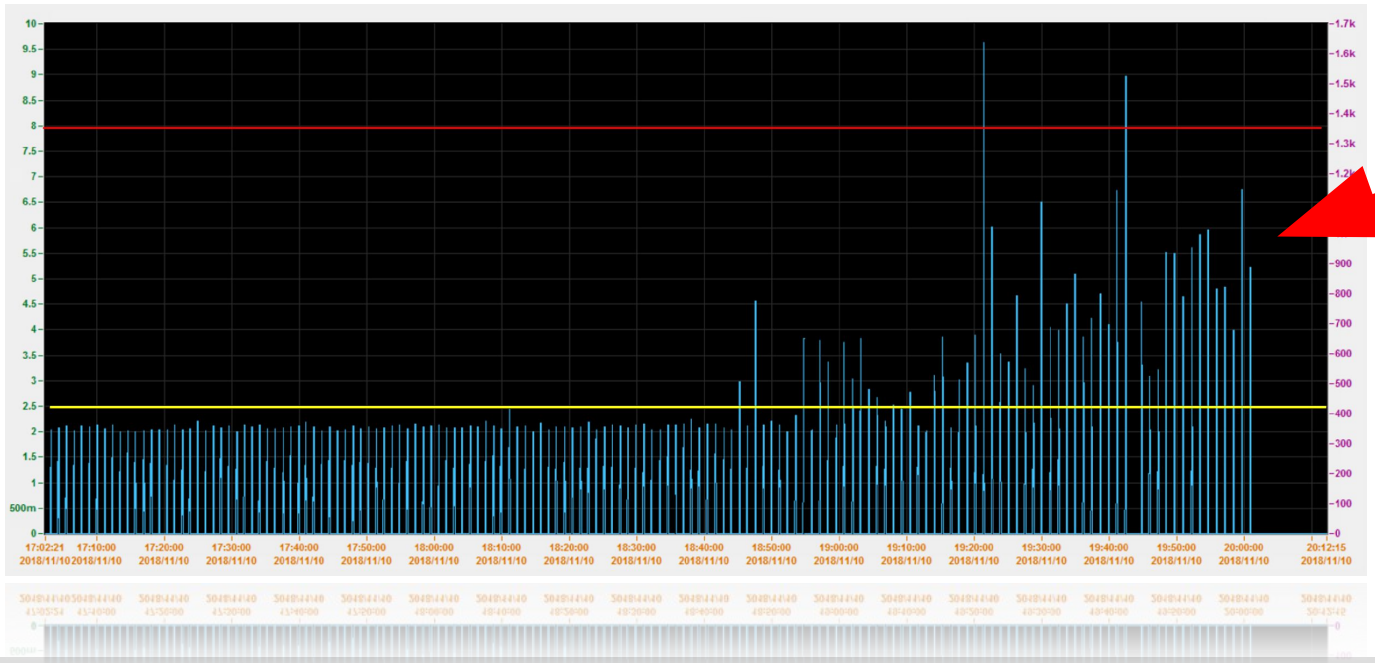


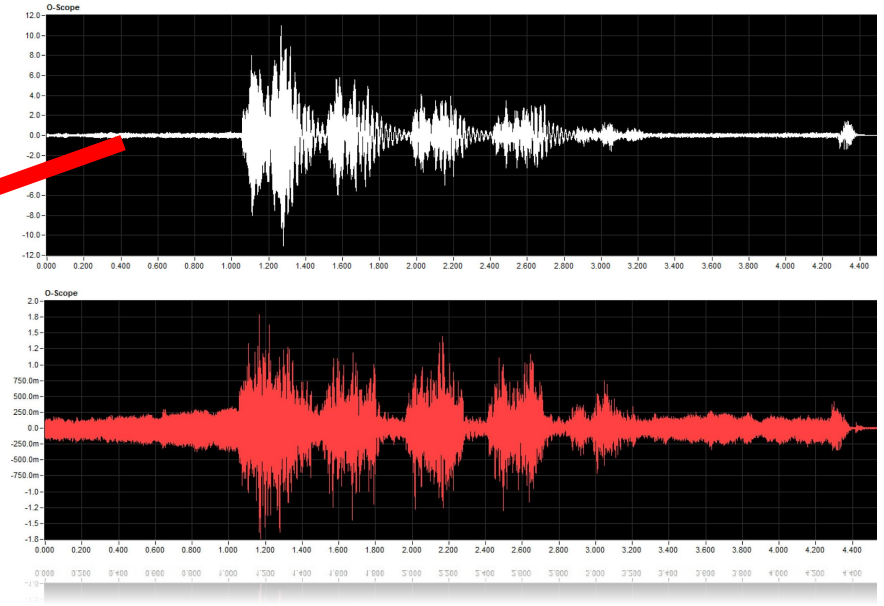
Accelerometer monitoring

Recoater system collision with parts

- Parts collision detection
- Acceleration max detection
- Threshold alarm setting to prevent recoater stop

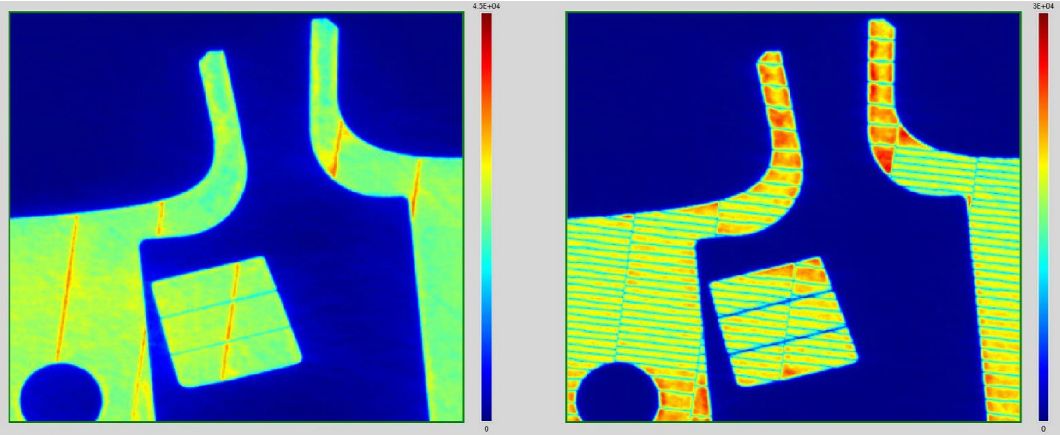


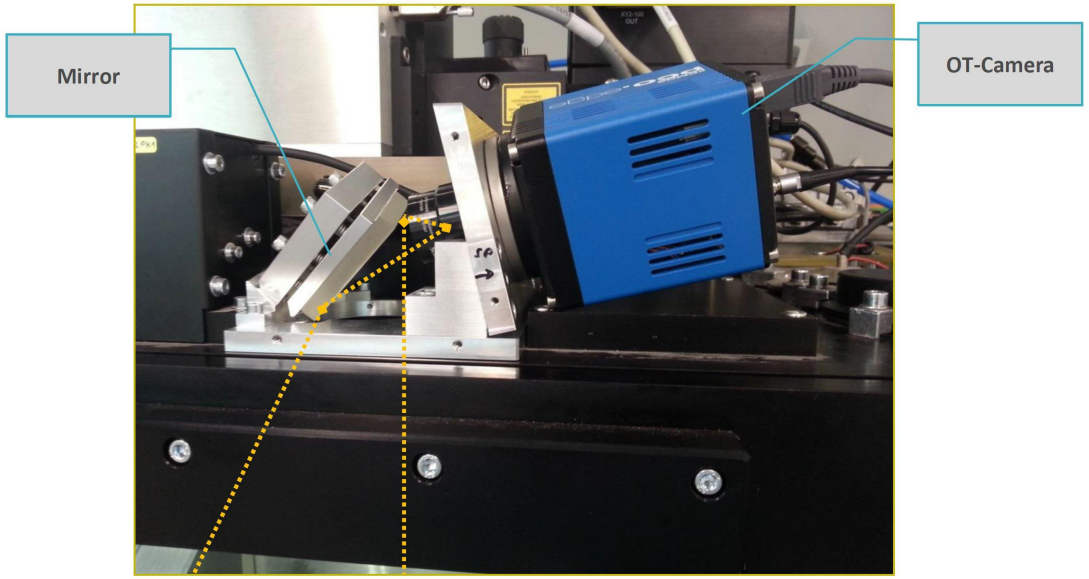




Optical Tomography Monitoring

- *CMOS Full HD Camera 10 fps*
- *Filter @960 nm*
- *Elaboration software with three different algorithms*

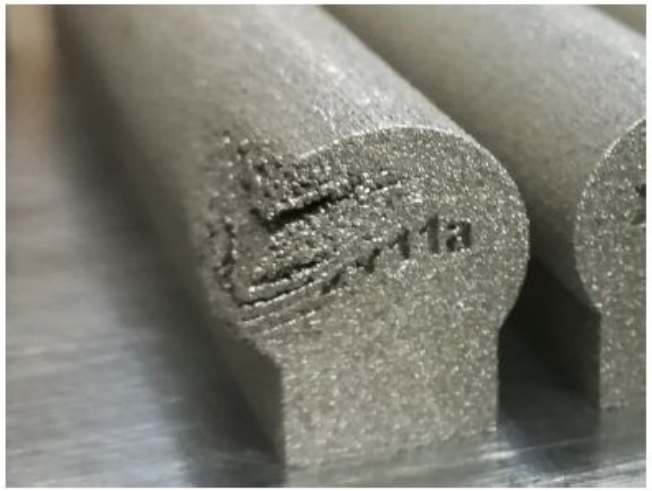




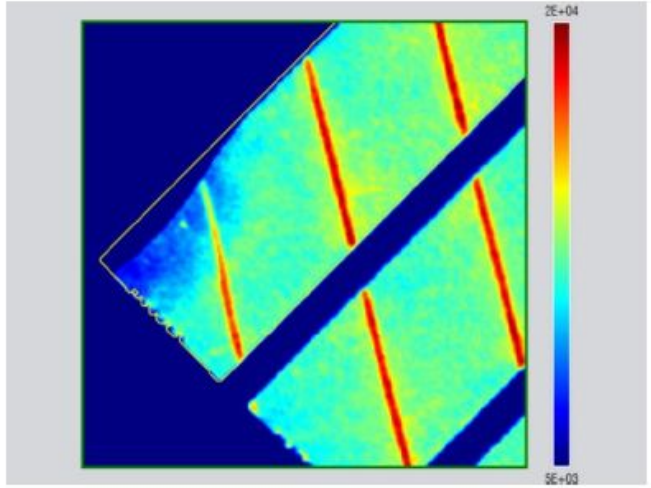
Optical Tomography monitoring

Lack of powder

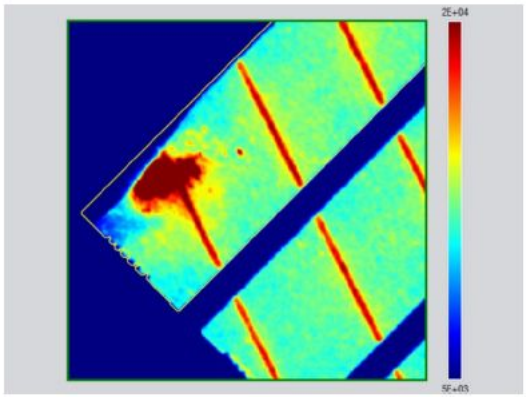
- Cold area during lack of powder
- Hot area during thicker layer melting



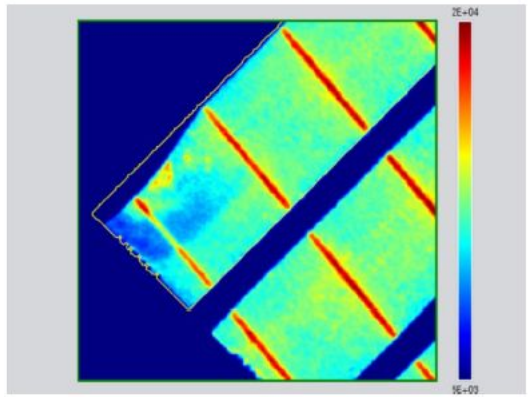
(a) *Parte finale stampata*



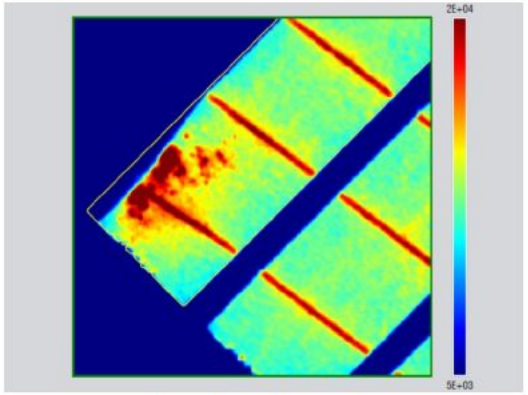
(b) *layer* 272 - $h = 10.88\,\text{mm}$



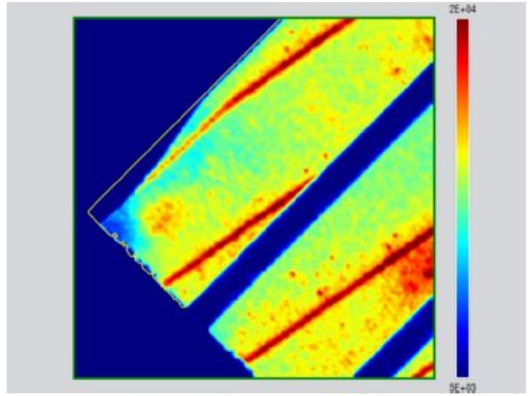
(c) *layer* 274 - $h = 10.96\,\text{mm}$



(d) *layer* 276 - $h = 11.04\,\text{mm}$



(e) *layer* 278 - $h = 11.12\,\text{mm}$

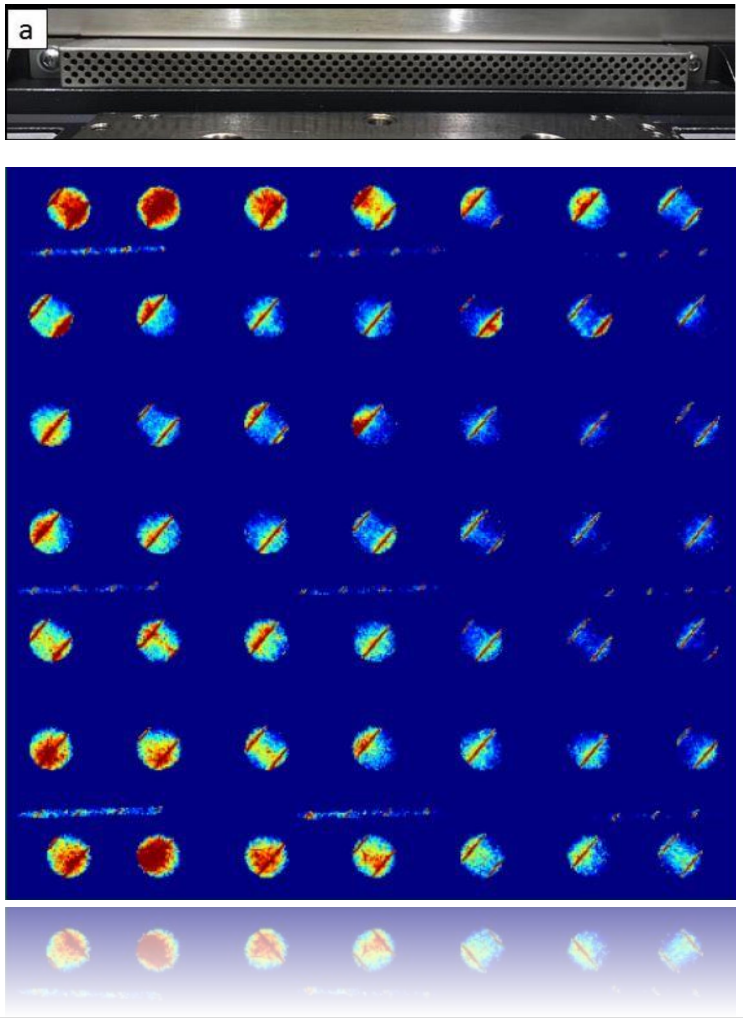


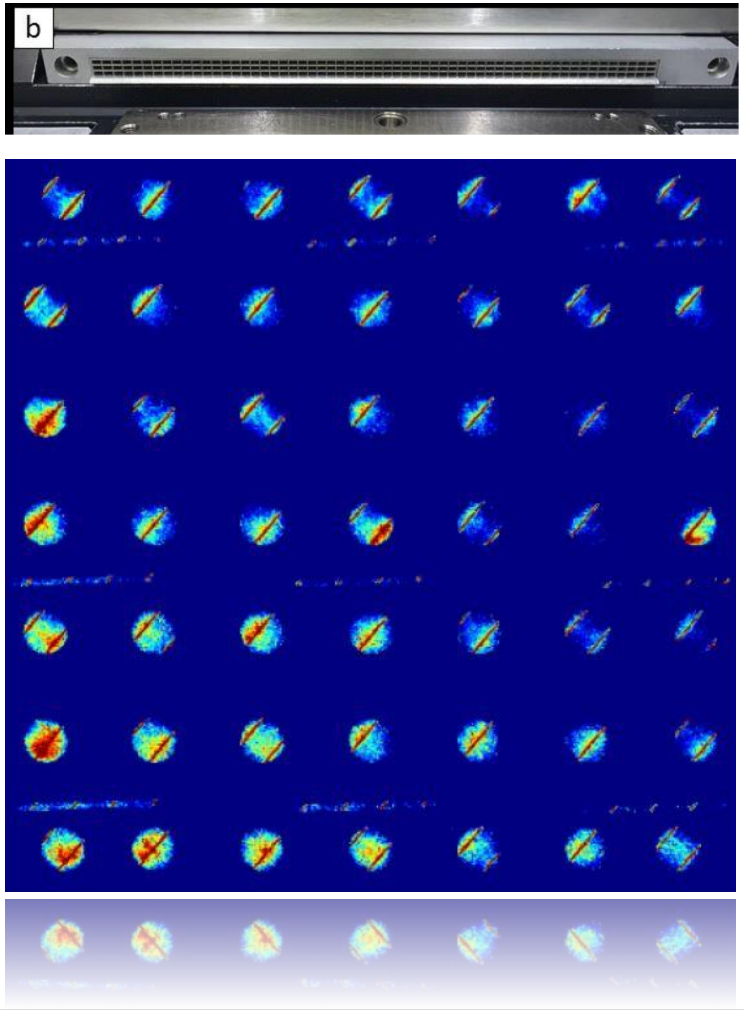
(f) *layer* 280 - $h = 11.20\,\text{mm}$

Optical Tomography monitoring

Gas flow analysis

- Parts thermal profile with different nozzles



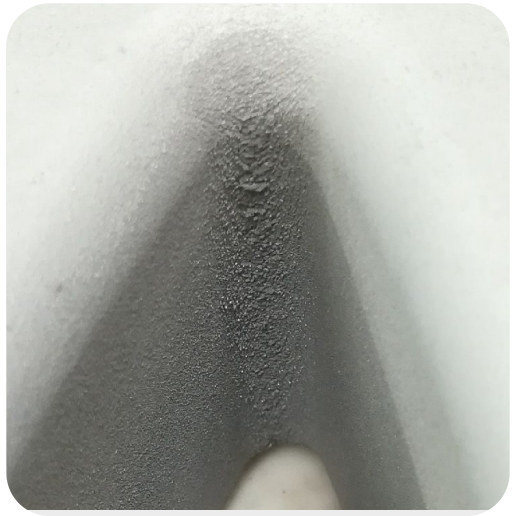


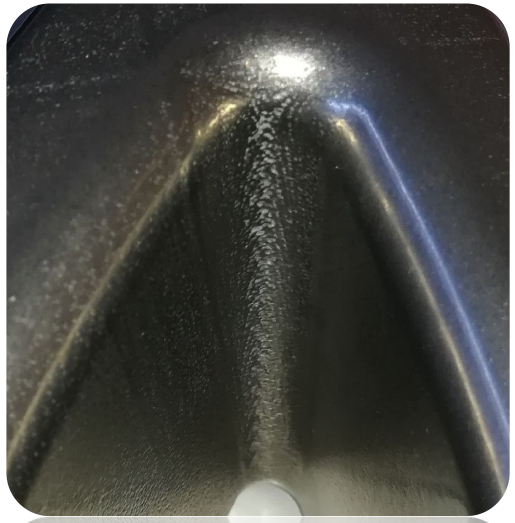
Optical Tomography monitoring

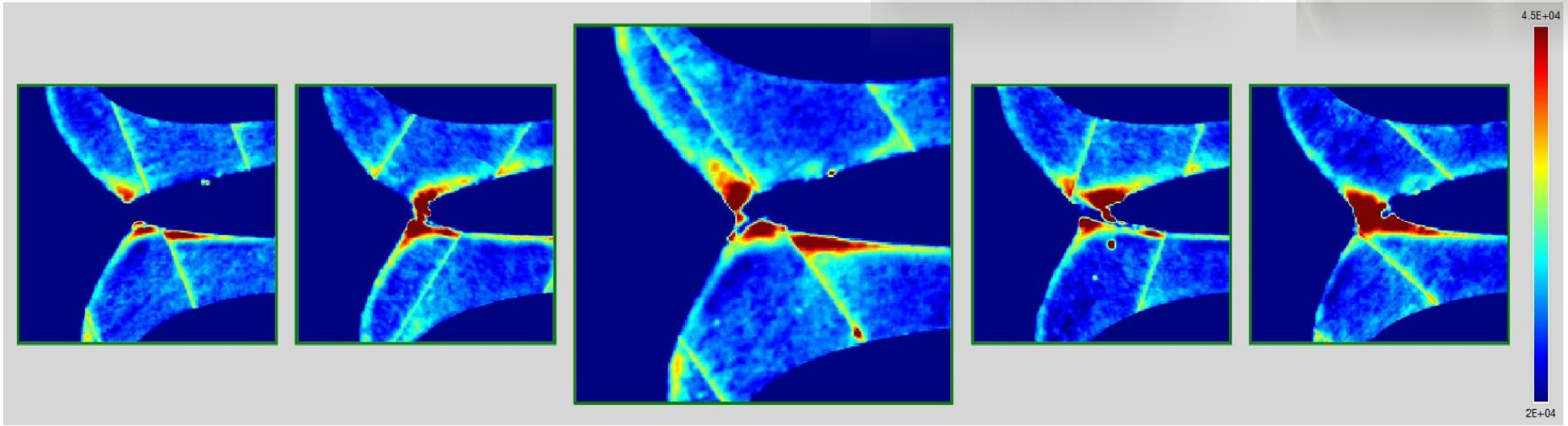
Defects identification examples

Hotspots in downskin area

High roughness on the part



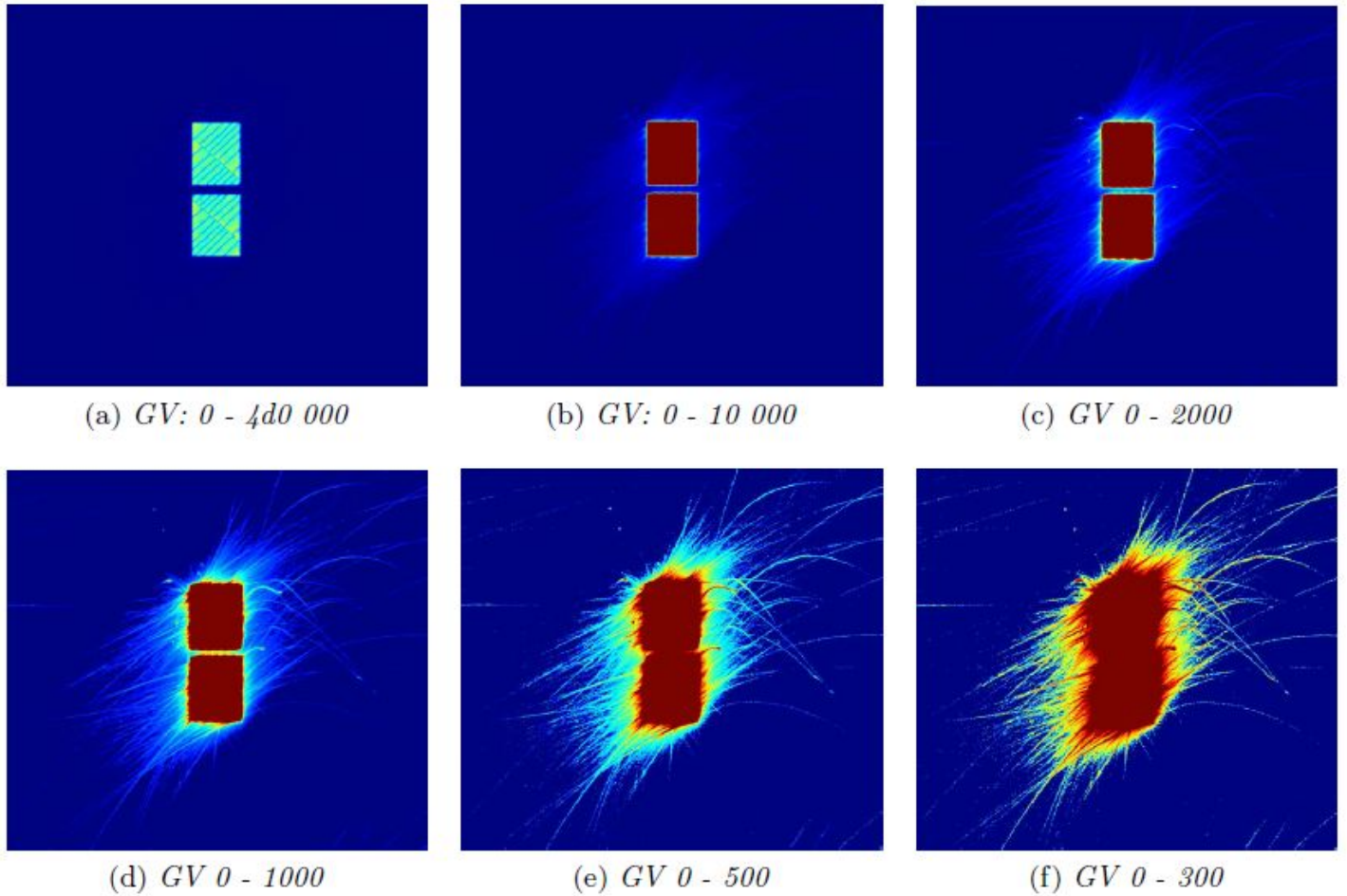




Optical Tomography monitoring

Defects identification examples

- Spatter emission visualization with different GV (Grey value)



(a) *GV: 0 - 4d0 000*

(b) *GV: 0 - 10 000*

(c) *GV 0 - 2000*

(d) *GV 0 - 1000*

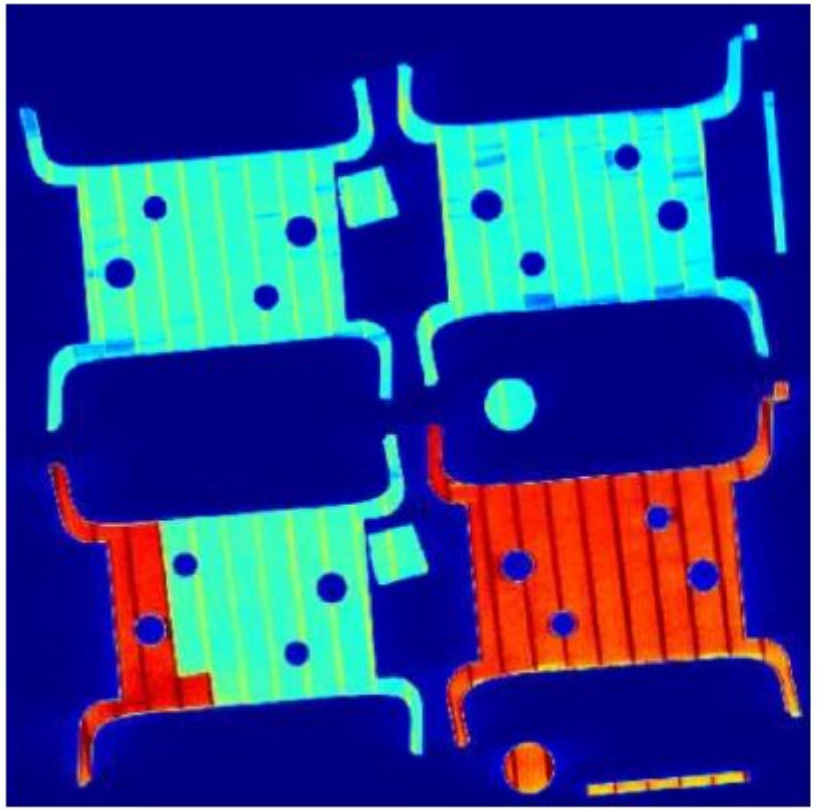
(e) *GV 0 - 500*

(f) *GV 0 - 300*

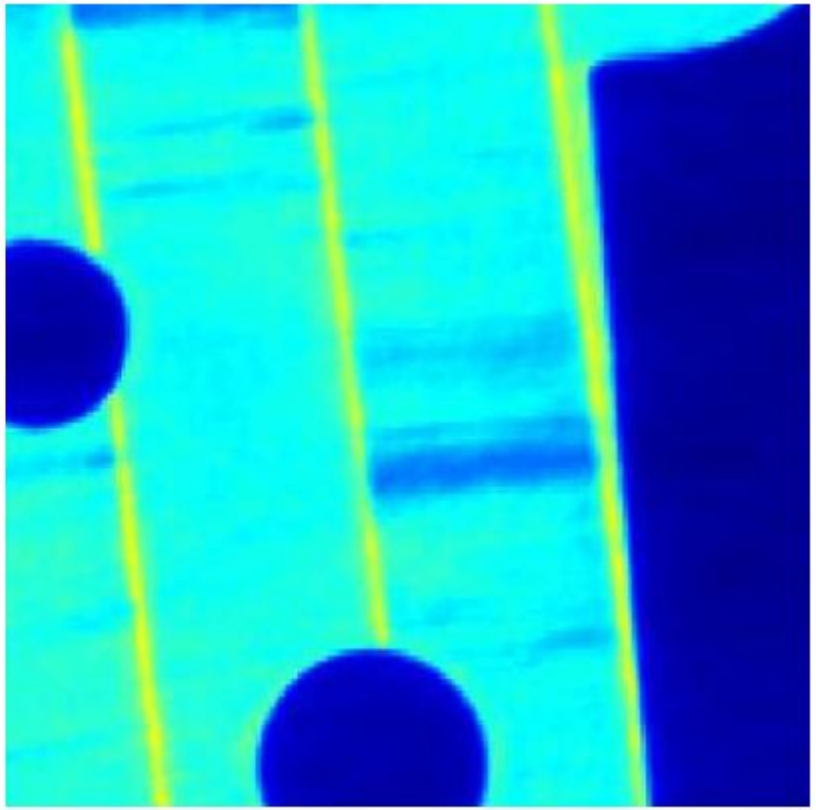
Optical Tomography monitoring

Key hole collapse

- Key hole collapse zone are visible like colder stripes



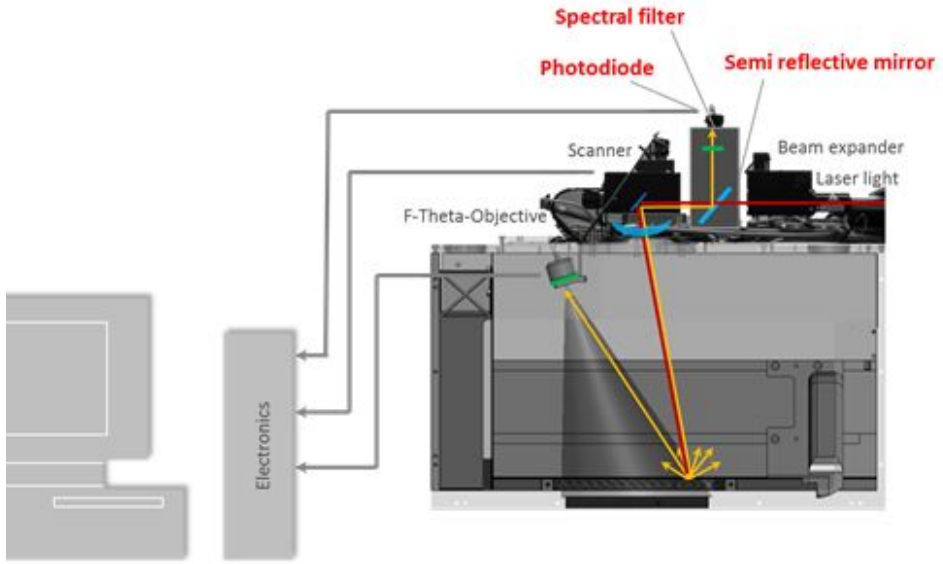
(a) *Immagine OT del primo layer di stampa. La zona più calda è quella nella quale è già avvenuta la seconda esposizione.*

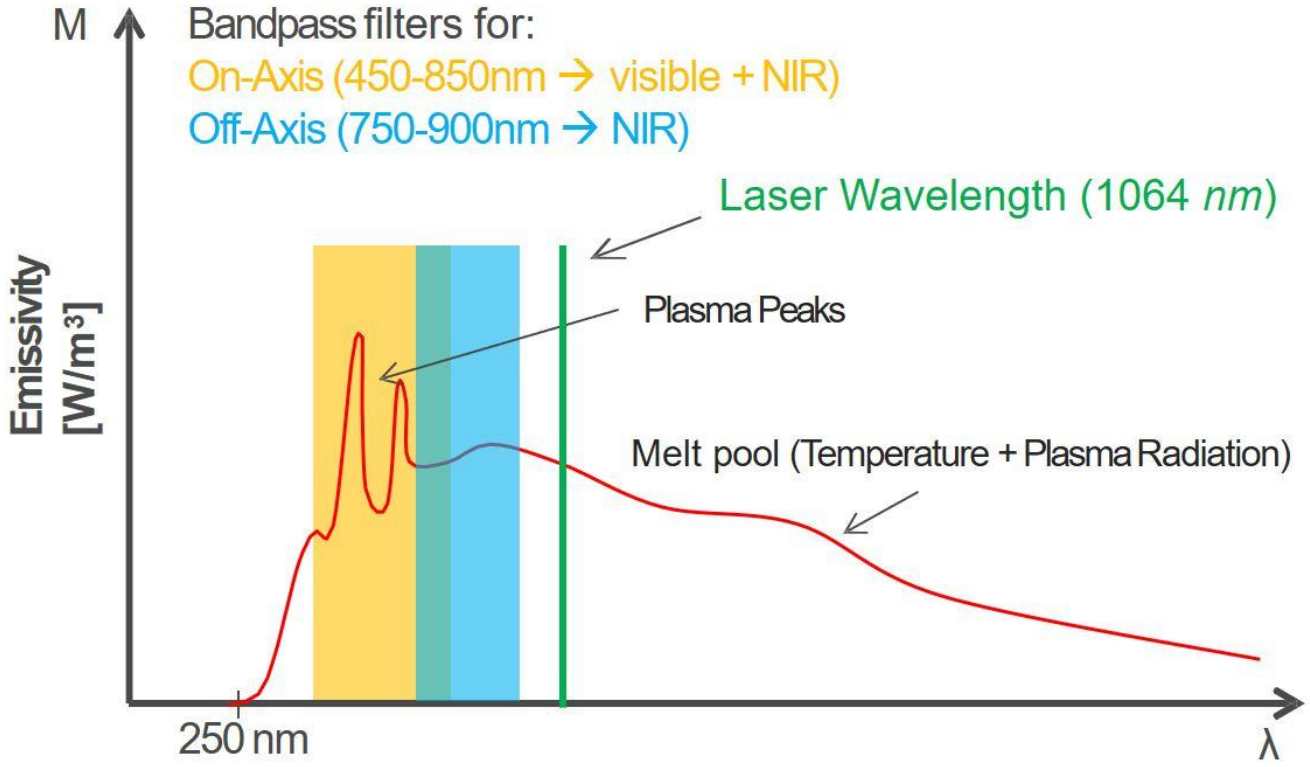


(b) *Particolare di zone nelle quali è avvenuto il collasso del key hole.*

MeltPool Monitoring

- 2 photodiodes with different filters
- On-axis and off-axis signal
- Online and offline analysis software

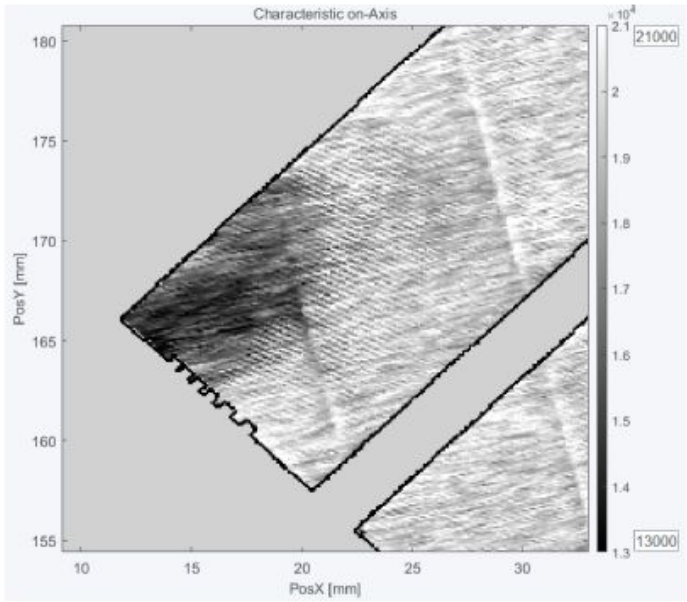




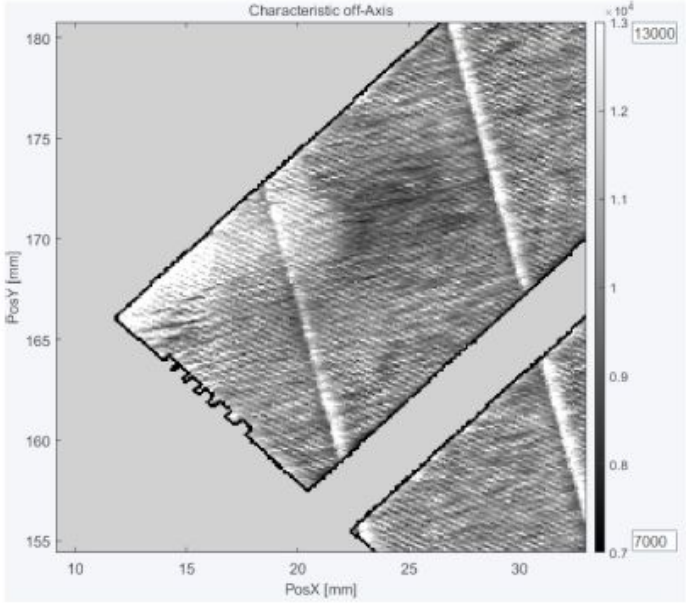
MeltPool monitoring

Lack of powder

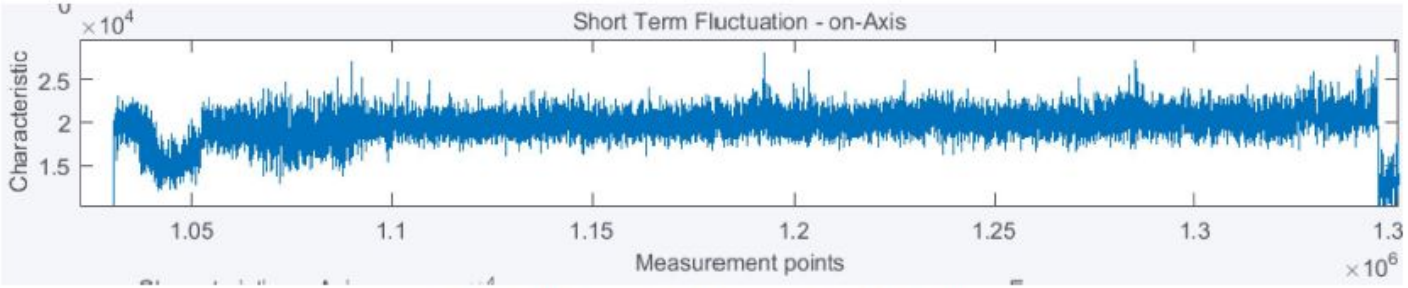
- 60 kHz signal visualization
- Differences between on- and off-axis images



(a) *Mappa della caratteristica on-axis della parte.*



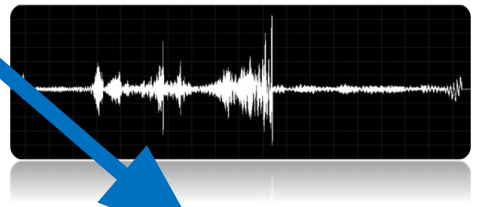
(b) *Mappa della caratteristica off-axis della parte.*



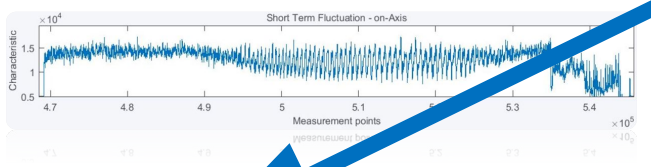
(c) *Segnale on-axis nel tempo per la parte.*

Sensors integration

Accelerometer

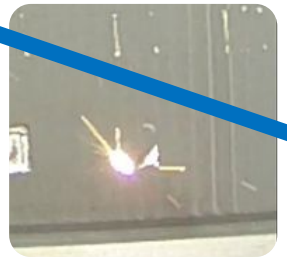


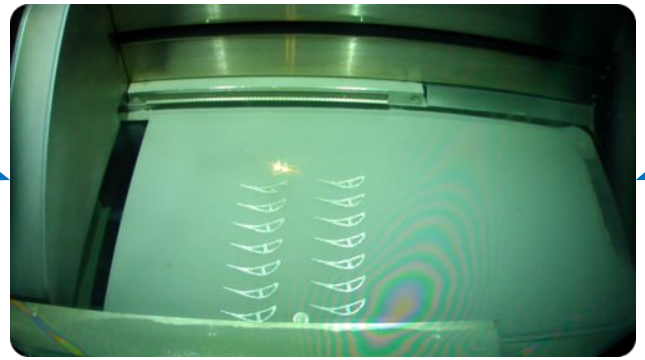
Photodiodes

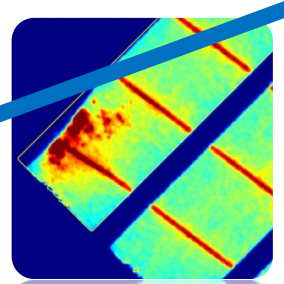


IR camera

Camera



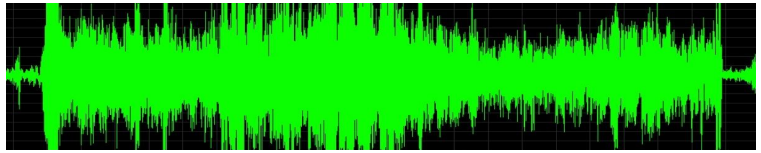


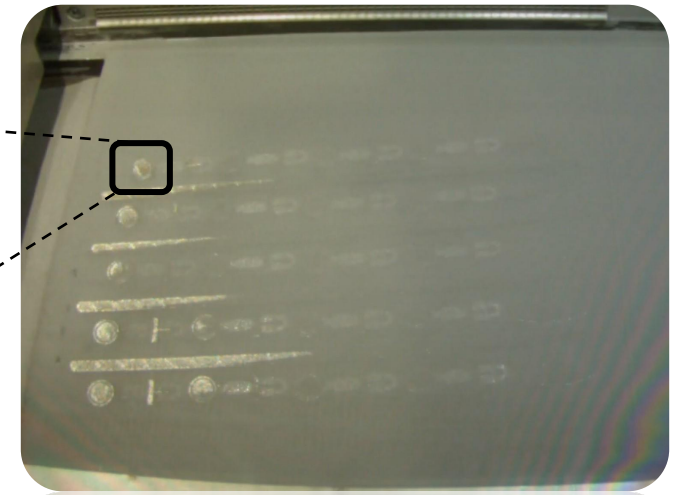


Sensor integration

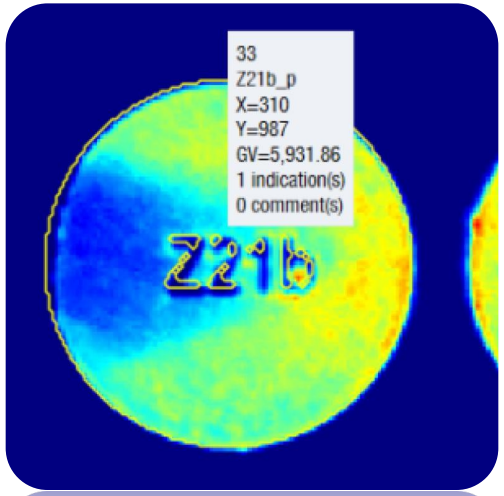
Lack of powder

Accelerometer signal

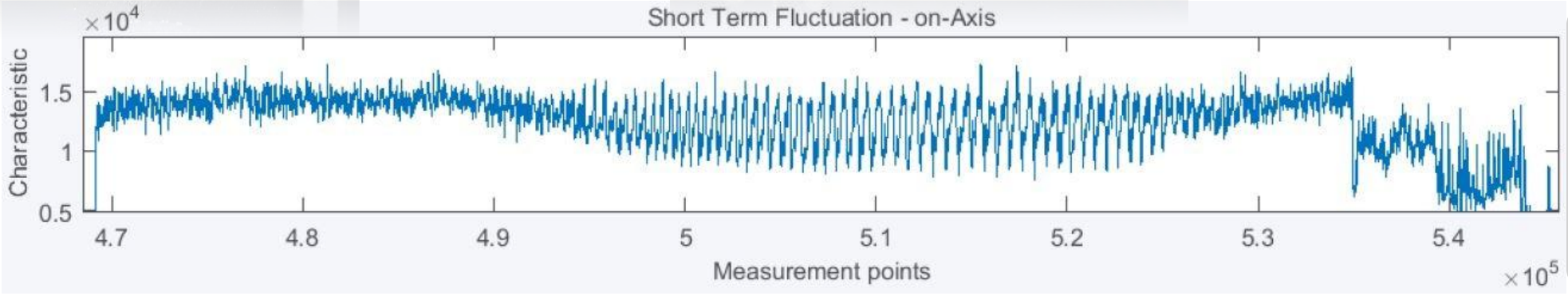




OT image

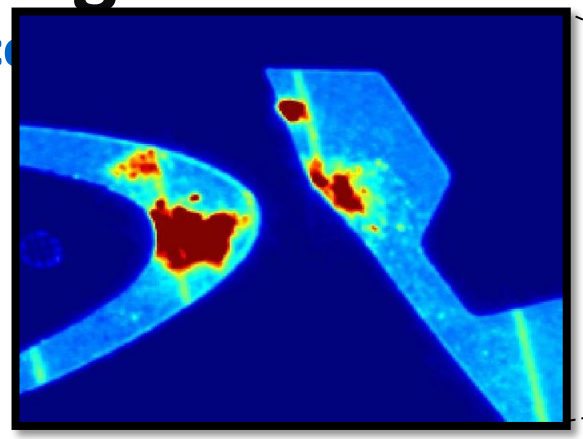


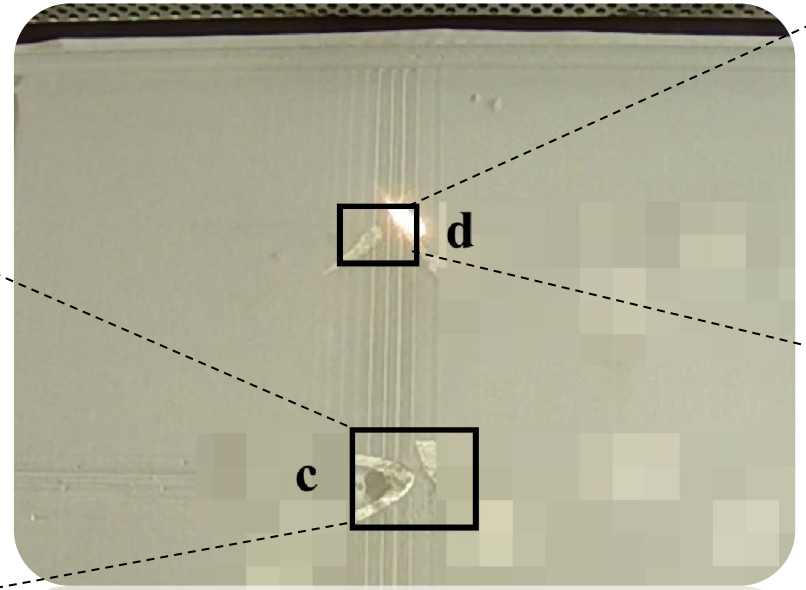
MeltPool signal and Exposure map

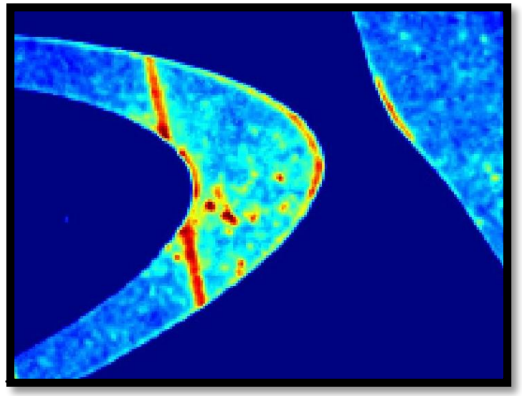


Sensor integration

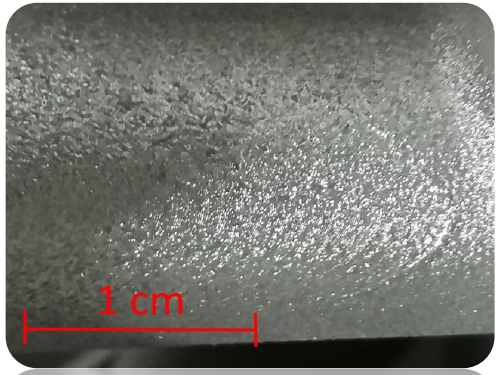
Rec

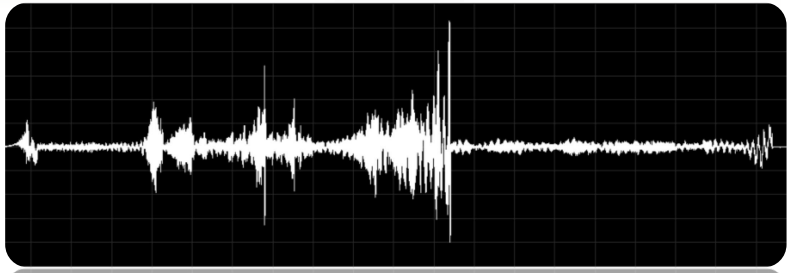




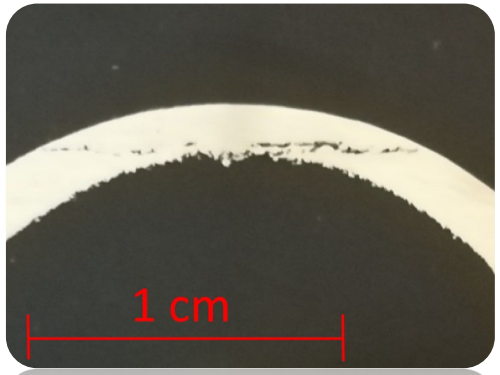


Rugosità



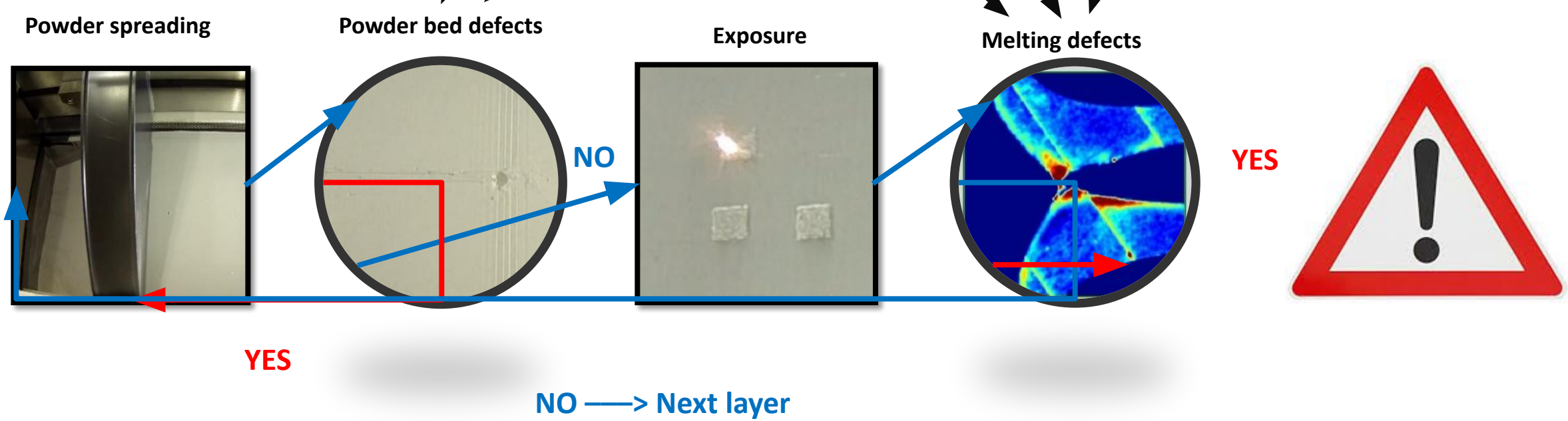


Porosità



Sensors integration

Online feed-back



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09 - 11 APRIL 2019 | MANCHESTER, UK

Towards an integrated sensor system control for direct laser melting

Michele LANZETTA, Francesco MORANTE

University of Pisa Italy Department of Civil and Industrial Engineering

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