

# Process Control for Selective Laser Melting



# ○ Content

- Company Profile
- SLM Process & Materials
- Process Control
- Application Examples



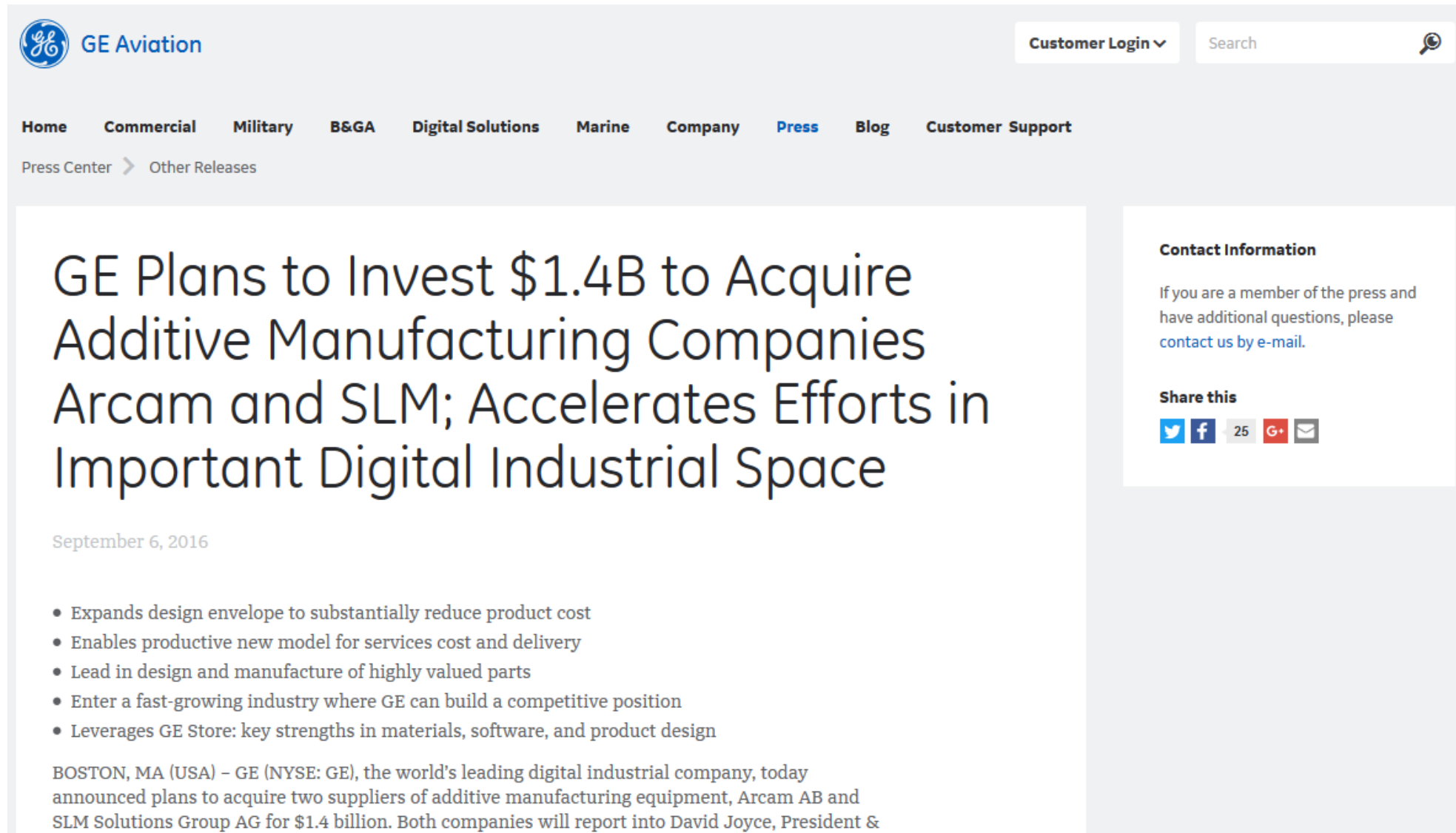




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# Company Profile

# ○ GE Aviation made public offering for SLM Solutions



The screenshot shows the GE Aviation website's press center. At the top, there's a navigation bar with links: Home, Commercial, Military, B&GA, Digital Solutions, Marine, Company, Press (highlighted), Blog, and Customer Support. Below this is a sub-navigation bar with 'Press Center' and 'Other Releases'. The main headline reads: 'GE Plans to Invest \$1.4B to Acquire Additive Manufacturing Companies Arcam and SLM; Accelerates Efforts in Important Digital Industrial Space'. The date is 'September 6, 2016'. A bulleted list highlights key points: expanding design envelope to reduce cost, enabling a new service model, leading in design and manufacture of parts, entering a fast-growing industry, and leveraging GE Store strengths. The text continues: 'BOSTON, MA (USA) – GE (NYSE: GE), the world's leading digital industrial company, today announced plans to acquire two suppliers of additive manufacturing equipment, Arcam AB and SLM Solutions Group AG for \$1.4 billion. Both companies will report into David Joyce, President &'. On the right, there's a 'Contact Information' section for press members and a 'Share this' section with social media icons (Twitter, Facebook, LinkedIn, Google+, Email) and a share count of 25.

**GE Aviation**

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## GE Plans to Invest \$1.4B to Acquire Additive Manufacturing Companies Arcam and SLM; Accelerates Efforts in Important Digital Industrial Space

September 6, 2016





- Expands design envelope to substantially reduce product cost
- Enables productive new model for services cost and delivery
- Lead in design and manufacture of highly valued parts
- Enter a fast-growing industry where GE can build a competitive position
- Leverages GE Store: key strengths in materials, software, and product design

BOSTON, MA (USA) – GE (NYSE: GE), the world's leading digital industrial company, today announced plans to acquire two suppliers of additive manufacturing equipment, Arcam AB and SLM Solutions Group AG for \$1.4 billion. Both companies will report into David Joyce, President &

**Contact Information**

If you are a member of the press and have additional questions, please [contact us by e-mail](#).

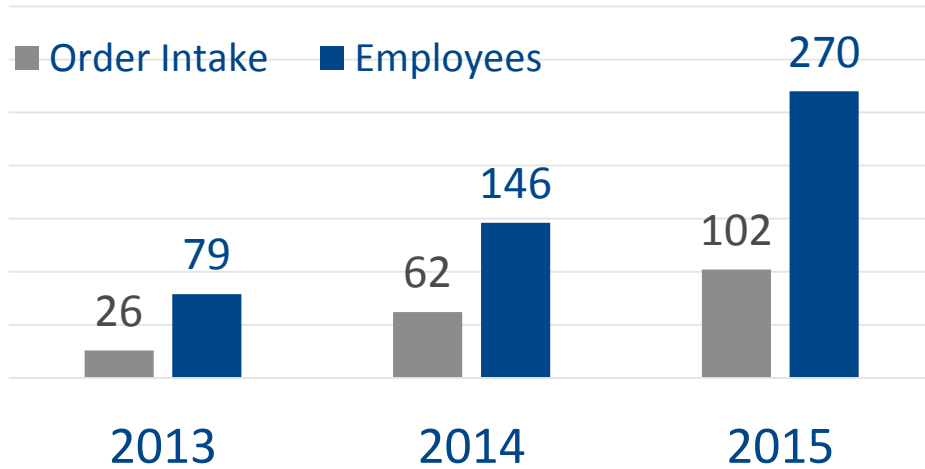
**Share this**

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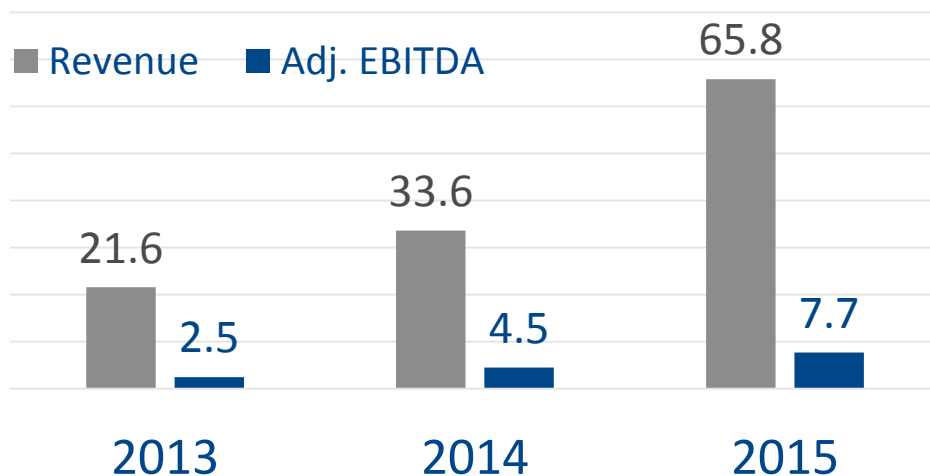
Source: GE Aviation website

# ○ SLM Solutions – A strong growth story

## Orders & Employees



## Financial Performance



- **March 21<sup>st</sup> 2016 enters TecDAX**
- Strategic focus on **metal based 3D printing**
- **Multi-laser systems 60% of orders**
- Strong **blue chip customer base**
- **40% orders from existing customer base**
- **Global presence** with subsidiaries in North America, China, Singapore, Russia

# ○ SLM Solutions – Product Portfolio



## **SLM 125<sup>HL</sup>**

**Build Chamber: 125 x 125 x 75mm**

**Laser – Single: 1 x 400 W**

**Build Speed: up to 25 cm<sup>3</sup>/h**



## **SLM 280<sup>HL</sup>**

**Build Chamber: 280 x 280 x 365mm**

**Laser – Single: 1 x 400 W or 700 W**

**Laser – Twin: 2 x 400 W**

**Build Speed: up to 55 cm<sup>3</sup>/h**



## **SLM 500<sup>HL</sup>**

**Build Chamber: 500 x 280 x 365mm**

**Laser – Twin: 2 x 400W or 700W**

**Laser – Quad: 4 x 400W**

**Build Speed: up to 105 cm<sup>3</sup>/h**



## ○ Customer Profile: Honeywell

- Honeywell operates multiple AM centers globally: Phoenix, Brno (Czech Republic), Shanghai
- Recently opened their reactive materials lab for Titanium and Aluminum
- “Honeywell plans a 30,000-square-foot facility for production additive manufacturing that will have another 10 to 16 machines.” (Source: AM Magazine)



Source:

<https://aerospace.honeywell.com/en/Error-500?aspxerrorpath=/en/blogs/2016/august/honeywell-commissions-new-3d-printing-facility>  
<https://aerospace.honeywell.com/news-listing/2016/may/honeywell-aerospace-chihuahua-mexico-opens-additive-manufacturing-center>  
<http://www.additivemanufacturing.media/blog/post/slideshow-inside-the-new-honeywell-am-facility-for-reactive-metals>



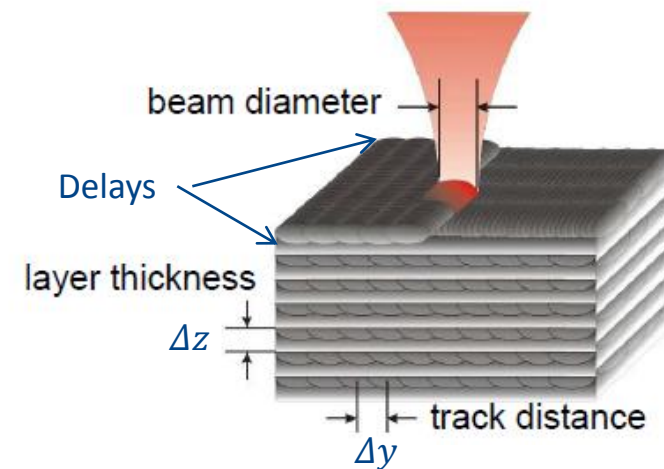
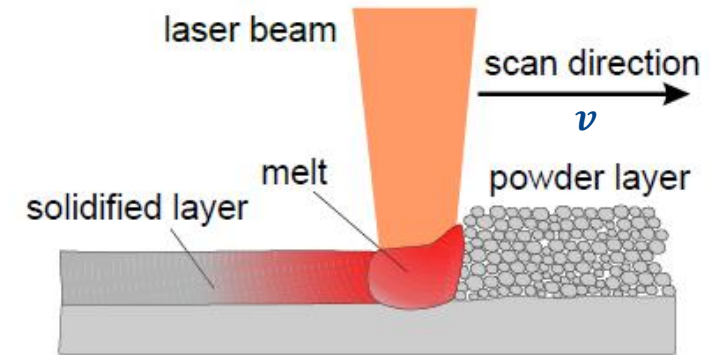
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# SLM Process & Materials



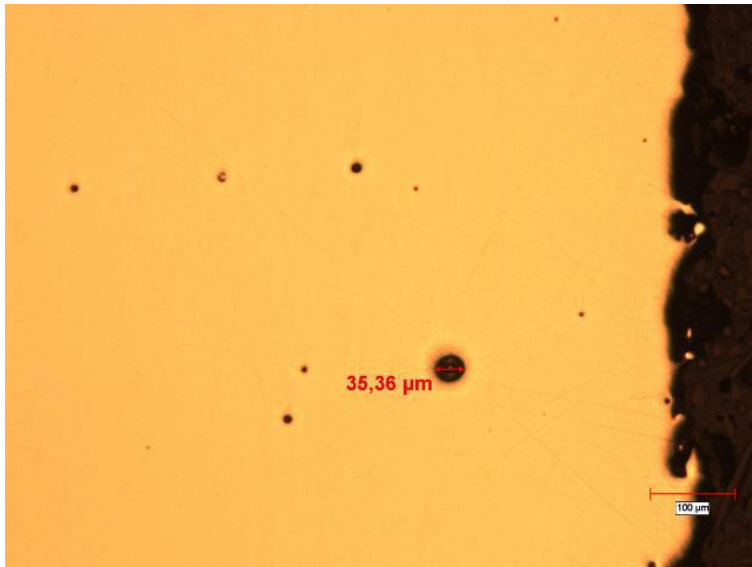
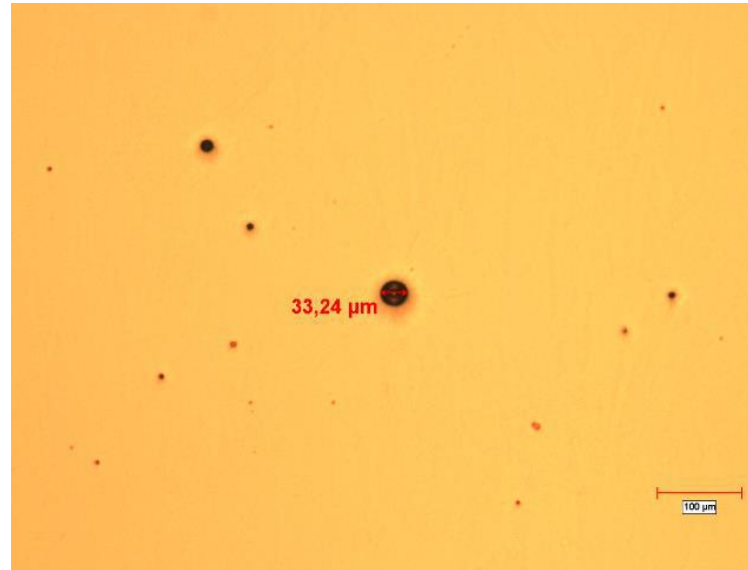
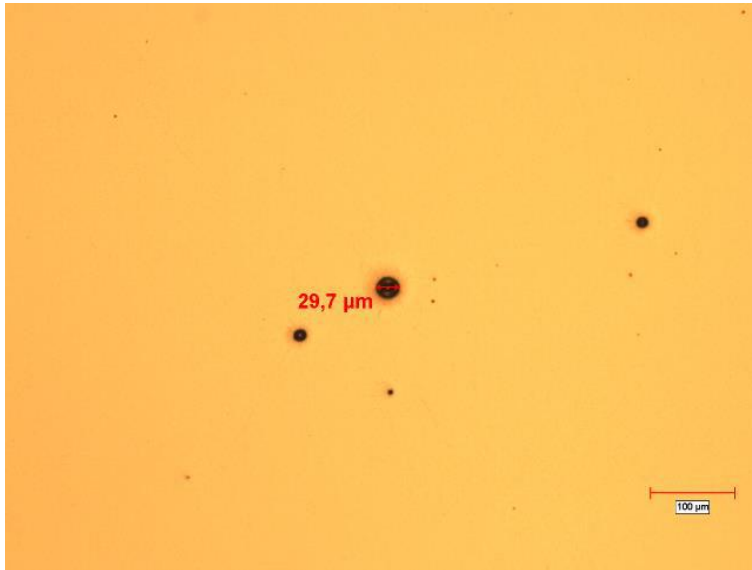
# ○ Key Parameters of the SLM Process

- Laser Power:  $L$
- Scan Velocity:  $v$
- Hatch Distance:  $\Delta y$
- Layer Thickness:  $\Delta z$
- ***Energy Density  $E = L / (v \times \Delta y \times \Delta z)$***



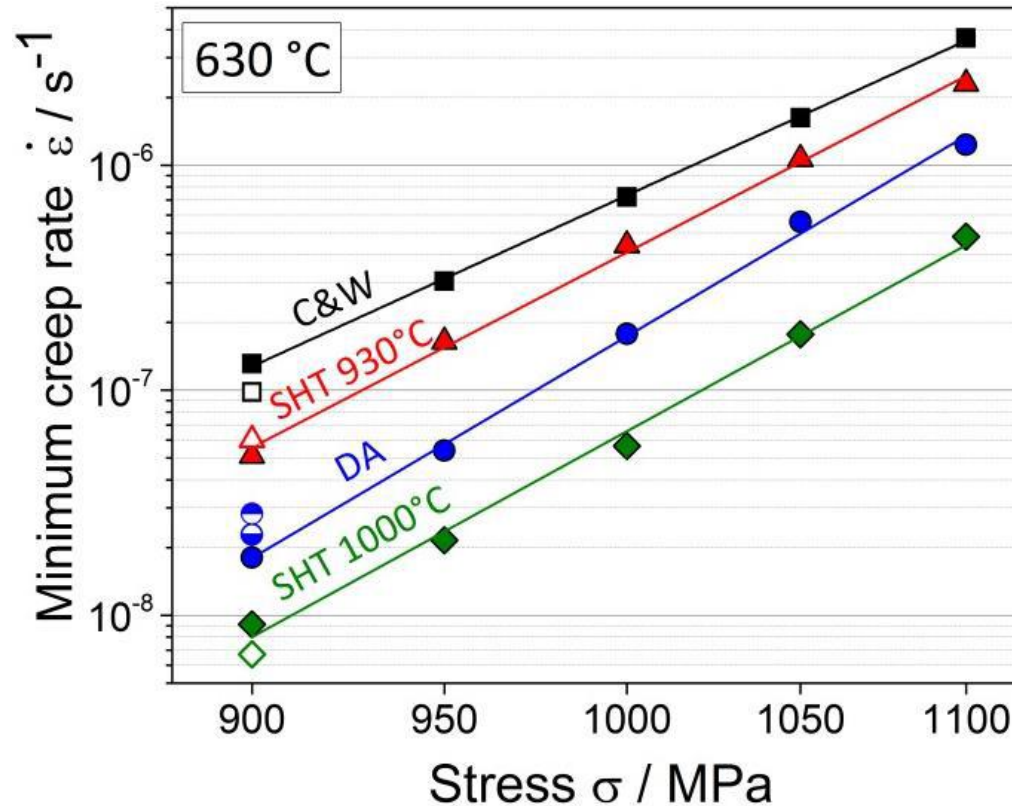
Picture Source: FhG ILT Aachen

# ○ Optimized Process Results for Inconel 718



Property	As-Built
Relative Density	> 99,5%
Largest Pore Size	< 100μm

# ○ Superior Creep Properties of SLM INC718 vs. Wrought INC718



- „C&W“: Cast and Wrought Material
- „SHT 930°C“: SLM Material Solution Heat Treated at 930°C
- „DA“: SLM Material Direct Aged
- „SHT 1000°C“: SLM Material Solution Heat Treated at 1000°C

Source: M. Pröbstle, S. Neumeier, J. Hopfenmüller, L.P. Freund, T. Niendorf, **D. Schwarze** and M. Göken, Superior creep strength of a nickel-based superalloy produced by selective laser melting, Materials Science & Engineering A, <http://dx.doi.org/10.1016/j.msea.2016.07.061>

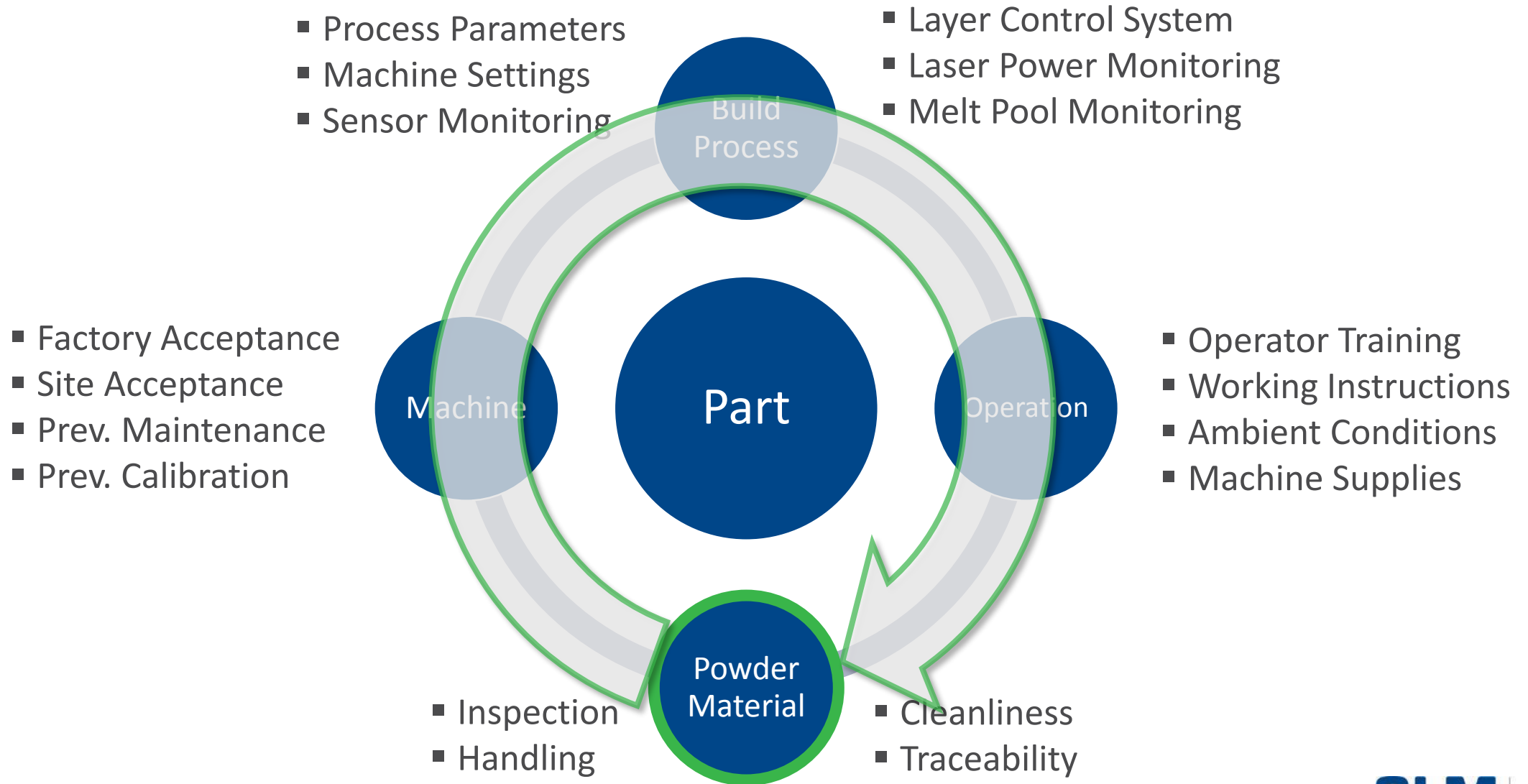




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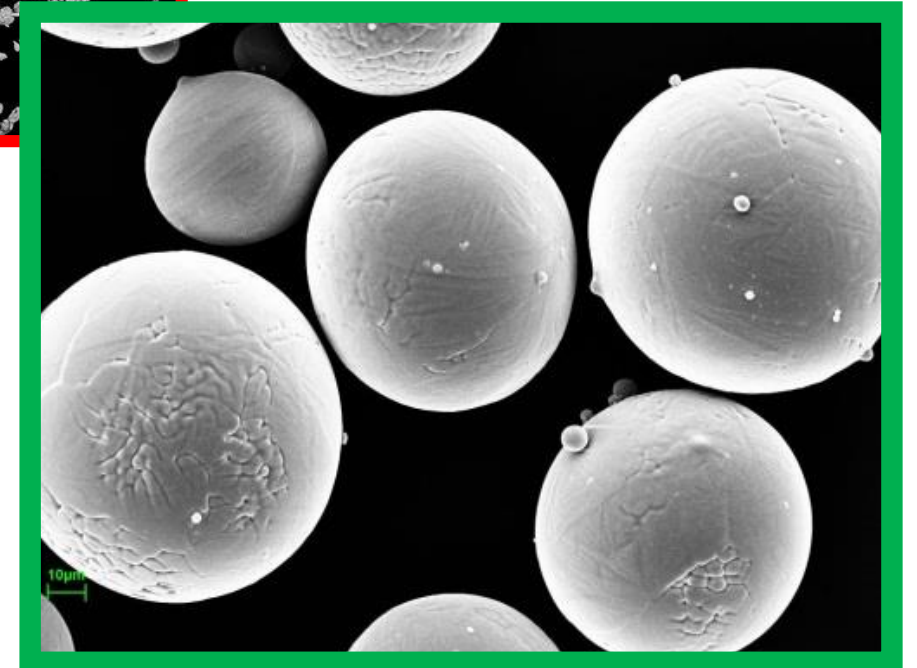
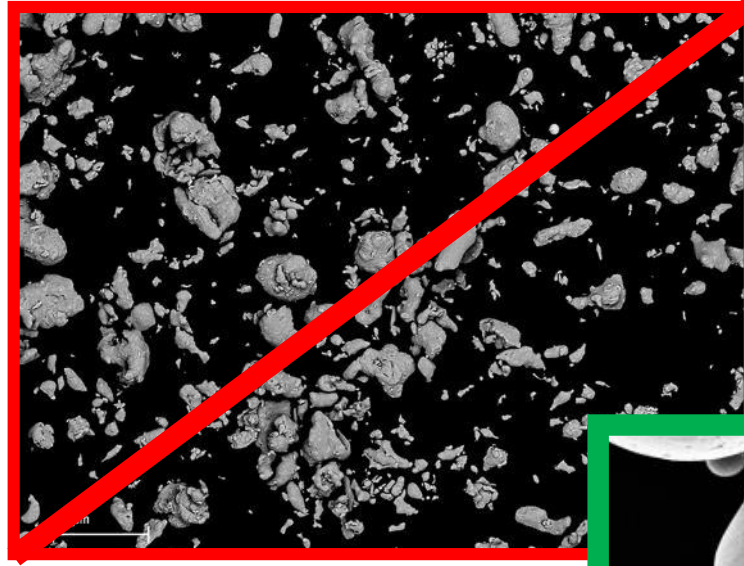
# Control of SLM Process

# ○ SLM Solutions – Approach for Process Control



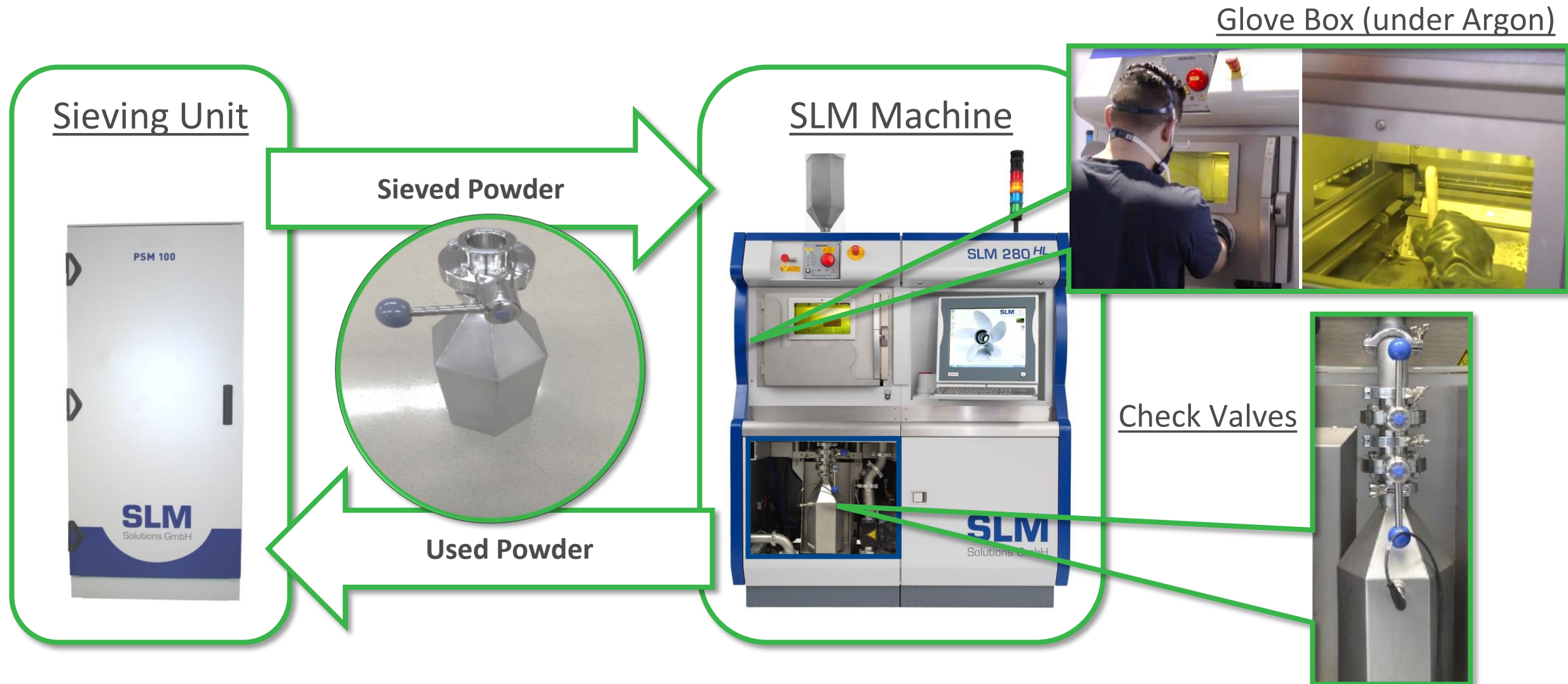
## ○ Powder Control – Incoming Inspection

- Spherical Particle Shape
- Particle Size Distribution
- Good Flowability
- Low Humidity
- Specified Chemical Composition

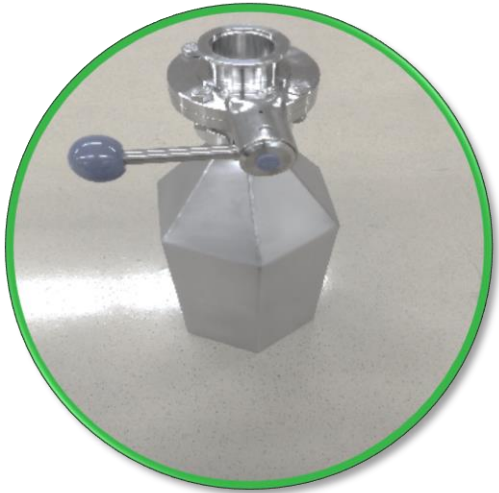




# ○ Powder Control – Canister Handling Solution



## ○ Powder Control – Benefits of the Canister Concept



- **Reduced Risk of Powder Contamination**
- **Traceability** of each Canister and Batch of Powder, e.g. by Bar-Code Labels
- Good Protection of worker's **Health & Safety**
- **Powder Refill without Interruption** of the Build Process

# ○ Powder Control – Closed-Loop Feeding Concept

## SLM Machine with Closed-Loop Feeding

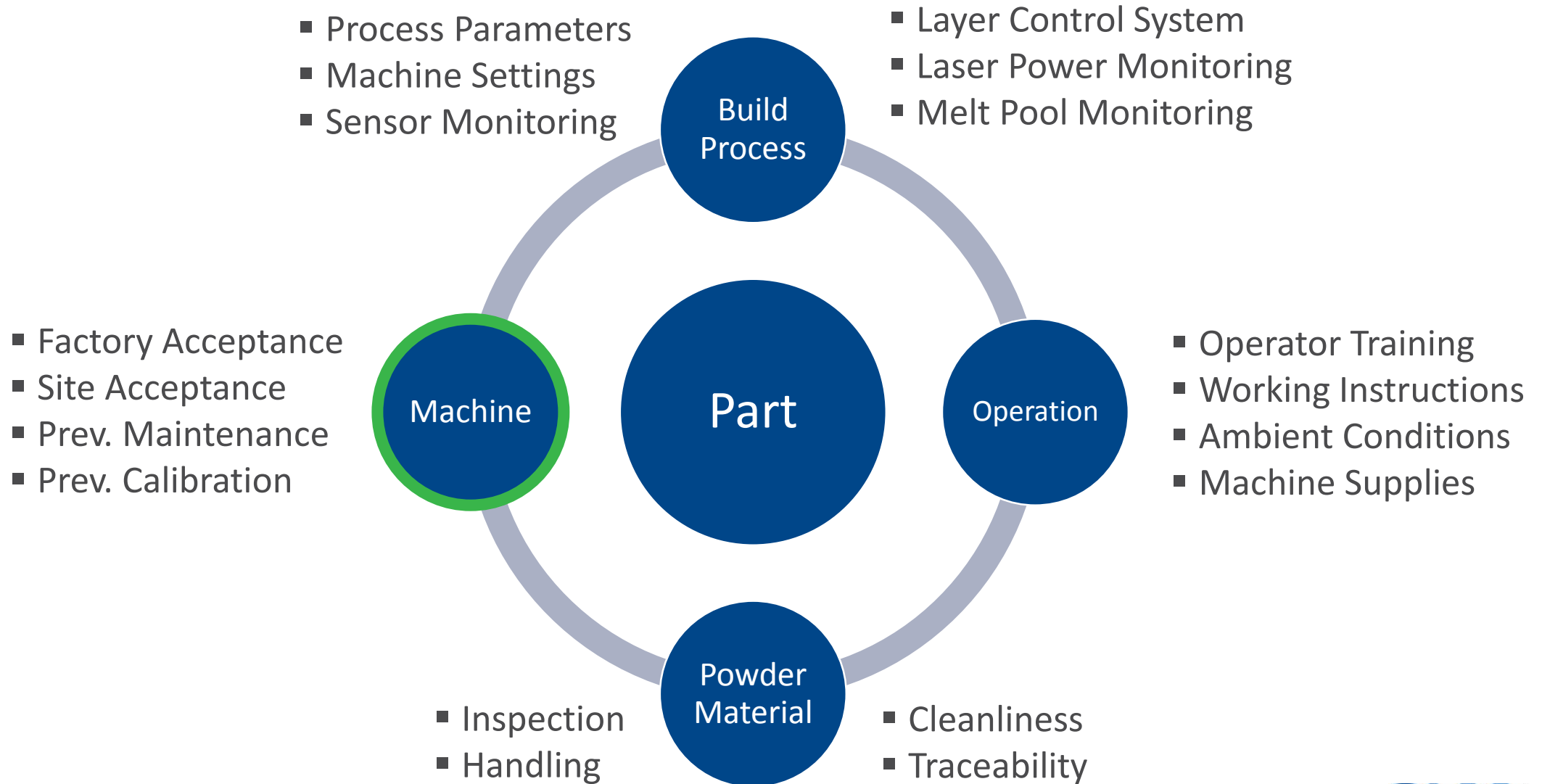


### Benefits:

- **No Powder Handling** for Sieving required
- **No Refill of Powder** over full build height required
- **Low Risk of Powder Contamination**
- **Excellent Protection of worker's Health & Safety**



# ○ SLM Solutions – Approach for Process Control

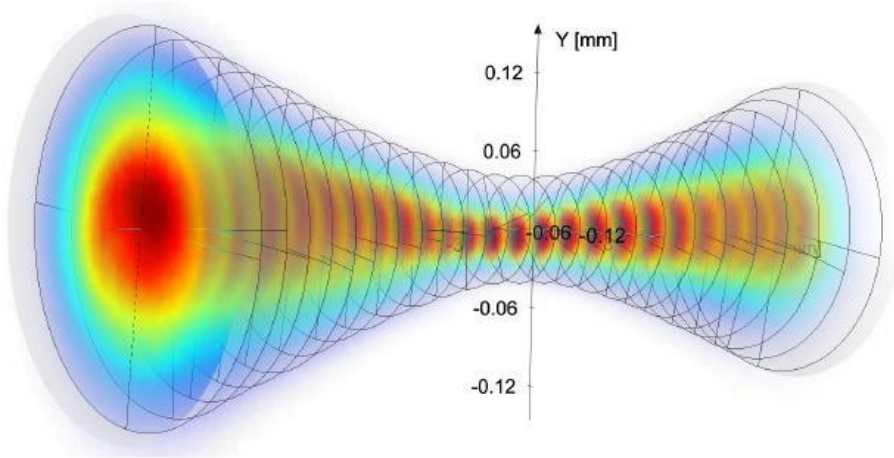


# ○ Machine Control – Preventive Calibration

## Defined Preventive Calibration Plan

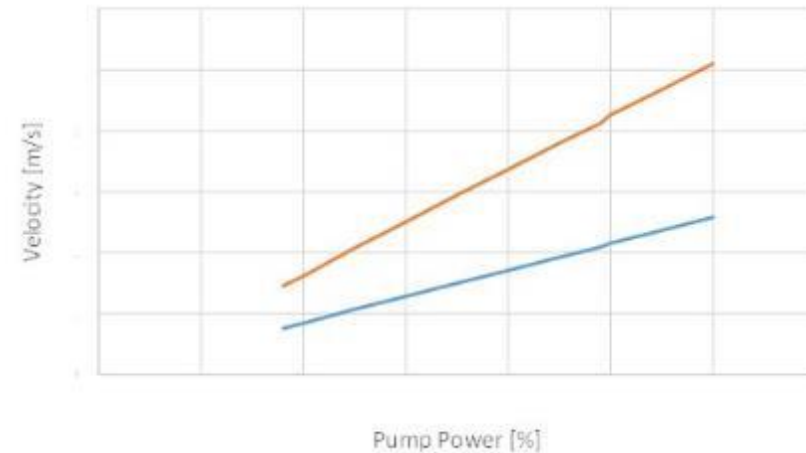
### ■ Calibration of **Optical Components**:

- Laser Power
- **Laser Beam Profile**
- Scanfield Calibration

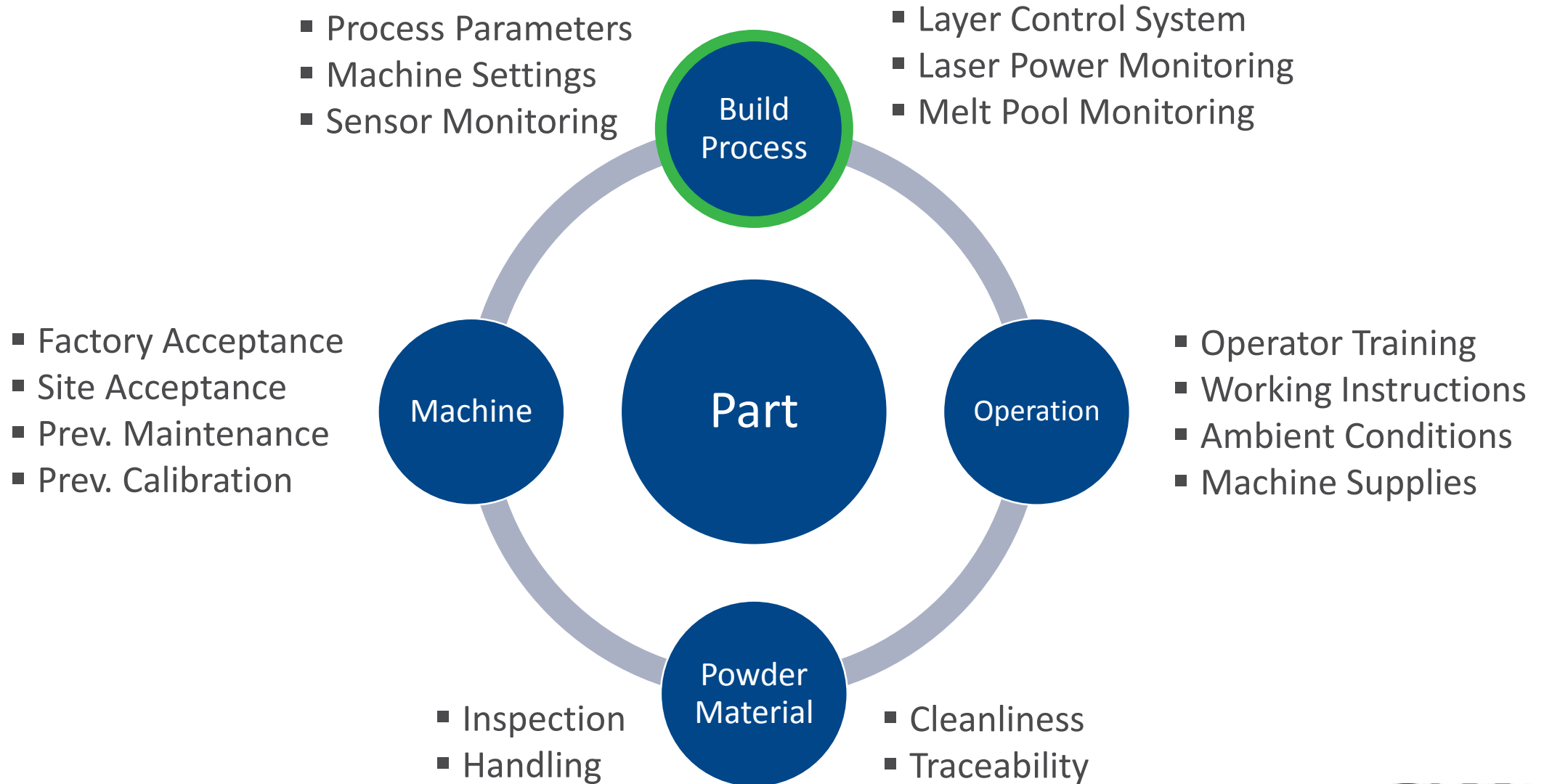


### ■ Calibration of **Sensors**:

- Oxygen
- **Gas Flow**
- Pressure



# ○ SLM Solutions – Approach for Process Control





# ○ Build Process Control – 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	-	-	-	I
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	I
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	I
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	I
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	I
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	I
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	I
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	I
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	I

Protocol

Sensors

## Specification:

- Monitoring of sensor data every 2 seconds.
- Control and output of for example:
  - Temperature,
  - Oxygen and
  - Filter Condition

## Benefits:

- Closed-loop control for stable process conditions
- Documentation of process conditions for identification of anomalies
- Possibility to adjust individual process limits

# ○ Build Process Control – Layer Control System

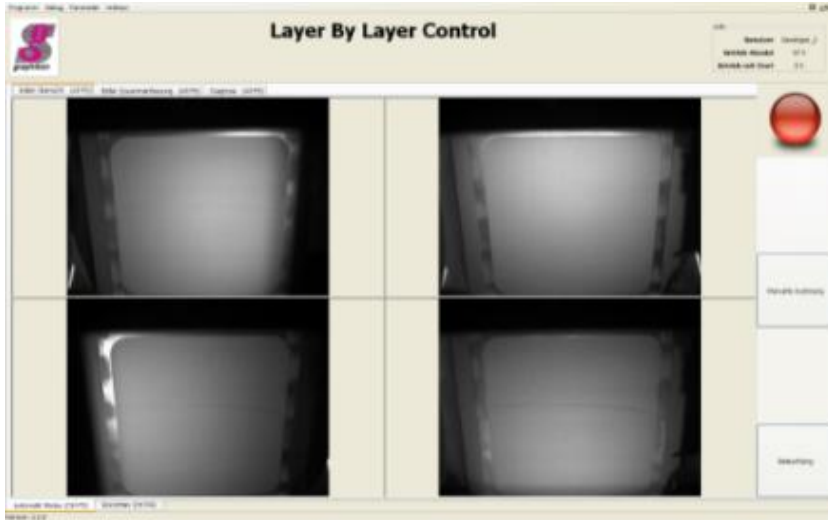


Figure: Automatic error detection of the hole platform.

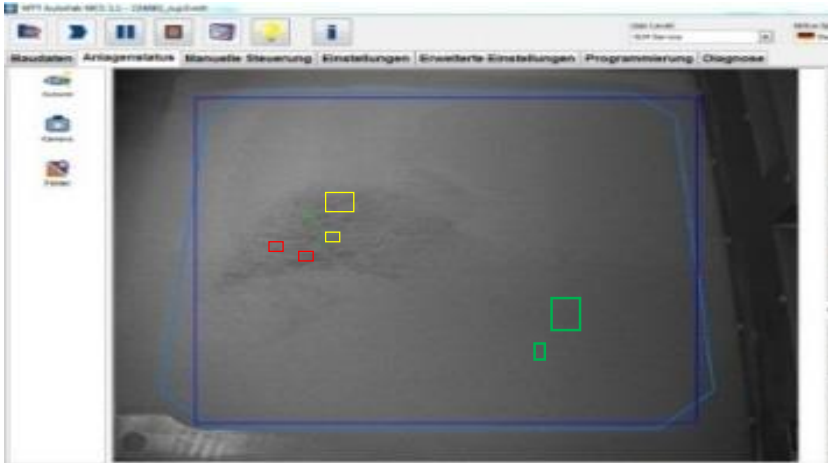


Figure: Automatic error detection of individual process errors.

## Specification:

- Image documentation after powder application and after exposure
- Automatic analysis of the captured image data
- Error detection according to defined limits

## Benefits:

- In-Process Identification of individual process errors
- Possibility of automatic error correction
- Documentation of all layers of the Build Job
- Time and cost savings by early cancellation of builds

## ○ Build Process Control – Laser Power Monitoring (LPM)

- Laser beam is split before entering the build chamber
- **As-Is laser power** is measured constantly
- Comparison with target laser power
- **Documentation** of the laser power over the full build job
- Analysis to **detect anomalies** in the power profile and correlate with **part defects**

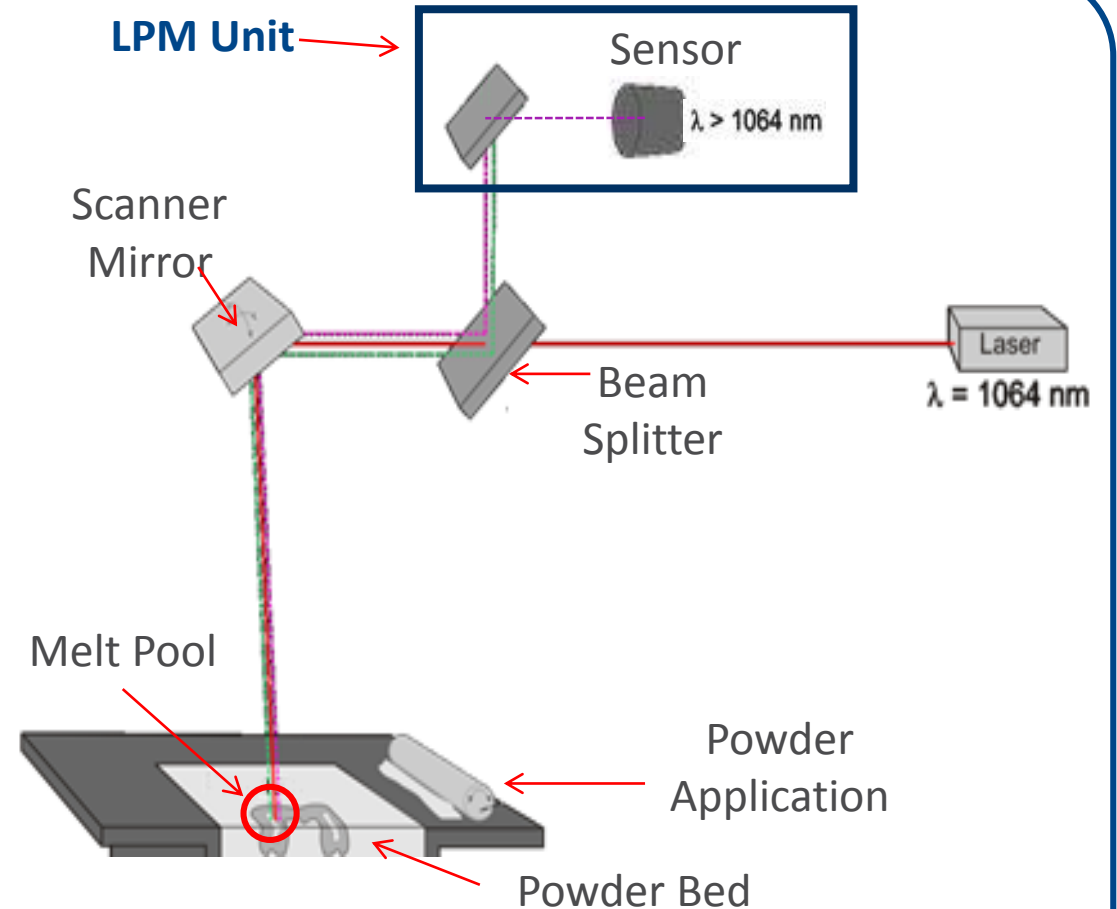
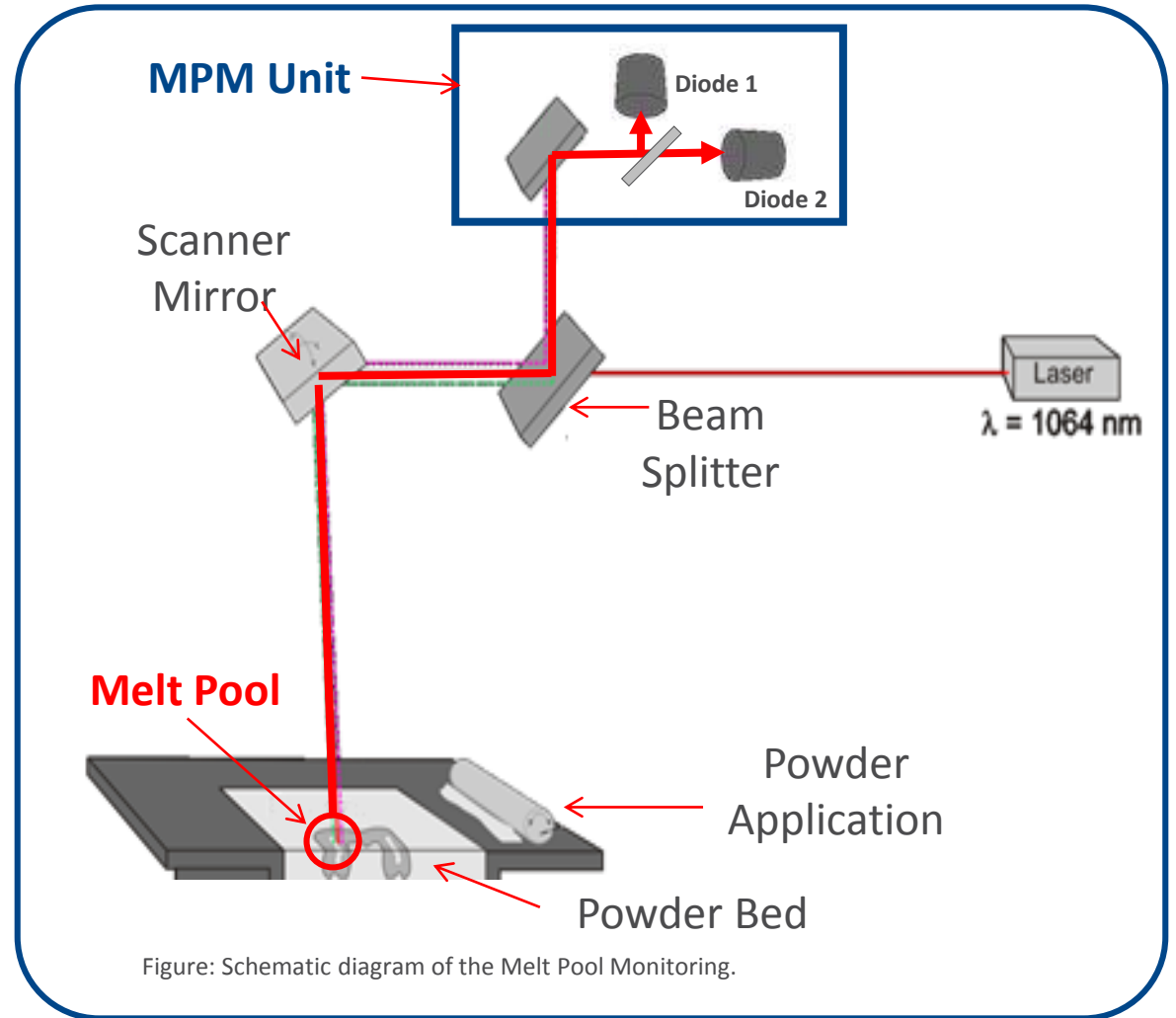


Figure: Schematic diagram of the Melt Pool Monitoring.



# ○ Build Process Control – Melt Pool Monitoring (MPM)

- Pyrometric Measurement of the **thermal radiation intensity** from the melt pool
- **On-Axis System** → Measurement point moves with the laser beam
- Use of a two colour pyrometer
- **Measurement with 100 kHz**  
→ potential to be used for closed-loop control
- Intensity profile of individual melting / scan lines
- **Correlation with material defects**



## ○ Build Process Control – MPM: Plotting and Analysis

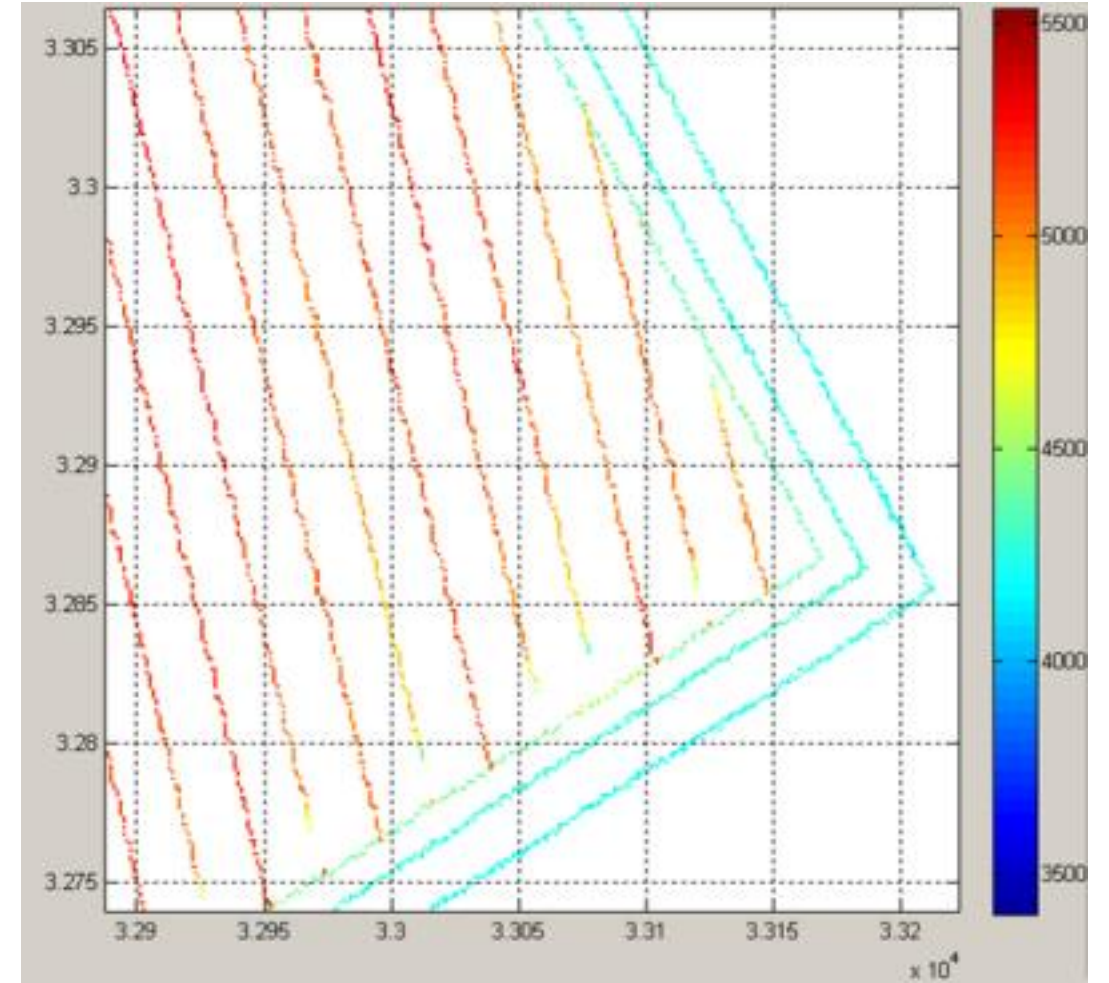
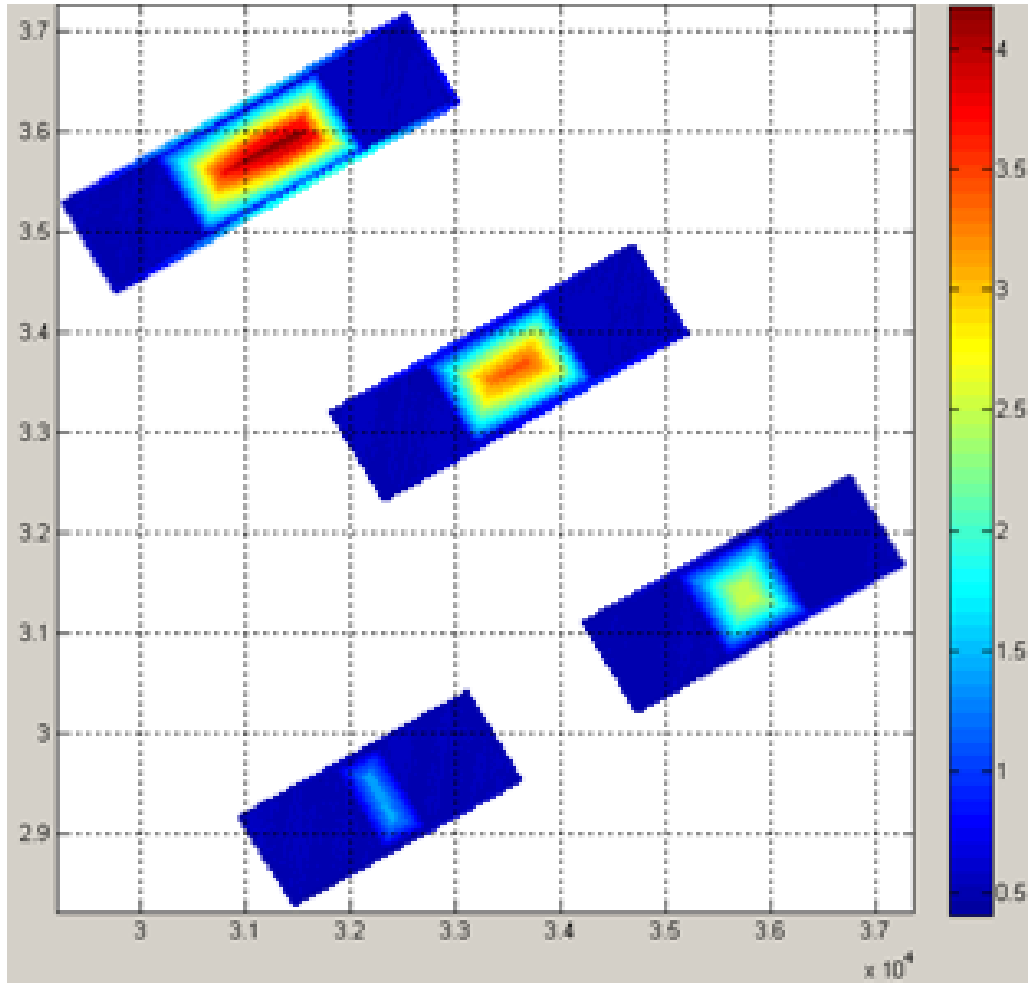
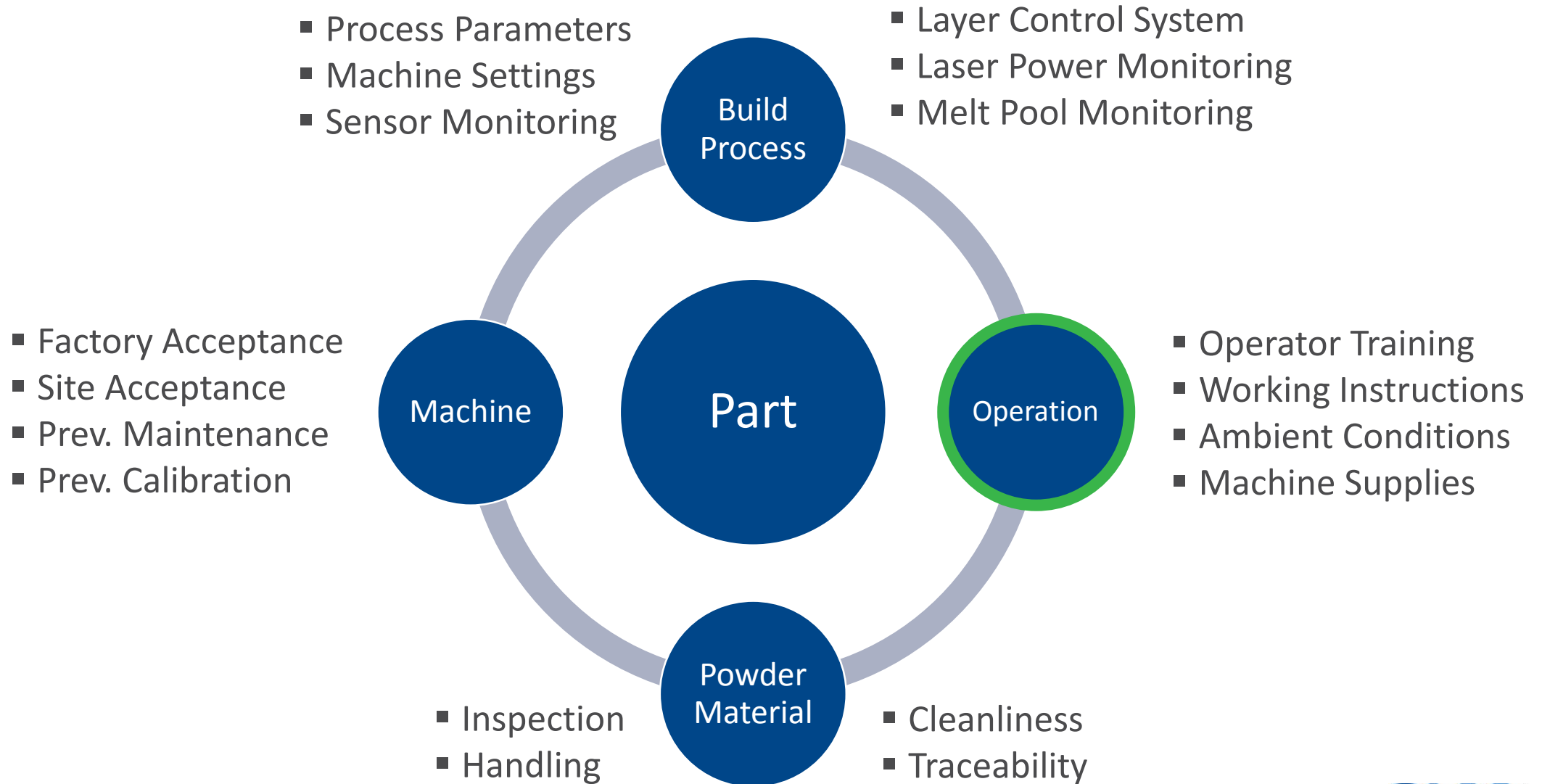


Figure: Visualization of the thermal radiation map of a current layer

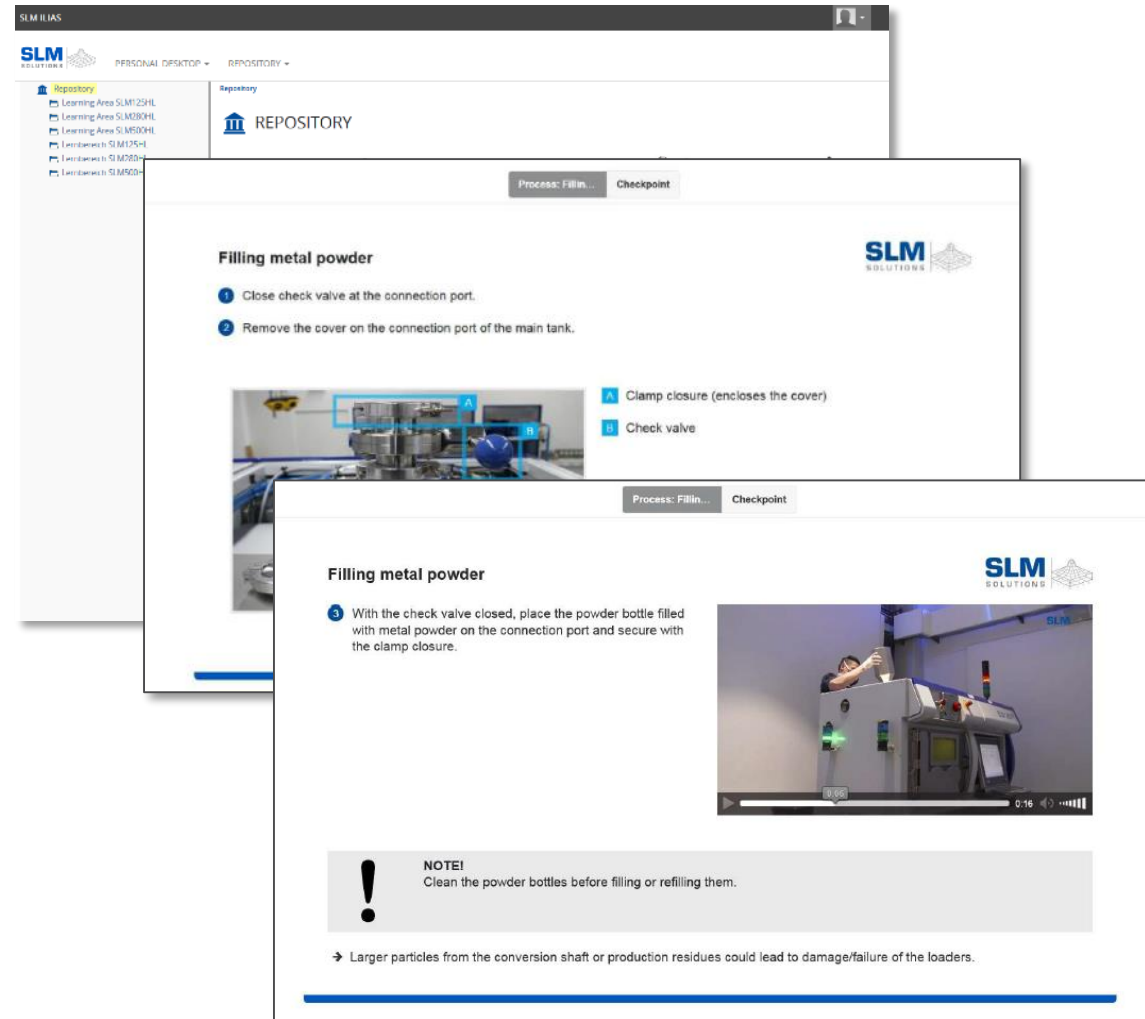
# ○ SLM Solutions – Approach for Process Control





# ○ Operation Control – SLM eLearning Portal for Operator Training

- Training for different Machines, Tasks and Experience Levels
- Step by step learning process including **video material**
- **Assessment** at the end of a session
- Follow **learning progress** of users
- Documented learning results





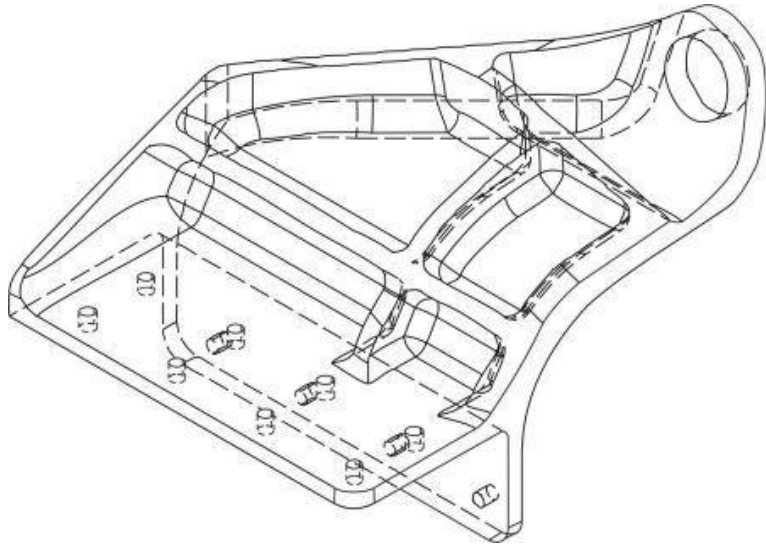
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# Aerospace Applications

# ○ Aircraft Application: Bionic Cabin Bracket



## Conventional Design



Source: Airbus

- Machined from Solid Block
- Buy-To-Fly Ratio: 13 (17kg/1,3kg)
- High Set-Up & Span Times
- 7000 Al Alloy

## Bionic Design



Source: Laser Zentrum Nord

- **50% Weight Reduction**
- **Improved Buy-To-Fly Ratio: ~1-2**
- Build Time for 2 Parts: 41:23h
- AlSi10Mg

## Application

- Aircraft:  
Airbus A380
- Upper Deck Cabin  
Bracket
- Connecting Crew  
Rest with Stringers
- Lot Size:  
1 part per aircraft



# ○ MRO Application: Turbine Shroud Repair

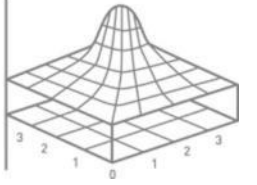


**Lufthansa Technik**

- High batch repair with SLM process
- Cost saving potential: 40%
- SLM Research Contribution:
  - Software Module for Hybrid Build
  - Clamping Device







**Thank you for listening!**

A presentation by:

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