SLM Solutions

Former:
HEK GmbH
MCP HEK Tooling GmbH
MTT Technologies GmbH

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JUBILÄUMSVERANSTALTUNG
20. FACHTAGUNG RAPID PROTOTYPING
06. November 2015
Hochschule OWL, Lemgo

Selective Laser Melting
Eine produktive Fertigungstechnologie
Automatisierung
Qualitätssicherung

Dr. Dieter Schwarze

SLM Solutions

2013

- DPE invests in SLM Solutions
- Production capacity enlarged to approx. 1000 m^2
- 79 employees by 31.12.2013

2014

- May 9
  IPO of SLM Solutions Group AG
- 150 employees by 31.12.2014
- > 220 employess by 30.09.2015

Real Pioneers / Real History

1993 – 1994
EU Project BRE20216 „Rapid prototyping metal components“
Krupp Forschungsinstitut GmbH, Prof. J. Peterseim

Since 1995
SLM® technology development in close co-operation between
Fockele & Schwarze (F&S, Paderborn) and the Fraunhofer ILT (Aachen)

1996
Patent filed by W. Meiners, K. Wissenbach and A. Gasser

1998
Delivery of first SLM machine from F&S to Trumpf

1999 ff
Further F&S machines delivered to industry and R&D institutes and start of the cooperation F&S – SLM Solutions

Everything else is a fairy tale …

SLM Solutions – a deep rooted 3D printing heritage

Focus on rapid prototyping

Since 1970

Development of SLM technology with Fraunhofer Institute/ F&S

1998 - 2002

Launch of first Fibre Laser technology with the SLM 250

2003

First company to process Aluminum and Titanium on SLM machines

Launch of SLM 100 as entry model

2006

Launch of the 400 Watt technology

2007

Launch of the new SLM 250HL

2009

Launch of SLM 125HL and SLM 280HL machines with hull and core technology

2011

Launch of SLM 500HL machines with multi laser technology

Launch of automated powder handling devices

2013

- Drive industrial application of 3D metal printing technology

2014 onwards

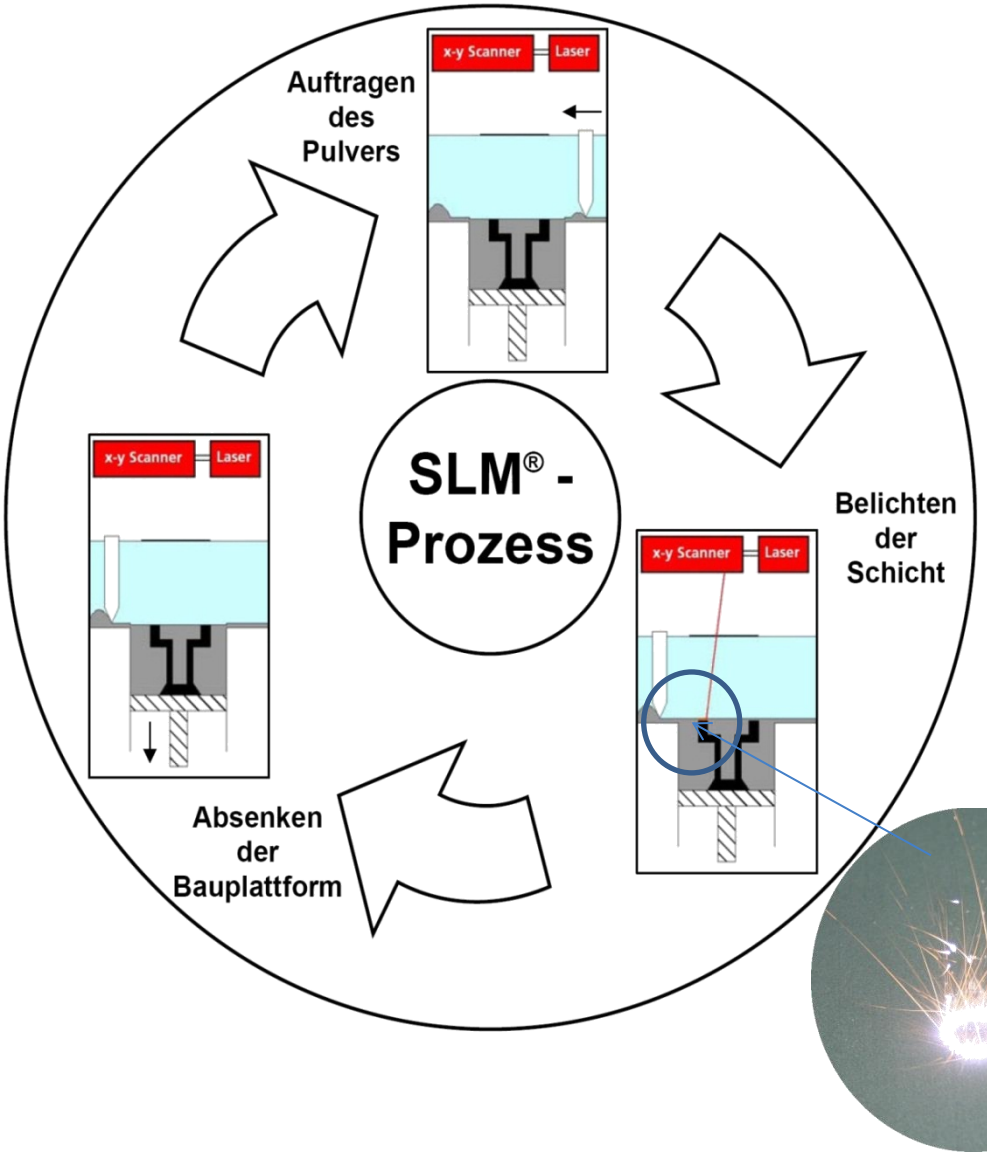
Note: History of SLM Solutions and its predecessors
Source: Company information

Selective Laser Melting Process

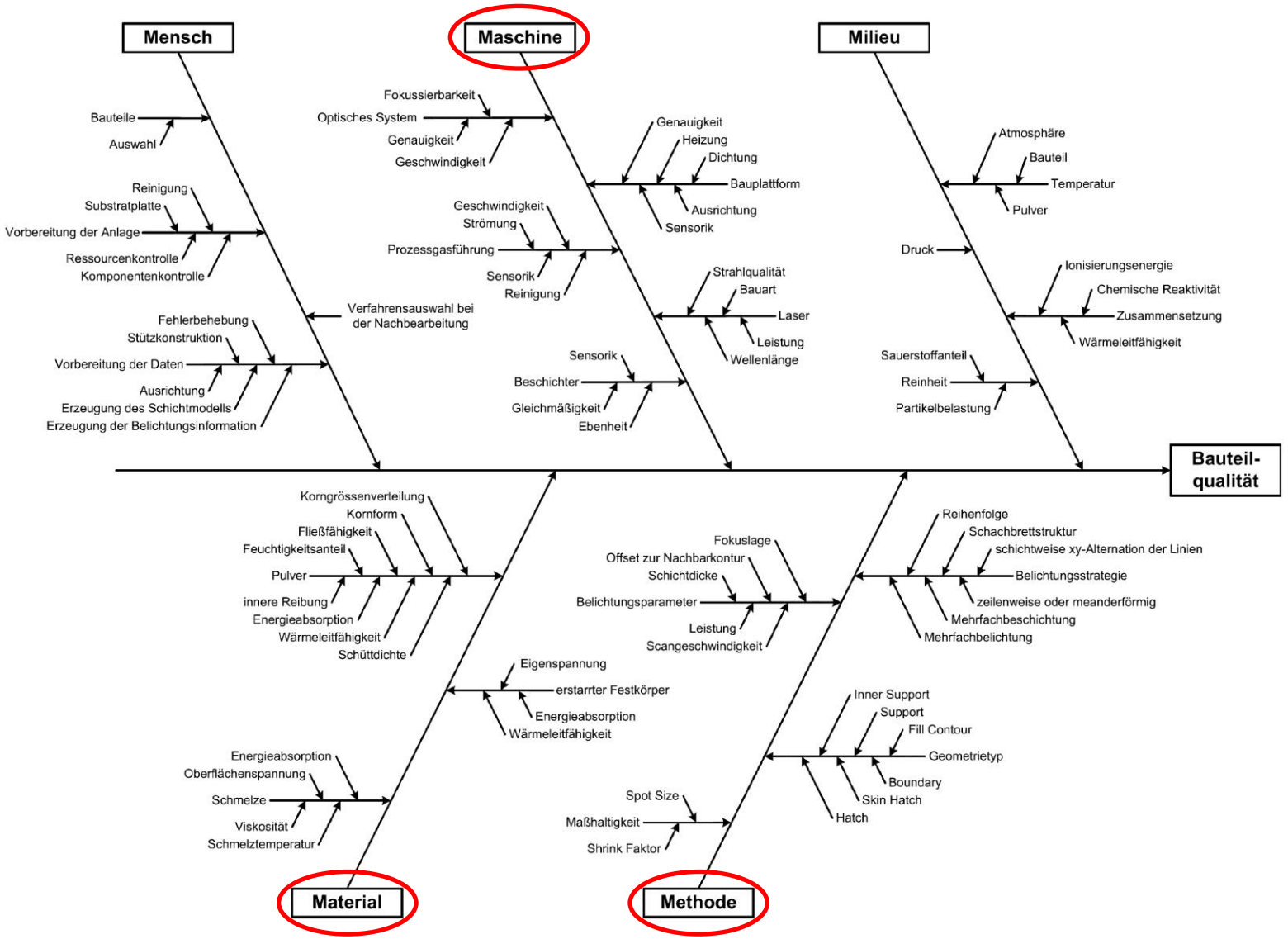
Selective Laser Melting
of metal powder materials

Cyclic Process:

1. Powder Layer Deposition
2. Laser Exposition
3. Lowering of Build Platform by exactly one Layer



Fishbone diagramm of the SLM process variables



Quelle: Projektarbeit, A. Wiesner

Main SLM variables

L: laser power
v: scan velocity
Δy: hatch distance
Δz: layer thickness

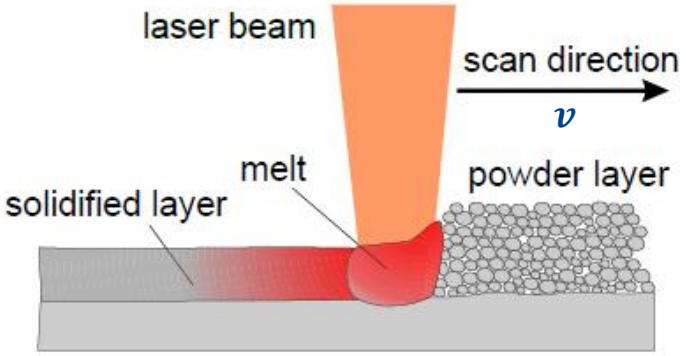
- $\boldsymbol{Energy\ Density\ E = L/(v \times \Delta y \times \Delta z)}$
- $\boldsymbol{Build\ Rate:\ V = v \times \Delta y \times \Delta z}$

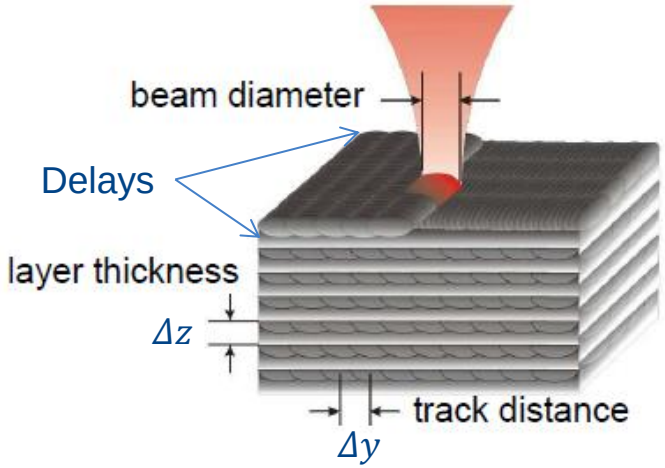
Example for aluminium with one laser:
v ≈ 1000 mm/s, Δy ≈ 0,2 mm, Δz = 0,05 mm

→ V = theoretical build rate ≈ 35 cm^3/h

- without delays and recoating time
- good accordance with reality for parts with large volume

Conclusion: The four main variables are strong levers for productivity increase





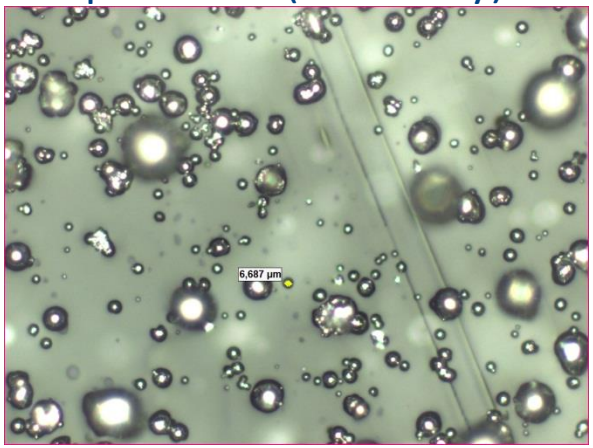
Picture Source: FhG ILT Aachen

Qualified metal materials

- Titanium (Ti cp, TiAl6Nb7, TiAl6V4)
- Aluminium (AlSi12, AlSi10Mg, AlSi7Mg)
- Cobalt Chrome (ASTM F75)
- Steels (1.2709, 1.2344 (H13), M333, 1.4404 (316L), 1.4410, 1.4542 (17-4PH))
- Inconel (e.g. 625, 718, 738, 939)
- Hastelloy X
- CuSn10 Bronze
- …

Spezifications:

- spherical particles
- 10 µm < ø < 45 µm
- 20 µm < ø < 60 µm (Alu)
- good flowability
- dryness
- pureness (chemistry)



Applications

Tooling / Mouldmaking and Part Production

Conformal cooling

Turbine
In718

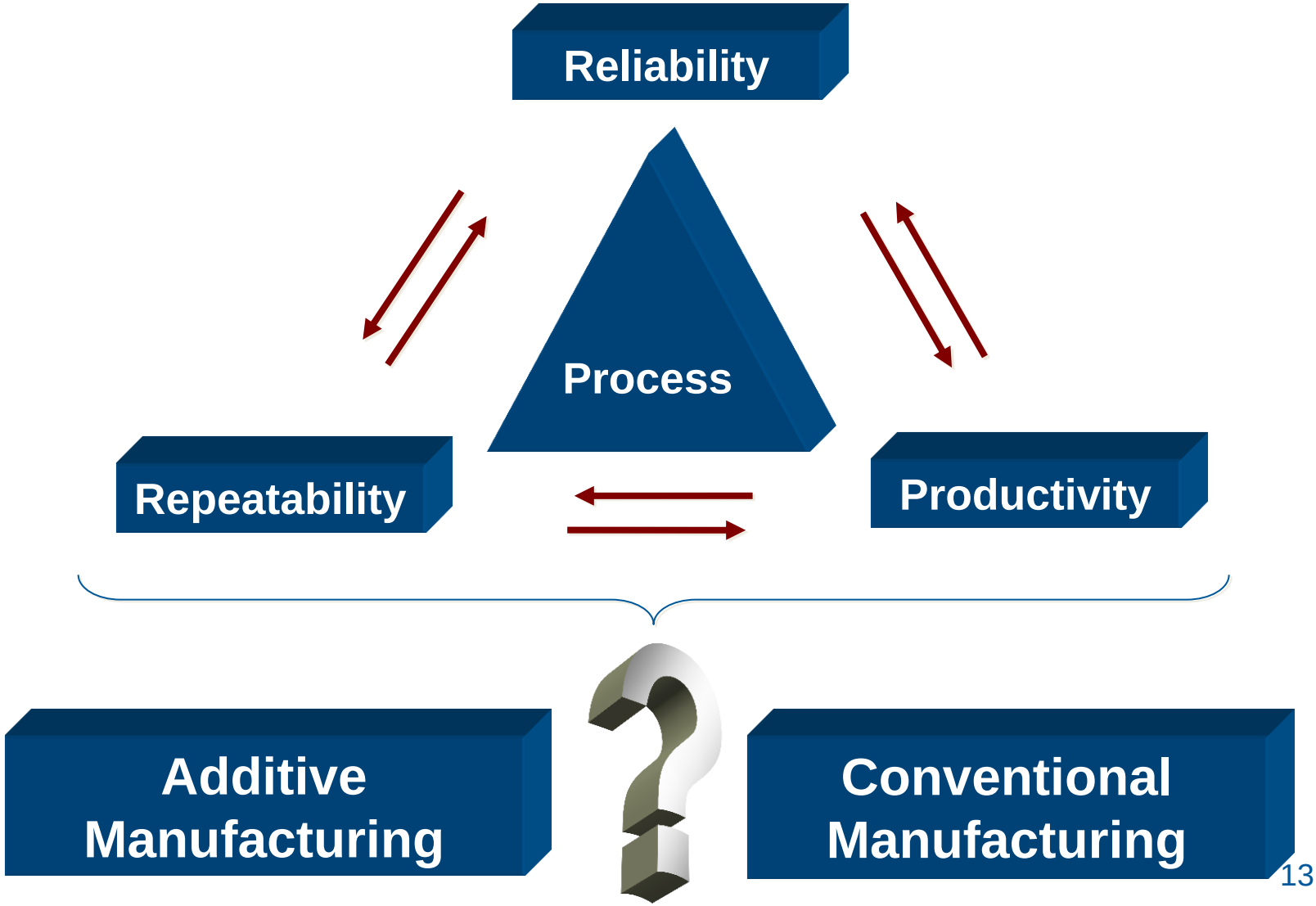
Airbus / ILAS

Ti 6Al 4V

Tire Mould
316 L

Caps / Crowns
CoCr

Reliability, Repeatability, Productivity



SLM Solutions – a leader in metal 3D printing

Key products

A leading metal 3D printing company

- Historical origins in rapid prototyping technology
- Paved the way for today's primary focus: *3D printing* for industrial volume production and prototyping
- A leader in selective laser melting technology
- Installed base of > 200 SLM systems
- > 100 machines planed for 2015

SLM 125^{HL}

Details Excerpt

- Build Volume 125 x 125 x 125 [mm]
- 1 Fiber Laser 1x400 W
- Productivity up to 15 cm^3/h
- Laser Focus 85 µm, variable
- New Optic Design without F-Theta
- Layer Thickness 20 µm – 50 µm
- Other Features like SLM 280 ^{HL}

SLM 280^{HL} / PSH 100

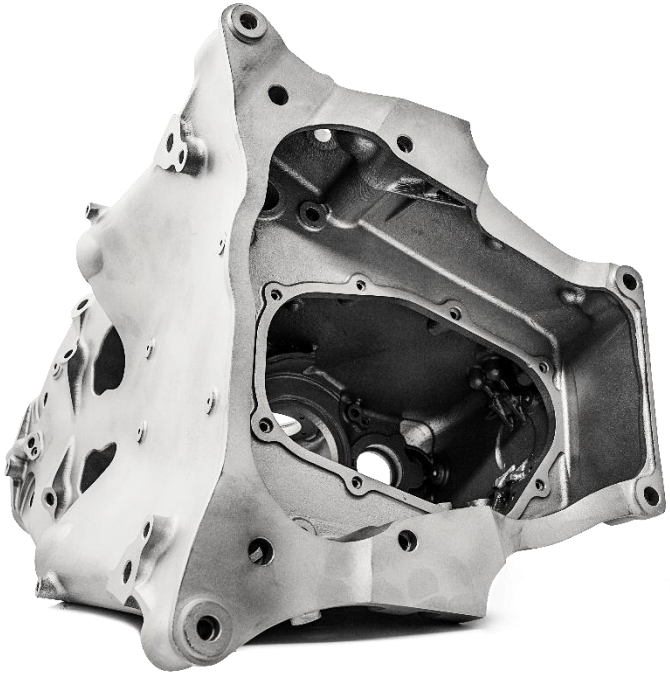
Details Excerpt

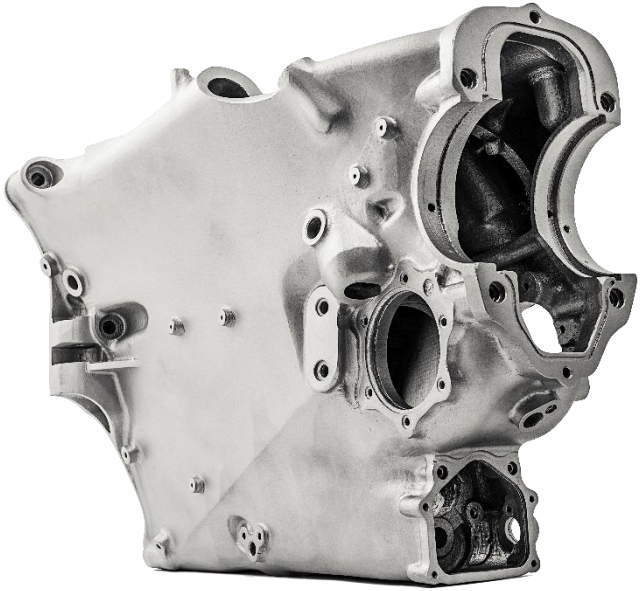
- Build Volume 280 x 280 x 350 [mm]
- 2 Fiber Lasers 2x400 W
- Focus Diameter 85 µm, variable
- Layer Thickness 30 – 50 µm (150 µm)
- New Optics without F-Theta
- Largely Increased Productivity
- Very Short Powder Deposition Time
- Highly Efficient Weld Smoke Exhaustion
- Argon Gas Recirculation
- Optical Layer Control for QA
- Substrate Plate Pre-Heating 200° C
- Closed Loop Powder Cycle
- …..

SLM 500HL with Part Removal Station and Powder Recycling Station

Build Volume 500 x 280 x 365 [mm]	Automatic Powder Recycling
Productivity increased > 100 cm^3/h	Exchange of Build Cylinder < 30 Min.
Twin System 2x 400 W Lasers	Quad System 4 x 400 W Lasers

Formula 1 gearbox (courtesy FIT AG)

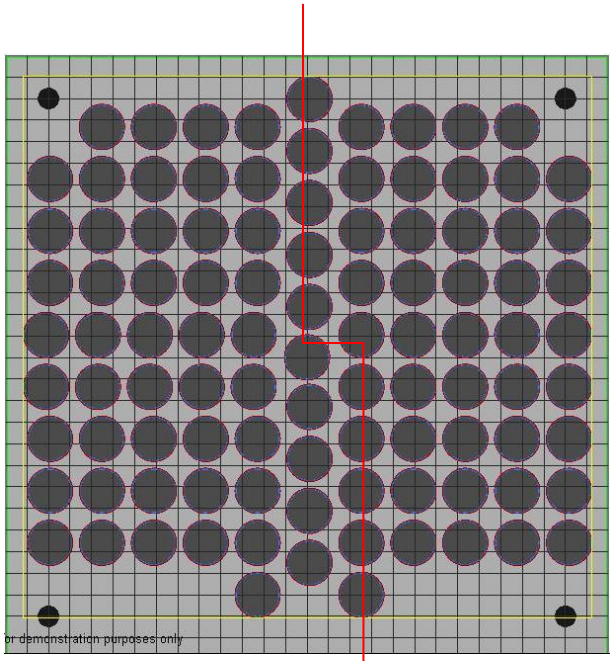




Aluminium parts built on a SLM 500^{HL} Quad System

Productivity P

Single scanner, single laser / 400 W	→	P
Single scanner, dual laser /400 W + 1000 W	→	P x F
Twin scanner, twin laser / 2 x 400 W	→	2P
Twin scanner, double dual laser/ 2 x 400 W + 2 x 1000 W	→	2P x F
Quad scanner, quad laser / 4 x 400 W	→	4P



Parting line between scan areas

Overlap area with the same high density and mechanical properties compared to single scanner/laser area?

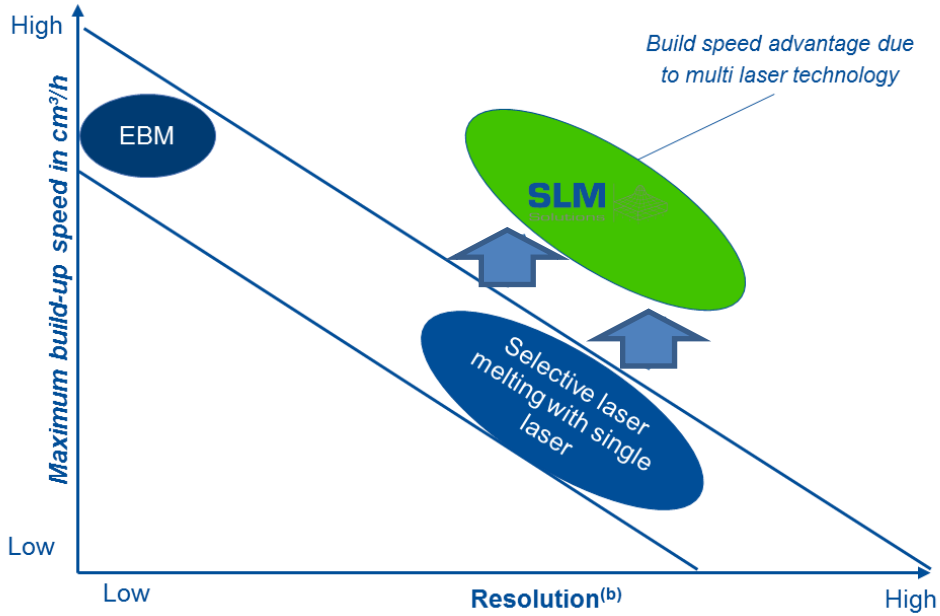
YES!

Production of parts with quad scanner and quad laser in the SLM 500 HL

- Production of large or many parts with 4 lasers in a SLM 500 HL with build envelope of 500 mm x 280 mm x 325 mm
- Build envelope can be increased in the future using even more lasers and scanners

The Industrial Automation of the SLM Technology

Illustrative build-up speed and resolution of selected powder bed fusion systems[a]



SLM Solutions

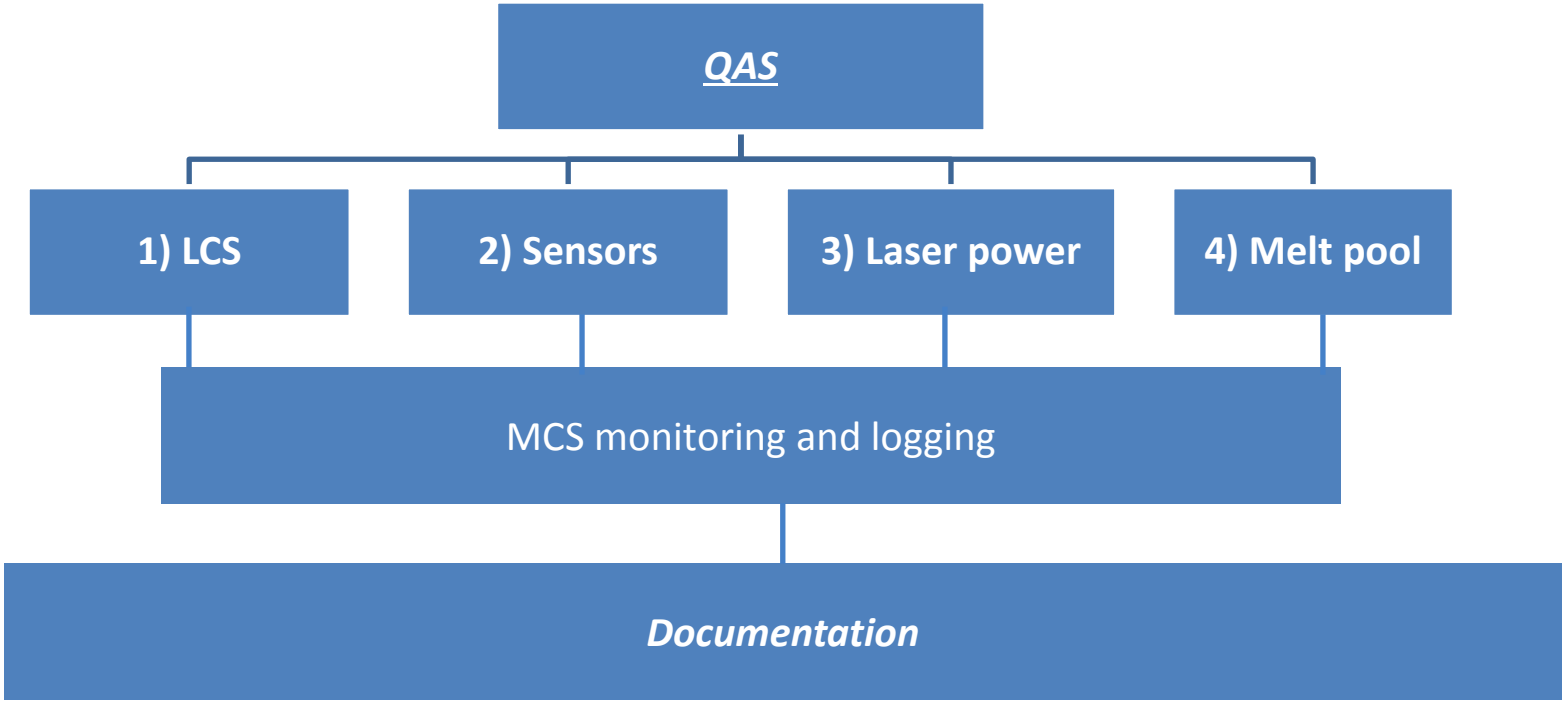
- Functionality
- Speed
- Surface finish
- Accuracy
- Performance

(a) Based on 2012 Wohlers report
(b) Measured by layer thickness

The Selective Laser Melting System SLM 500^{HL} provides a build chamber of 500 x 280 x 325 mm^3 and works with 2 – 4 scanners and up to 4 lasers. All scanners are working simultaneously which together with the high laser powers leads to a large productivity increase.

The transport of metal powder is done by a continuous conveying system due to the increased volumes and weights. This automates the management of powder and eliminates the manual handling of loads with bottles and containers.

QAS Quality Assurance System
Module overview



Status

- The QAS includes 6 modules (caustic measurement and dynamic powder control not shown here)
- The modules are already in place, are being tested or in development.
- Display and processing is divided into internal monitoring and logging.

QAS

1) Layer Control System LCS

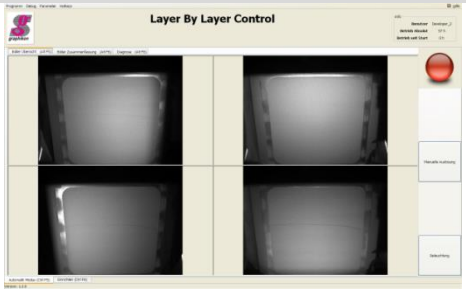


Figure: Single images for error detection and analysis..

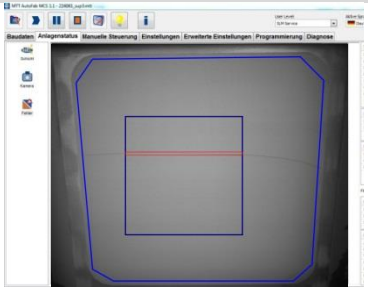


Figure: Automatic error detection of the whole platform.

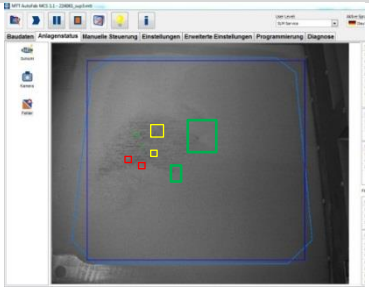


Figure: Automatic error detection of individual process errors.

Specification

- Image documentation after powder application **and** after exposure
- Automatic analysis of the captured image data and following error detection
- Possibility of manual adjustment of conditions and limits for error detection

Advantages

- Automatic and immediate identification of individual process errors instead of analysing the hole platform
- Possibility of additional powder layering on some error patterns
- Time and cost savings by:
  - unloading of process critical parts during a job
  - build parts by trouble-free process flow

QAS
2) Sensors

Time	Platform	Build Chamber	Pump1	Cabinet	Cabinet 2	Optical Bench	Collimator	Ambiance	Oxygen 1	Oxygen 2	Pressure	Filter Status	T_LL	T_LR	T_U	R_LL	-	-	-
15:22:49	30.4 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.48 %	17.00 %	0.1 mbar	0.0 mbar	0	0	0	1	0	0	0
15:22:51	30.5 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.49 %	17.00 %	0.1 mbar	0.0 mbar	0	0	0	1	0	0	0
15:22:53	30.4 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.48 %	17.00 %	0.0 mbar	0.0 mbar	0	0	0	1	0	0	0
15:22:56	30.5 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.49 %	17.00 %	0.1 mbar	0.0 mbar	0	0	0	1	0	0	0
15:22:57	30.4 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.49 %	17.00 %	0.2 mbar	0.0 mbar	0	0	0	1	0	0	0
15:22:59	30.4 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.49 %	17.00 %	0.1 mbar	0.0 mbar	0	0	0	1	0	0	0
15:23:01	30.4 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.49 %	17.00 %	0.0 mbar	0.0 mbar	0	0	0	1	0	0	0
15:23:03	30.5 °C	31.9 °C	23.9 °C	25.9 °C	25.2 °C	25.9 °C	24.5 °C	24.6 °C	22.49 %	17.00 %	0.0 mbar	0.0 mbar	0	0	0	1	0	0	0

Protocol | Sensors

Figure: Extract of the sensor representation in the process constrol system of the Selective Laser Melting System.

Specification

- Automatic data monitoring of all sensors every two seconds
- Control and output of temperatures, oxygen control, inert gas pressure and filter conditions

Advantages

- Ensuring consistent process conditions
- Process control used as a security guard
- Possibility for the input of individual limits
- Documentation and the possibility of error feedback

QAS
3) Laser Power Monitoring

Specification

- Detecting via beam splitter in the optical bench
- Permanent laser power measurement, display of percentage variation every second
- Depression of laser power or laser breakdown leads to warning or process interruption

Advantages

- Permanent monitoring of the actual laser power during build process
- Long time monitoring and detection of laser power losses, predictive life cycle management
- Cost reduction

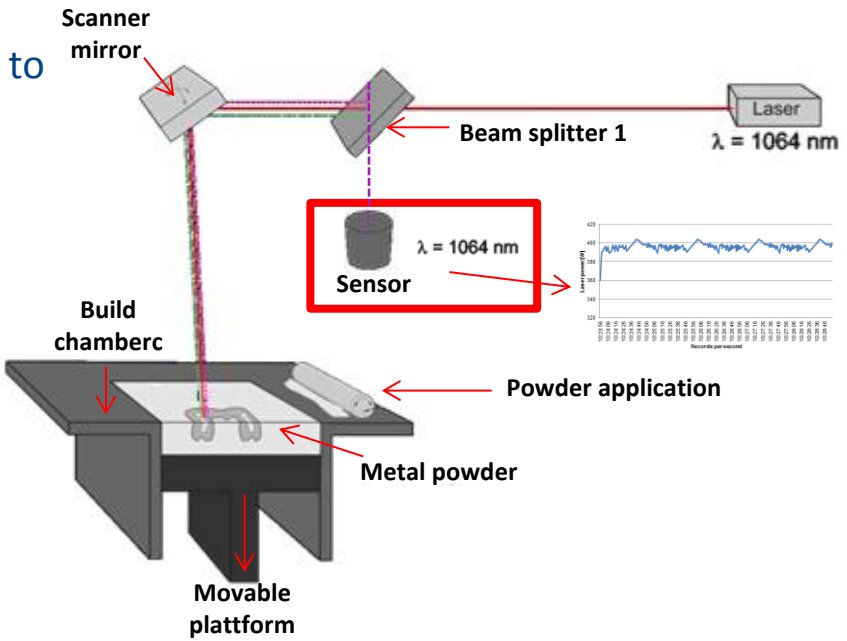


Figure: Schematic diagram for the assembly of the Laser Power Monitoring

4) Melt Pool Monitoring

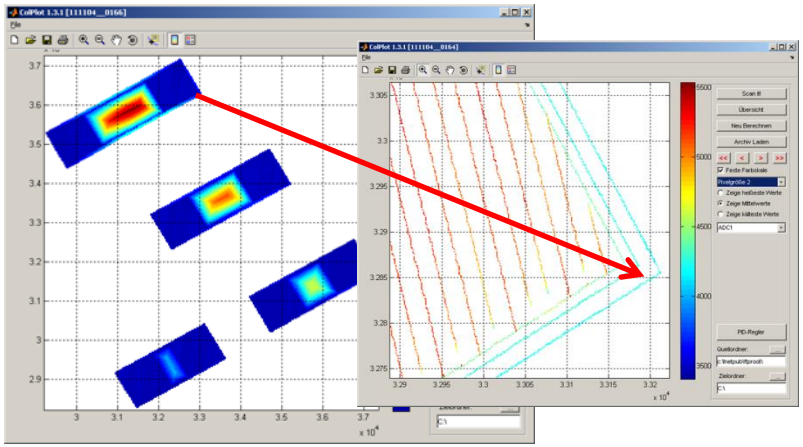


Figure: Visualization of the thermal radiation map of a current layer

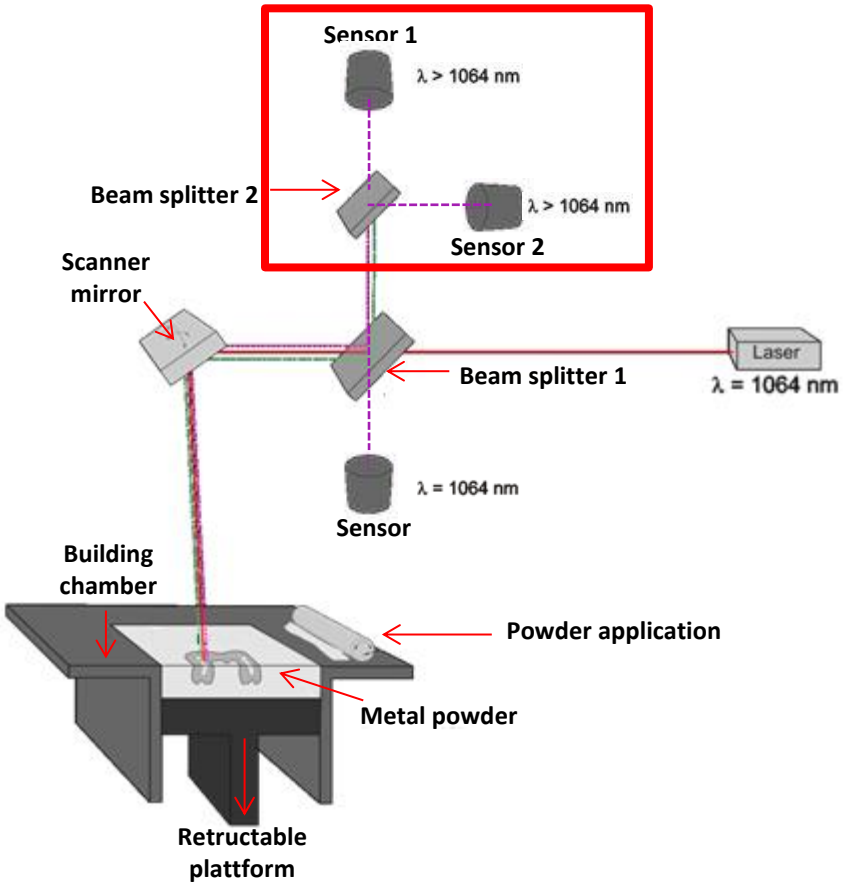


Figure: Schematic diagram of the Melt Pool Monitoring.

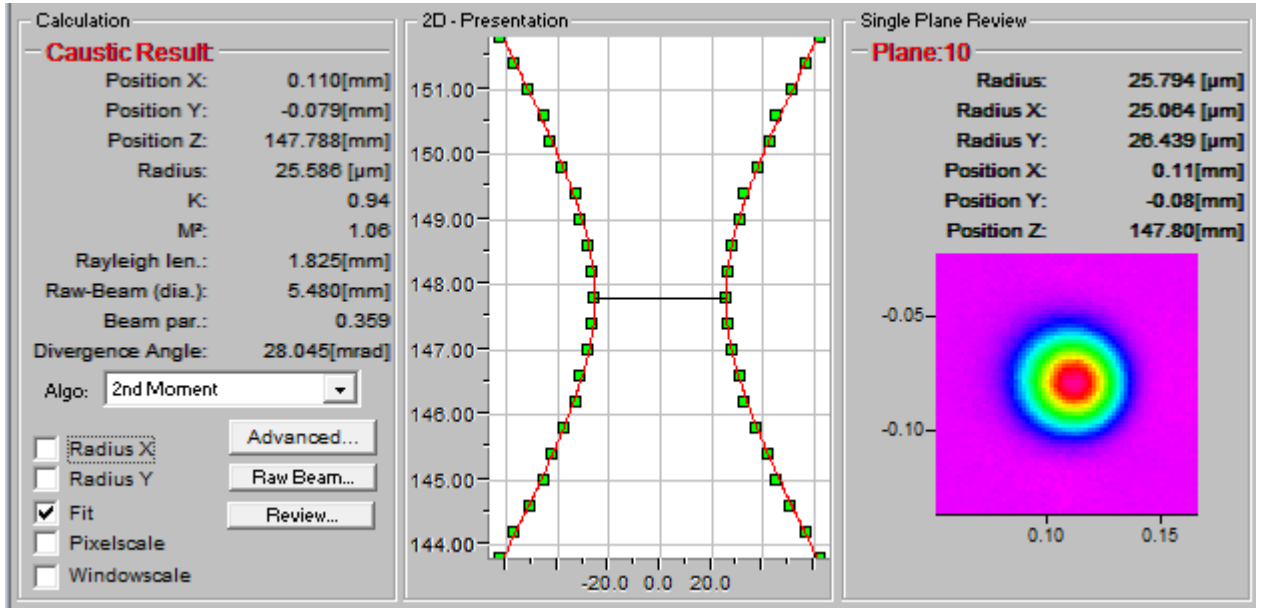
Specification

- Measurment of the thermal raidation ($I \sim T^4$) via two IR sensors
- Real-time (100 kHz repetition rate) measurement of melt pool thermal radiation
- Possible control of laser power
- Measurement and calculation of temperature and subsequent laser power control in 60 – 70 µs
- Intensity (temperature) profile of individual melting lines

QAS
5) Caustic Measurement

Specification

- Measurement of the beam profile
- M^2 value
- Laser spot size
- Thermal focus shift



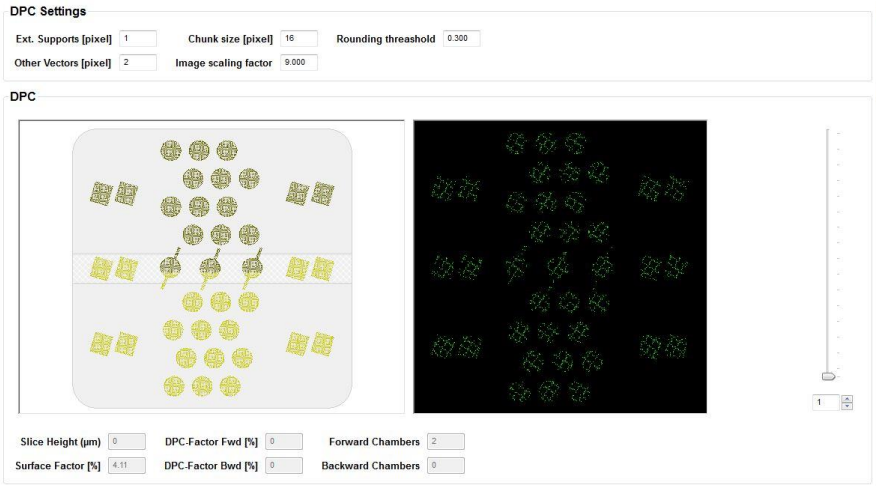
Advantages

- Beam diagnostic serves as an early warning system to maintain and improve process stability
- Error sources can be located quickly and easily
- Measurement during service (twice a year or more on demand)

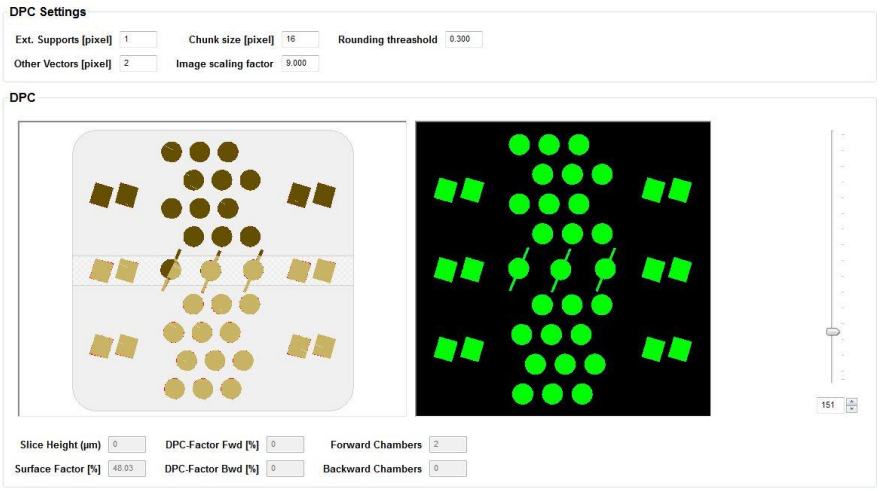
QAS
6) Dynamic Powder Control

Specification

- Automatic powder delivery dependent on surface coverage of each layer (percentage of surface covered with parts)



Surface coverage small



Surface coverage large

Advantages

- Reduced powder overdose
- Increased process stability
- Cost reduction

Vielen Dank für Ihre Aufmerksamkeit !