End-to-end process control with standardized off-the-shelf components

Daniel Reitemeyer
Business Development

Content

End-to-end process control with standardized off-the-shelf components

Part 1: Off-the-shelf components for modern LPBF machines

Part 2: End-to-end process control

SCANLAB at a Glance

- Worldwide leading OEM manufacturer of scan solutions for deflecting and positioning laser beams
- Our high-performance components are the core of e.g.:
  - Laser welding robots
  - Laser systems for medical treatments
  - Micro-structuring systems
  - LPBF machines
- About 40,000 units manufactured and installed annually
- Trendsetting developments in the fields of electronics, mechanics and optics

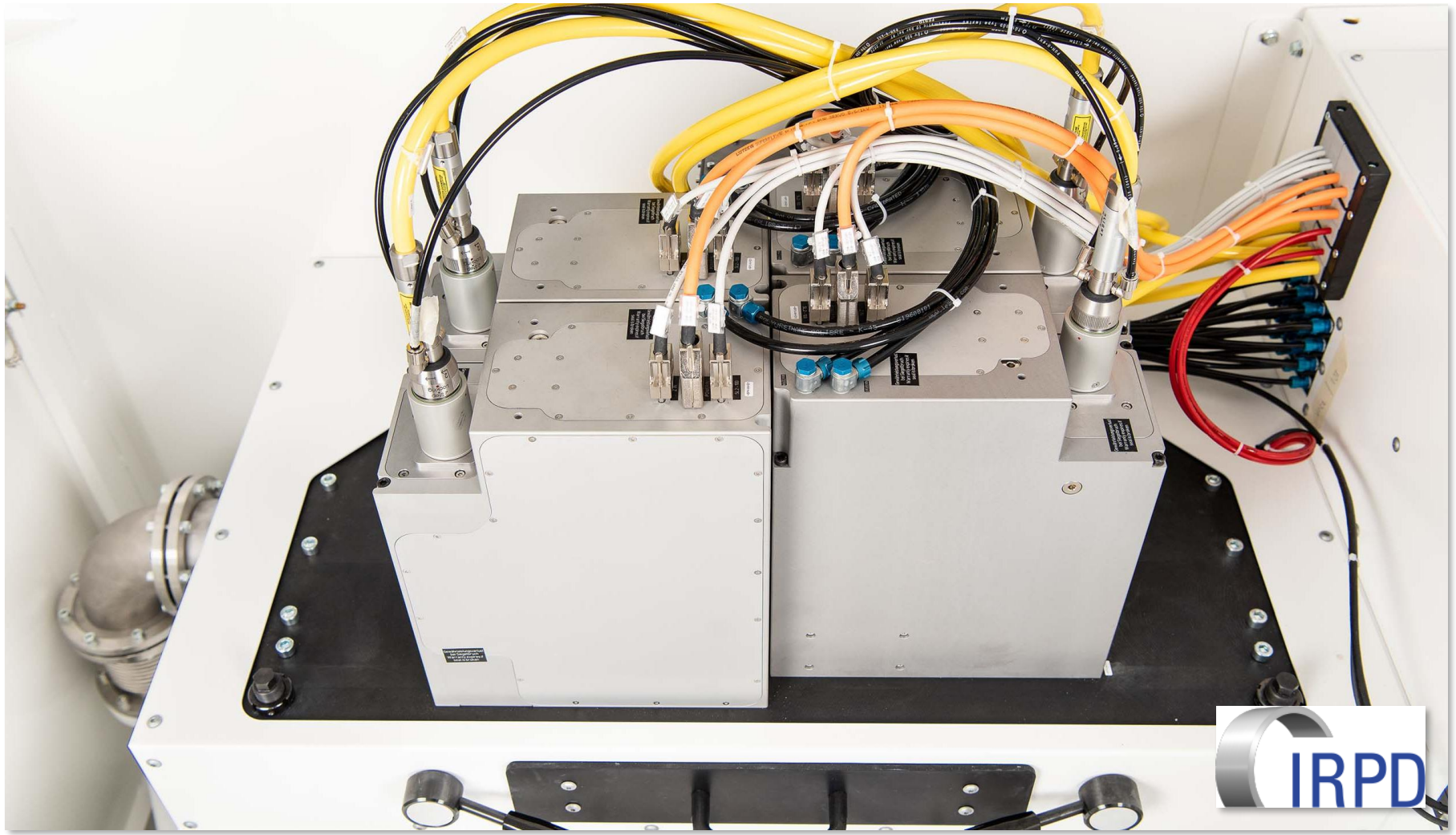
Mirrors in motion

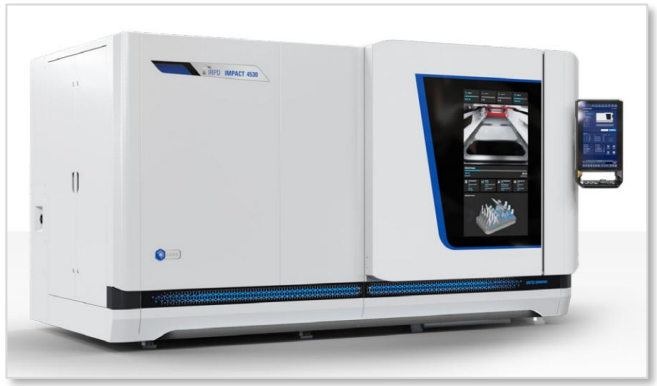
Fastest Beam Deflection for Laser Powder Bed Fusion

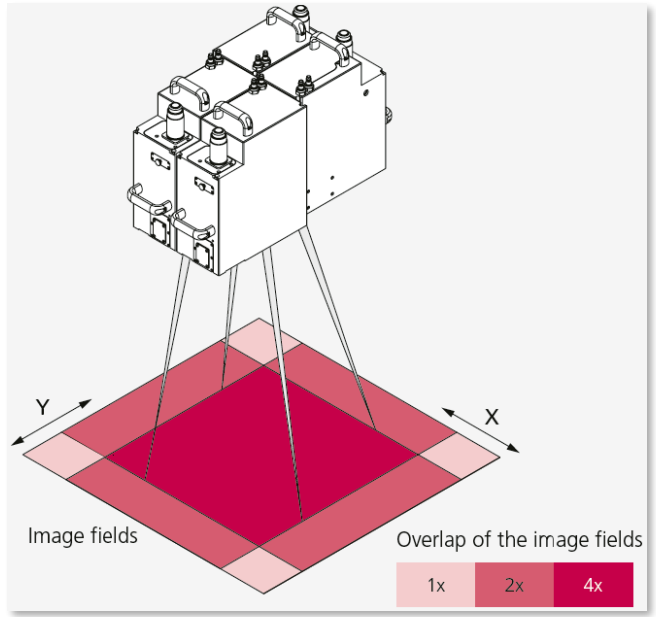
watch video online

Off-the-shelf optical bench for LPBF

fiberSYS – maximum field overlap for multi laser machines







Multi-laser synchronization - RTC

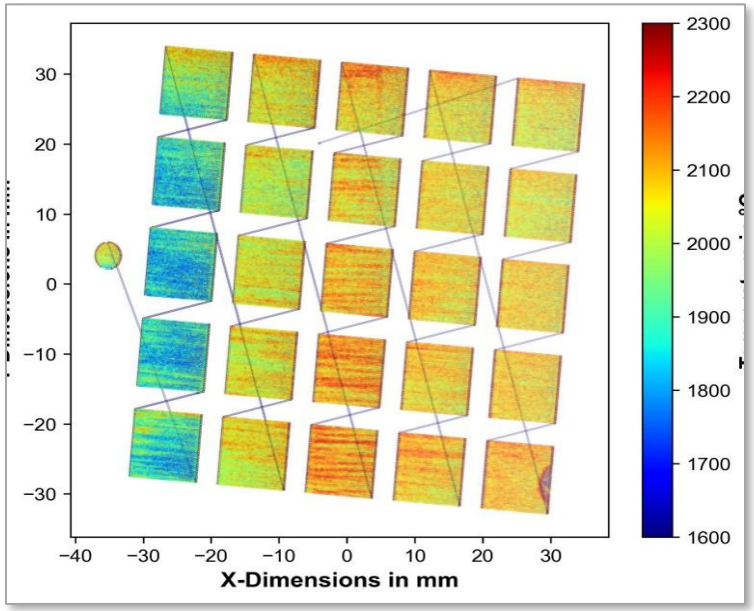
Real time control of Scan system and laser with 10 µs cycle time

RTC

- Quick, precise, synchronized control of 2D and 3D scan systems, lasers and peripheral equipment in real time
- 2D and 3D image field correction
- Status signal evaluation
- Processing-on-the-fly functionality for moving objects
- Control of 3-axis scan systems
- Option: micro vectoring with 10 µs steps
- Master/Slave configuration for synchronized processing in multi-laser machines, e.g. 2 trailing laser beams
- PCI_e and Ethernet interfaces, also as DIN rail version

100 kHz Process Monitoring & Closed Loop Control

Open Interface Extension (OIE) - Control Electronics and Sensor Interfaces



OIE extends the RTC6 Scan control card with

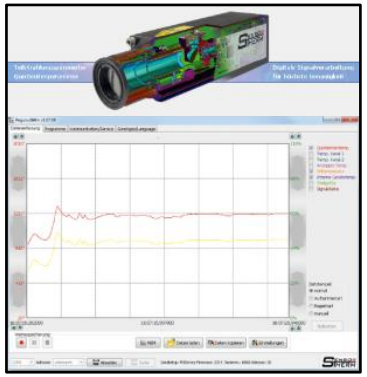
- Third Party Sensor Interfaces
- synchronization of third-party process sensors with 100 kHz position data
- Interface for machine’s process data base/analysis

Features

- 100 kHz data synchronization based on most accurate position data source: returned actual positions of the scan axes
- Correction of position dependent deviations possible
- Closed loop melt pool control and data synchronization at the same time

Closed-loop melt pool control

Real time systems for sensor based laser power control



Third-party process sensor

+

Open Interface Extension (OIE)

+

RTC scan and laser control board

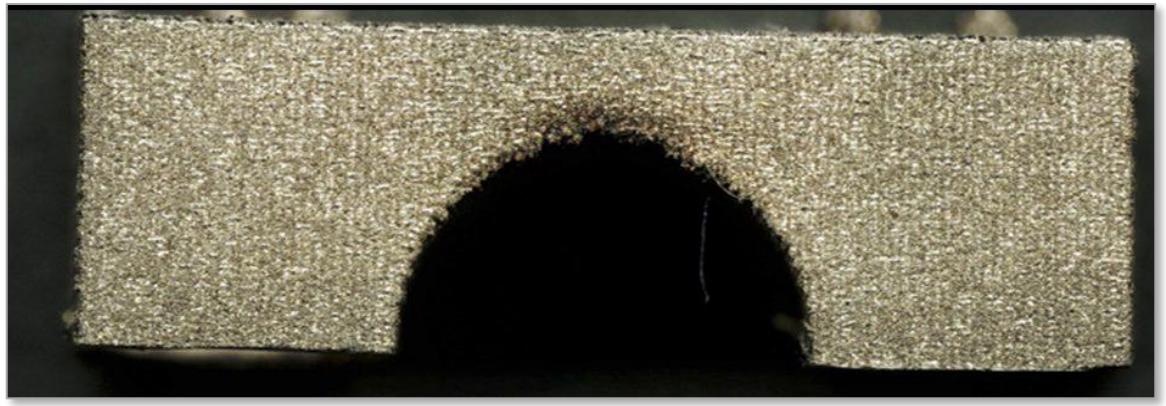
SCANLAB offers all hardware components for closed loop melt pool control

- real time scan head control: RTC sets laser power with 100 kHz
- with OIE: sensor input connected to real time system

OIE enables customers to transform process knowledge into own process control IP and USPs

100 kHz Closed-loop melt pool control

Advanced feature set for switching on vector level



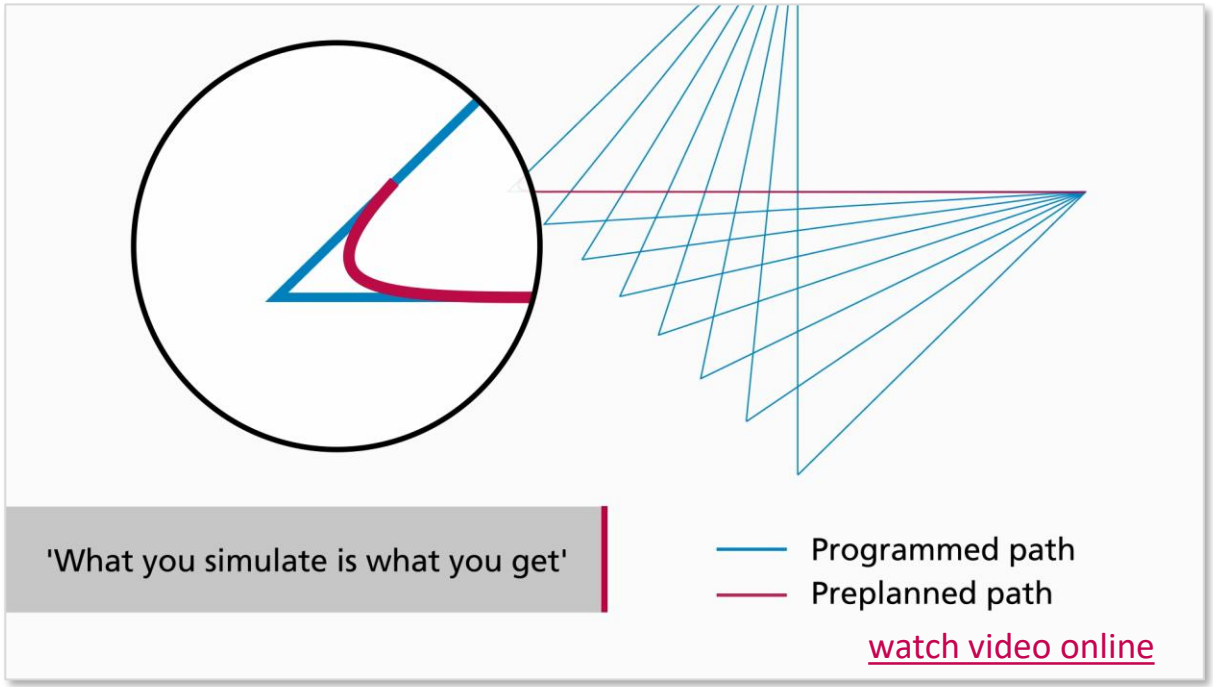
Overhang with uncontrolled laser power (316L, constant power 300W, 1050mm/s)

Overhang with controlled laser power (316L, base power 300W, 1050mm/s)

- **Parameter switching**
  - Up to 63 PID parameter sets per layer, vector-wise switchable, e.g. for hatch vs. contour
  - Auto switch to another parameter set after x-times 10 µs, for vector beginning vs. ongoing vector
- **Hold (e.g. for sky writing)**
  - Auto start/hold with Laser On/Off
  - Faulty measurement values during Laser Off are ignored
  - Filter buffer stays filled
- **Reset (e.g. for jumps to other areas)**
  - Resets filter buffer and/or control error

Scan Control

Real time control of Scan system and laser with 10 µs cycle time



Hardware: RTC6

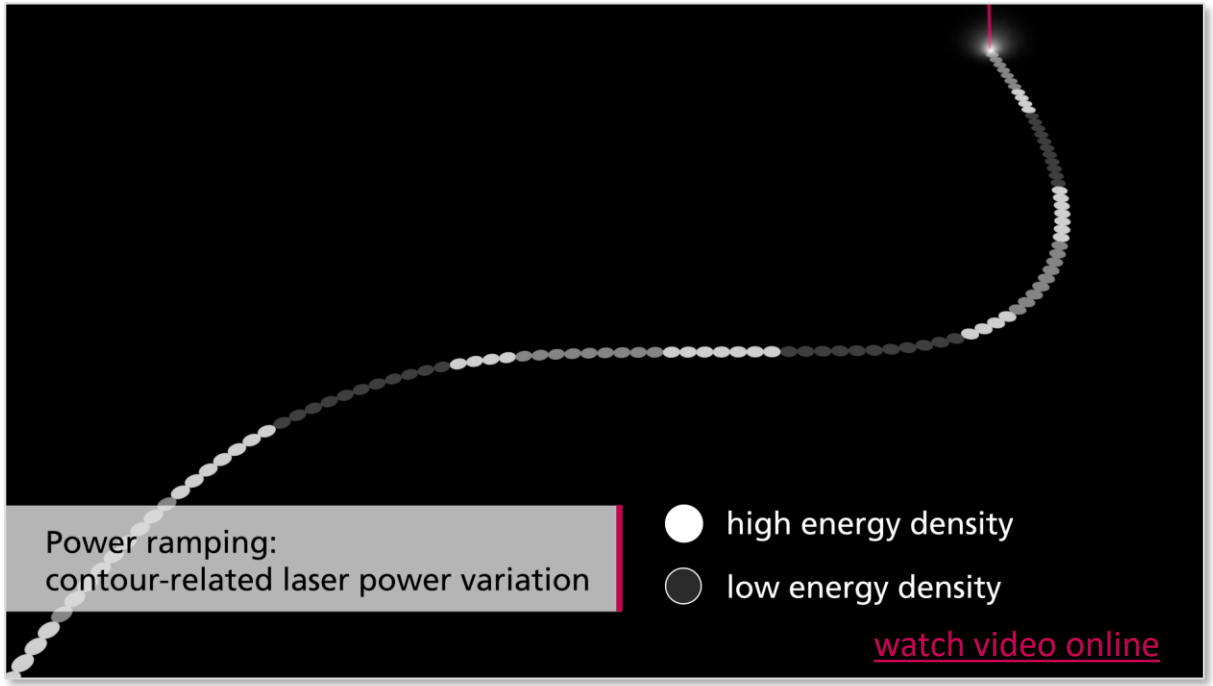
- Scan head and laser control with 100 kHz frequency
- Synchronization of all laser beams in multi-laser machines, e.g. 2 trailing laser beams

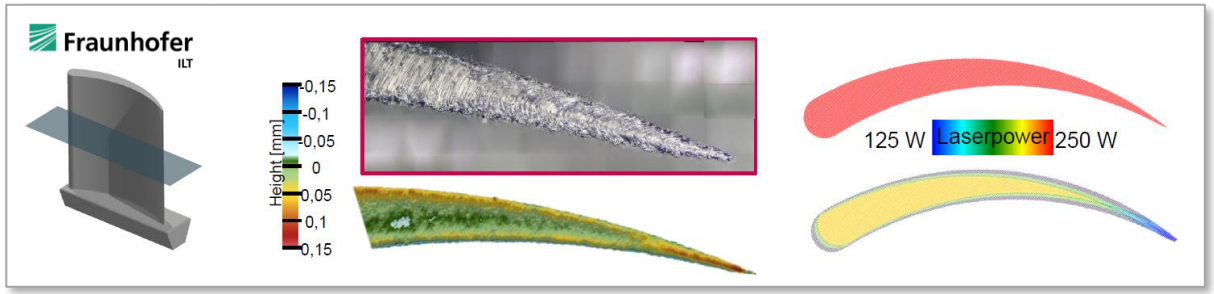
Software: *SCAN*motionControl

- pipeline based laser trajectory planning software
- offline laser path simulation including physical characteristics of the scan system
- “What you simulate is what you get”

Point cloud based parameter assignment

LPBF specific advantage of SCANmotionControl





SCANmotionControl

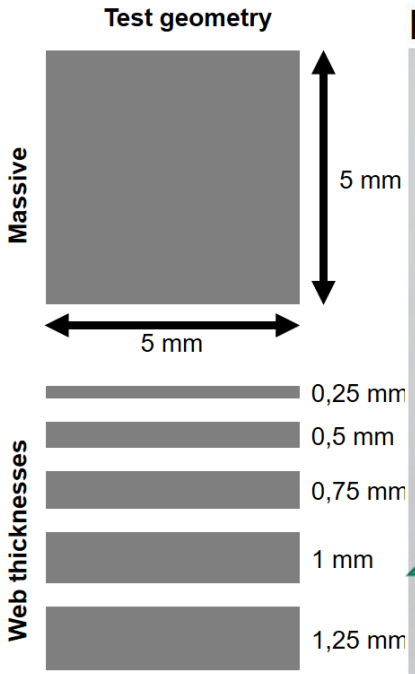
- 100 kHz power assignment -> @ typical LPBF speed of 1 m/s
  –> 10 µm point cloud parameter grid.
- Variation of speed at the same time

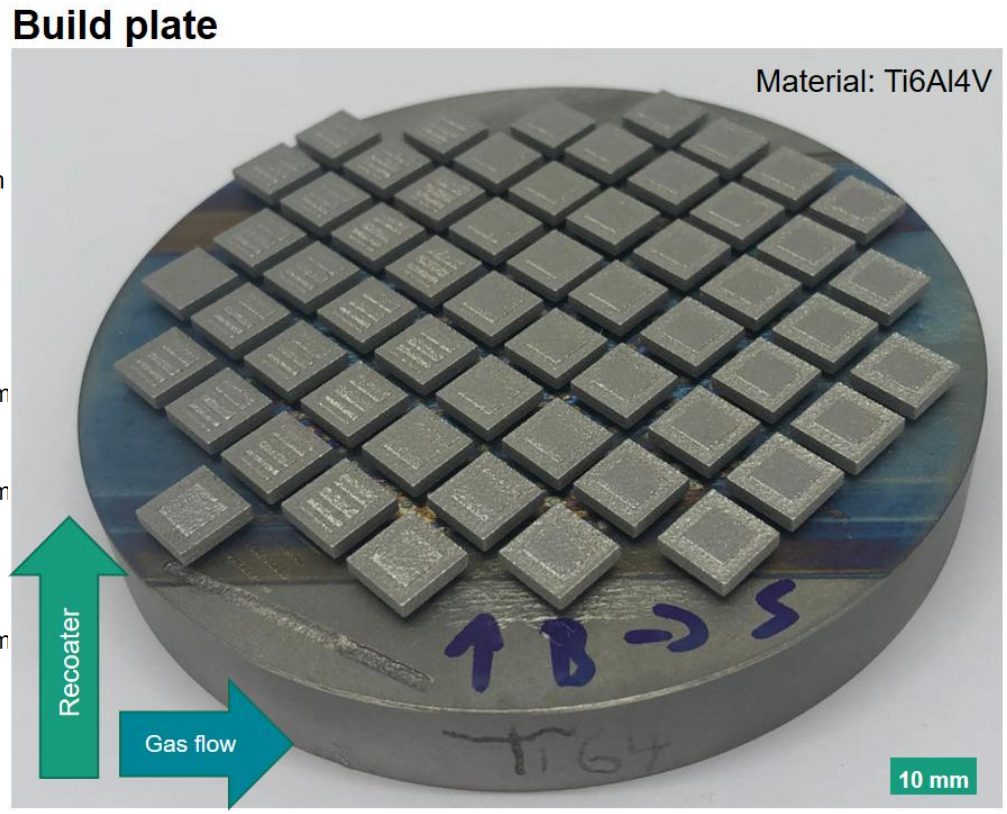
LPBF: Geometry adapted process control

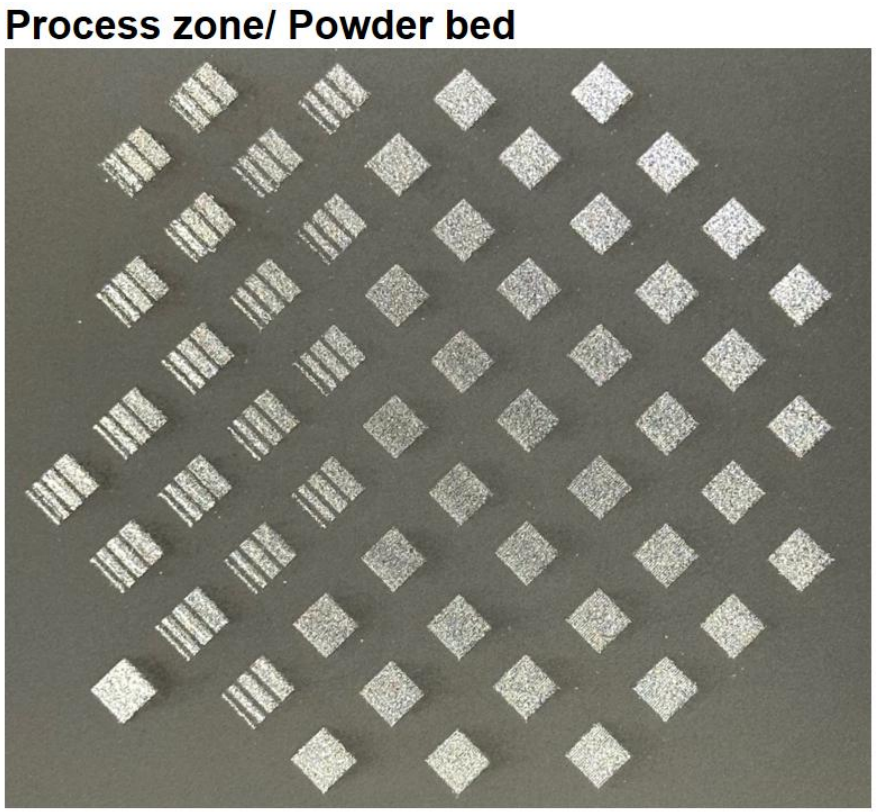
- Project with Fraunhofer ILT
- Suppression of edge bulging
- Rampings as a function of vector length

Experimental Set-up

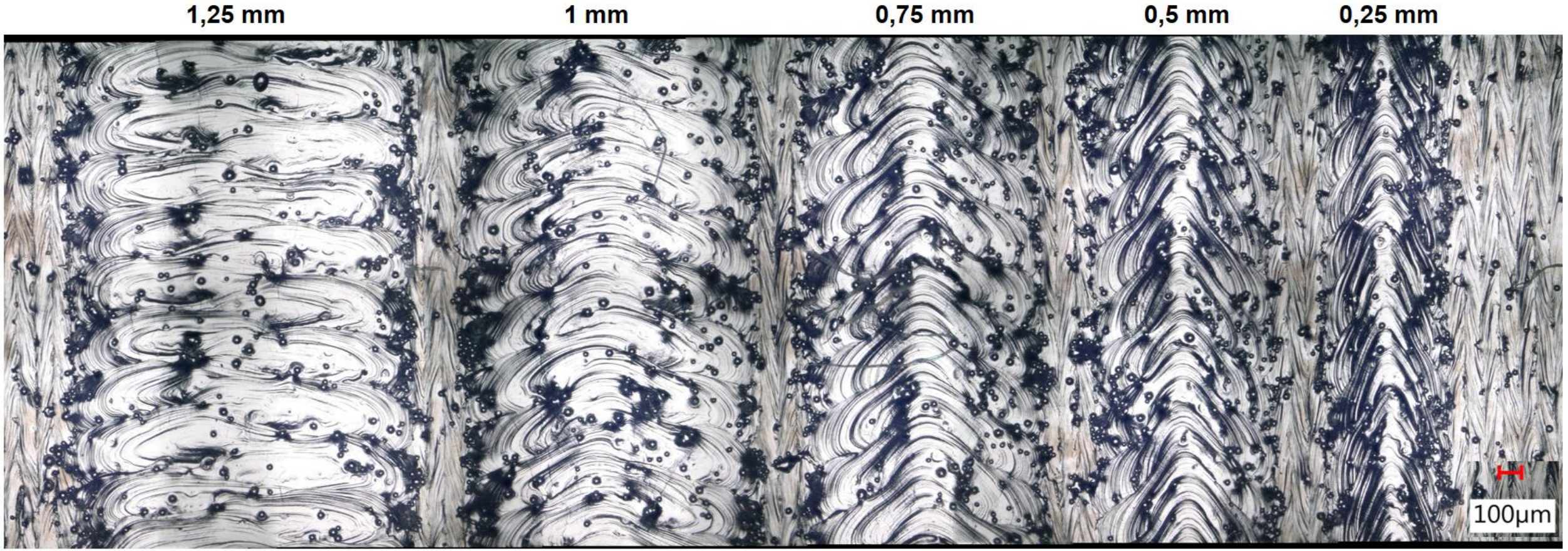
Parameter investigation with test cubes with varied web thicknesses







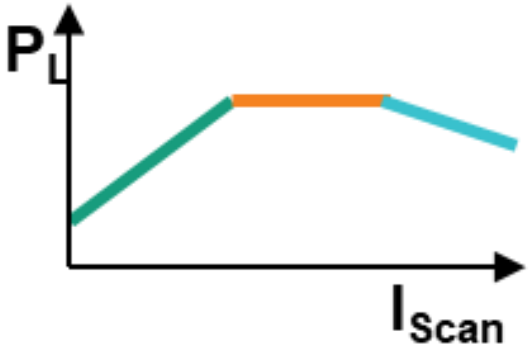
Benchmark: Constant parameters



- Melt tracks to not represent hatch vectors any longer when vectors get shorter
- → correlation between programmed and resulting geometry is reduced

New Possiblities with SMC

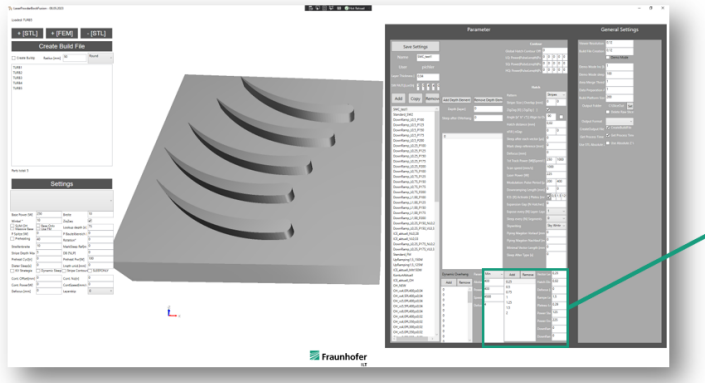
*SCAN*motionControl



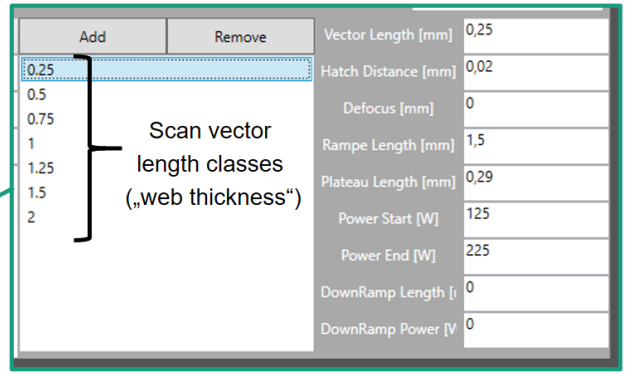
Data Preparation

- Process parameters for ramps as a function of vector length classes

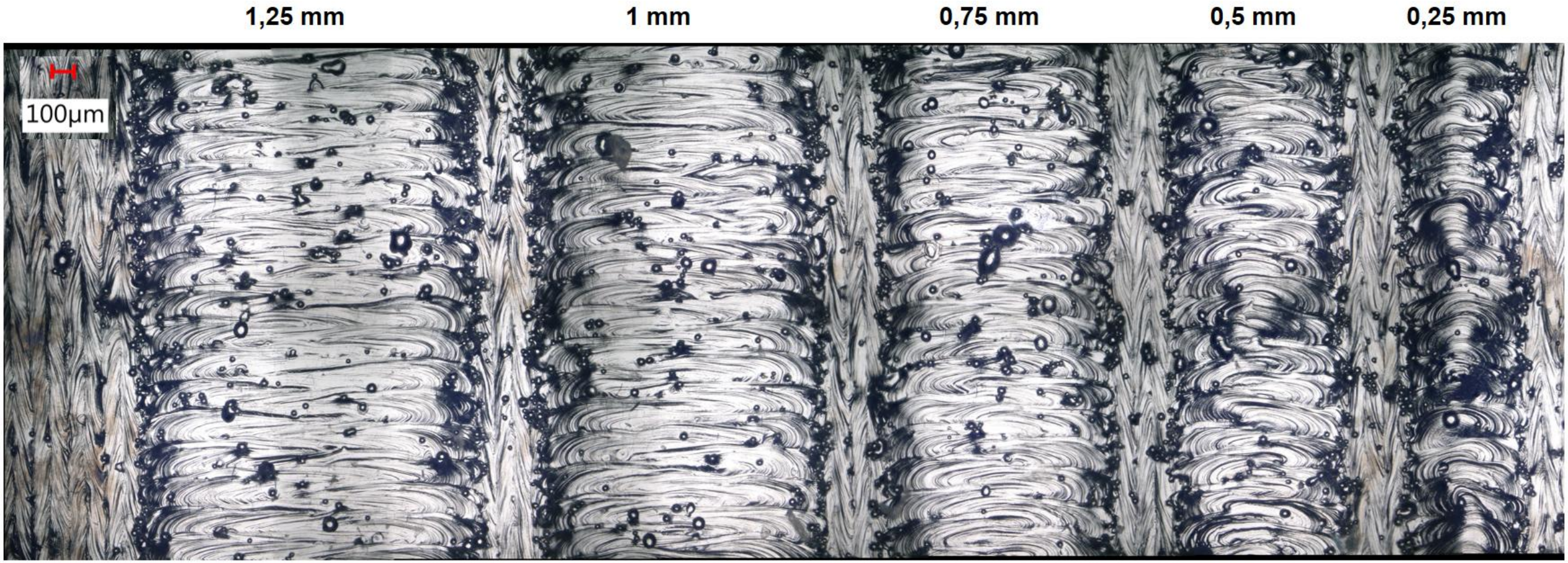
Software for Data Preparation



Adaptive Hatch Parametrization



Adaption with linear Power Ramps

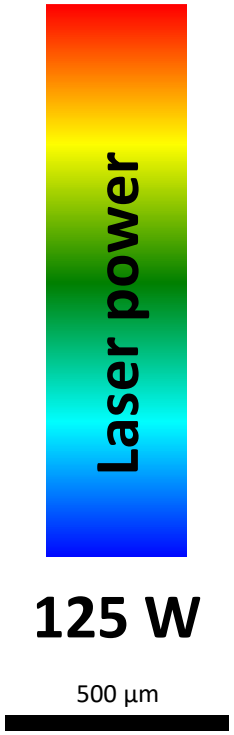


- **Melt tracks follow programmed vectors, even at short vectors**
- **Correlation between programmed and resulting geometry maintained**

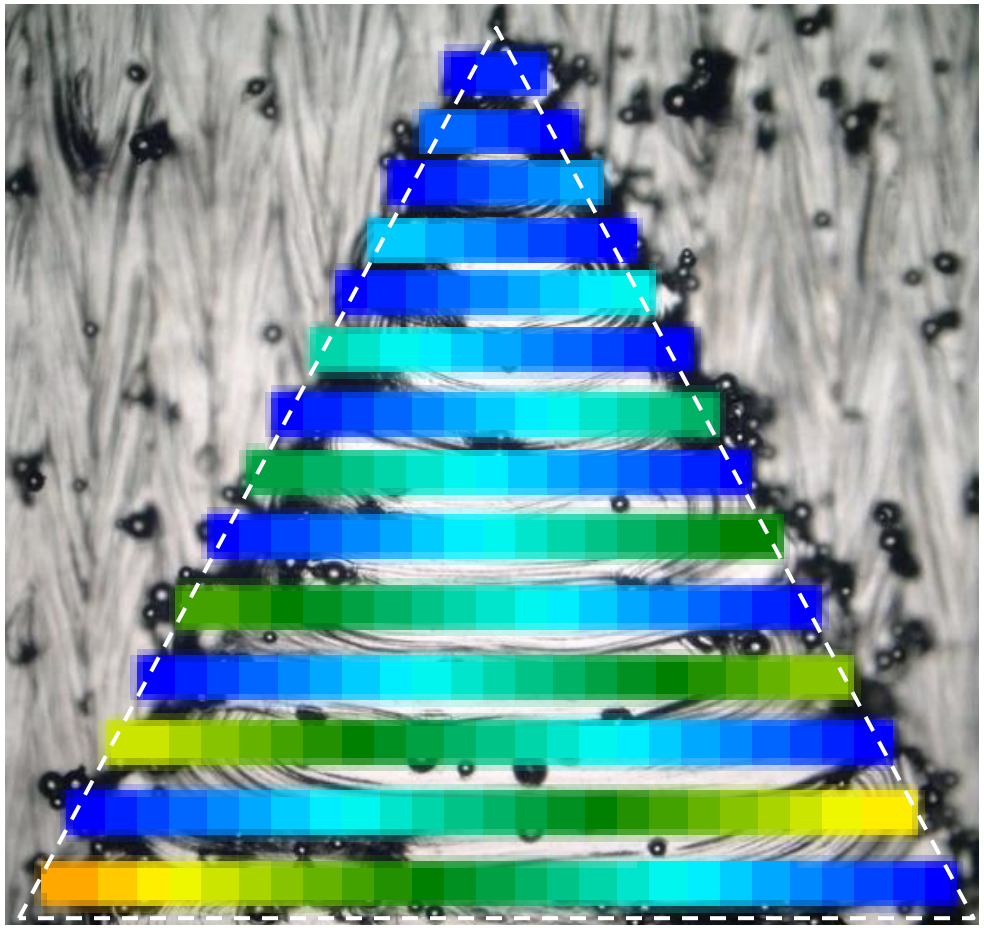
Melt Track Comparison for Tip Geometry

Exact heat input for suppression of Edge Bulging

Constant Parameters



Geometry adapted Control



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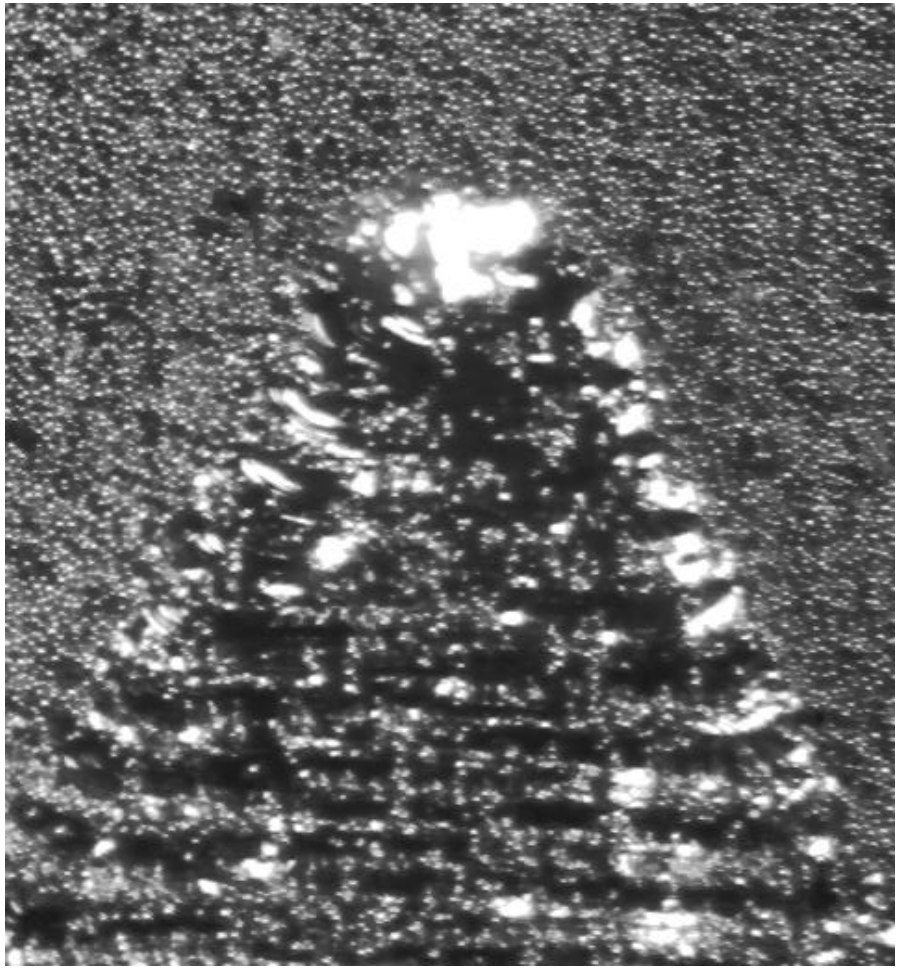
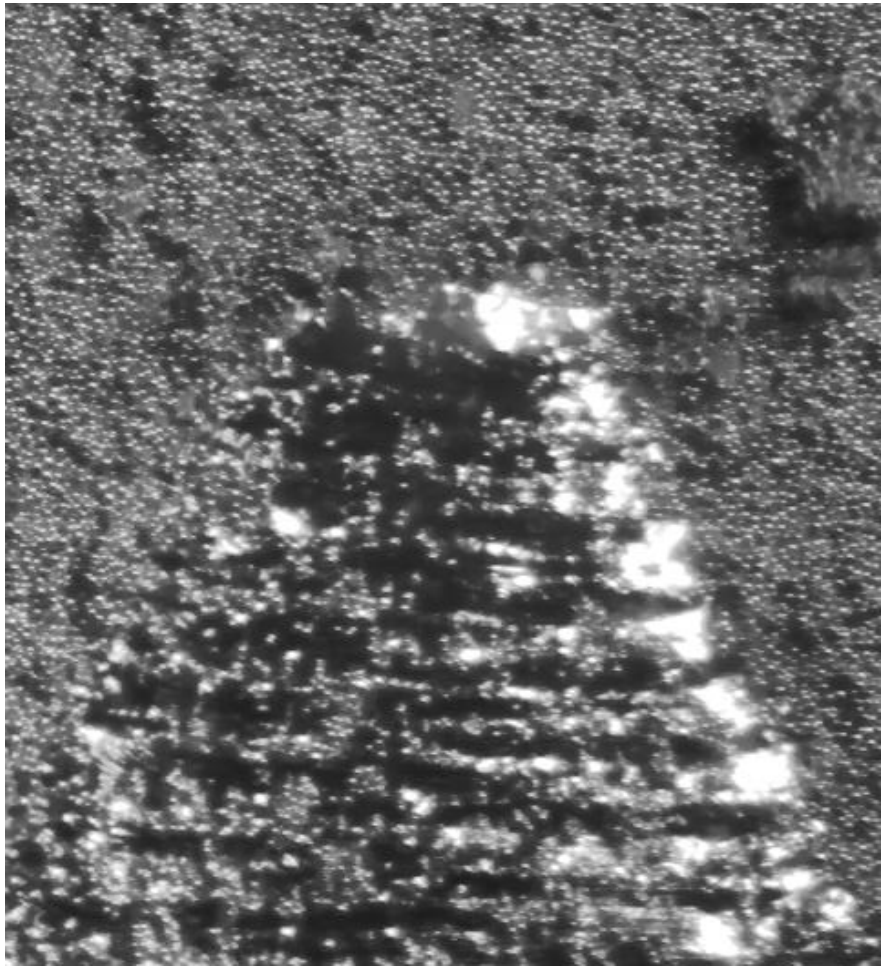


Geometry adapted Control

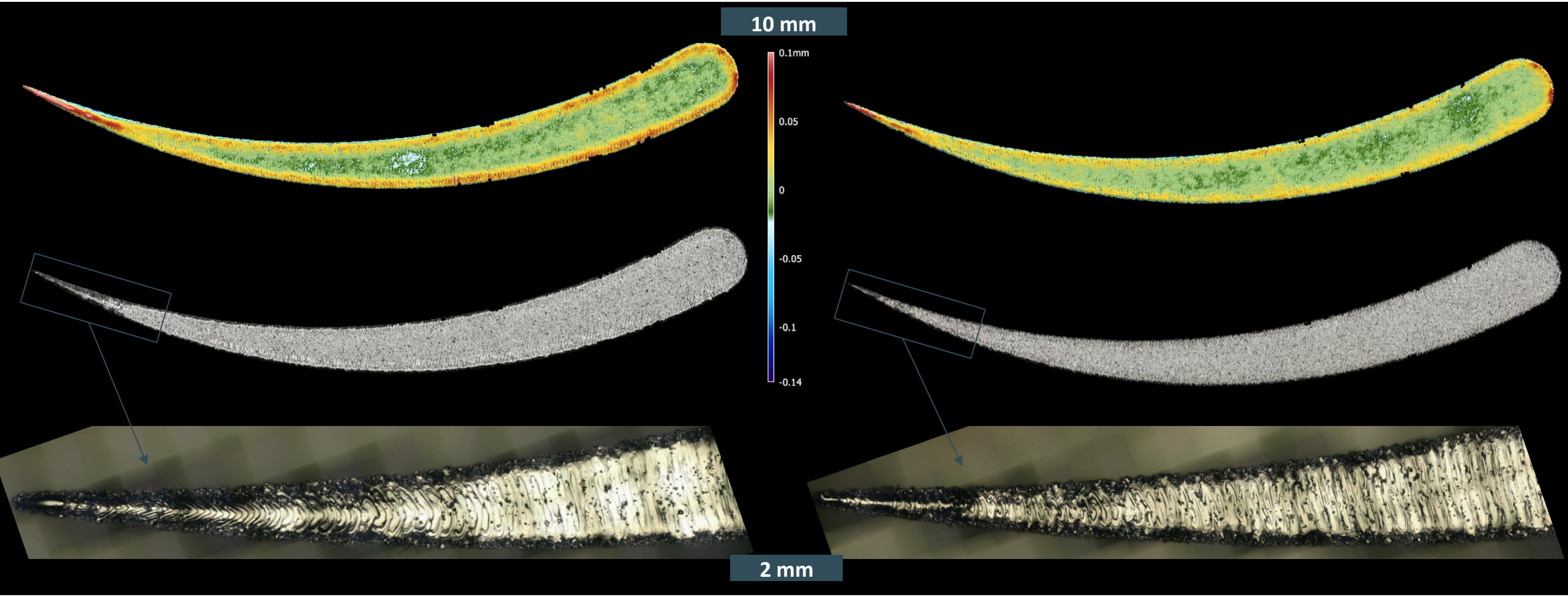


Demonstrator parts

Demonstrator parts

Constant Parameters

Adaptive Control



Conclusion of part 1

We have off-the-shelf machine components available for

- The complete optical bench for multi laser machines
- 100 kHz point cloud based parameter setting
- 100 kHz process and laser path monitoring
- 100 kHz closed loop control

Time-to-market

- a machine builder needs to integrate the components into his machine.
- The complete software stack needs to be adapted to make new possibilities available for the machine user.

Content

End-to-end process control with standardized off-the-shelf components

Part 1: Off-the-shelf components for modern LPBF machines

Part 2: End-to-end process control

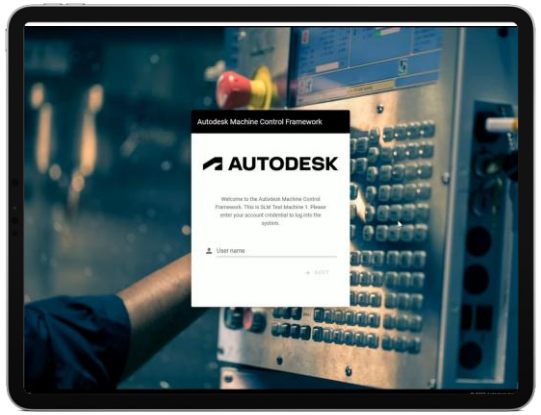
Machine Control Framework for Industrial LPBF

Shortening of Time-to-Market with prepared End-to-End Framework

SCANLAB Scan Systems

Autodesk Machine Control Framework

Standardized Interfaces (e.g. PLC)

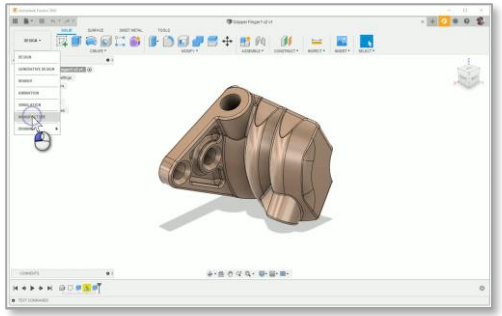


Open Access State of the Art Industrial Additive Manufacturing System

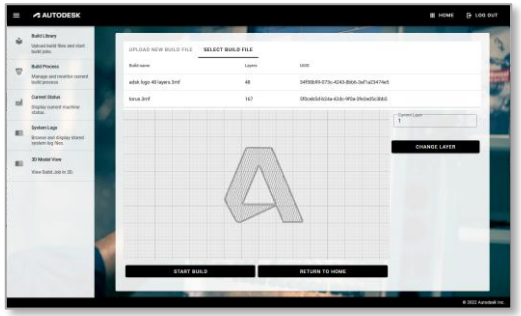
Open Access Closed Loop Application Stack

End-to-end process control with standardized off-the-shelf components

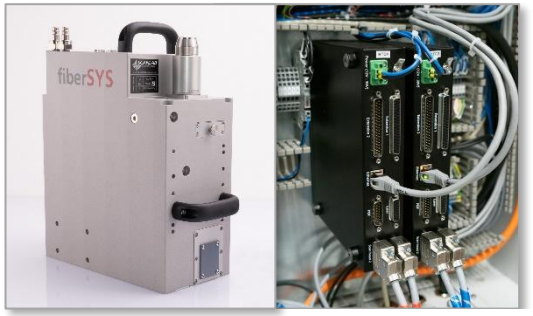
AUTODESK Fusion 360 or other



AUTODESK Machine Control Framework



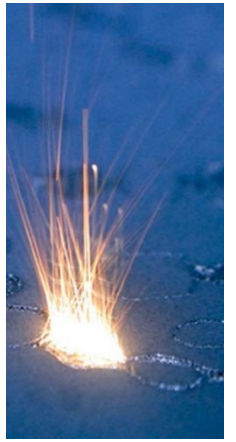
SCANLAB RTC + PLC



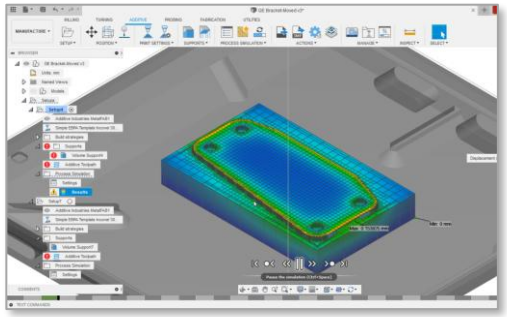
Layer wise laser power control

Closed loop melt pool control

Process

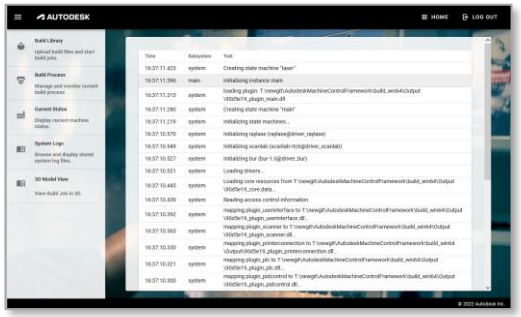


AUTODESK Fusion 360 or other



Inspection and mapping to CAD geometry

AUTODESK Machine Control Framework

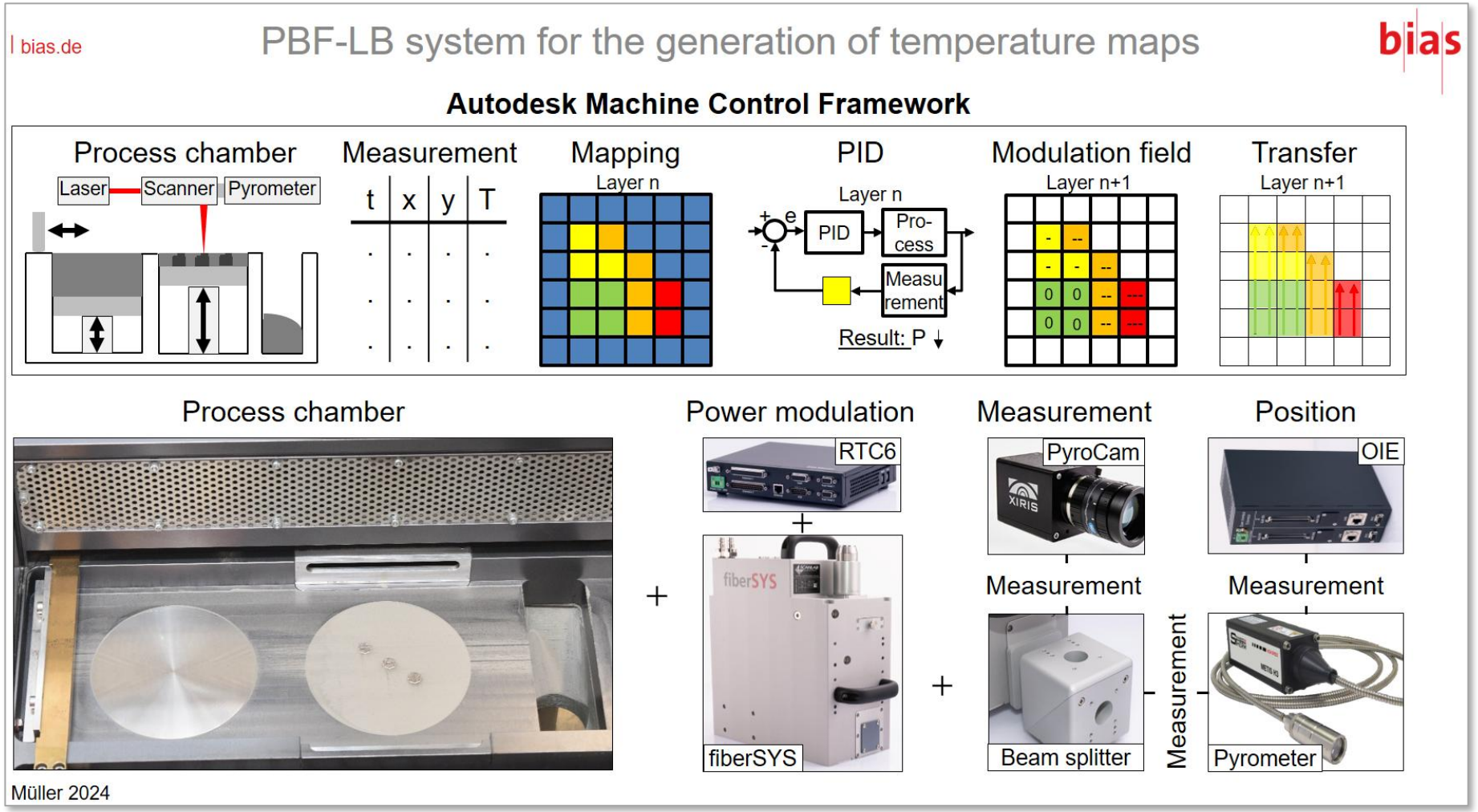


Data recording and process monitoring

SCANLAB **Open Interface Extension**

Sensor synchronization and data collection

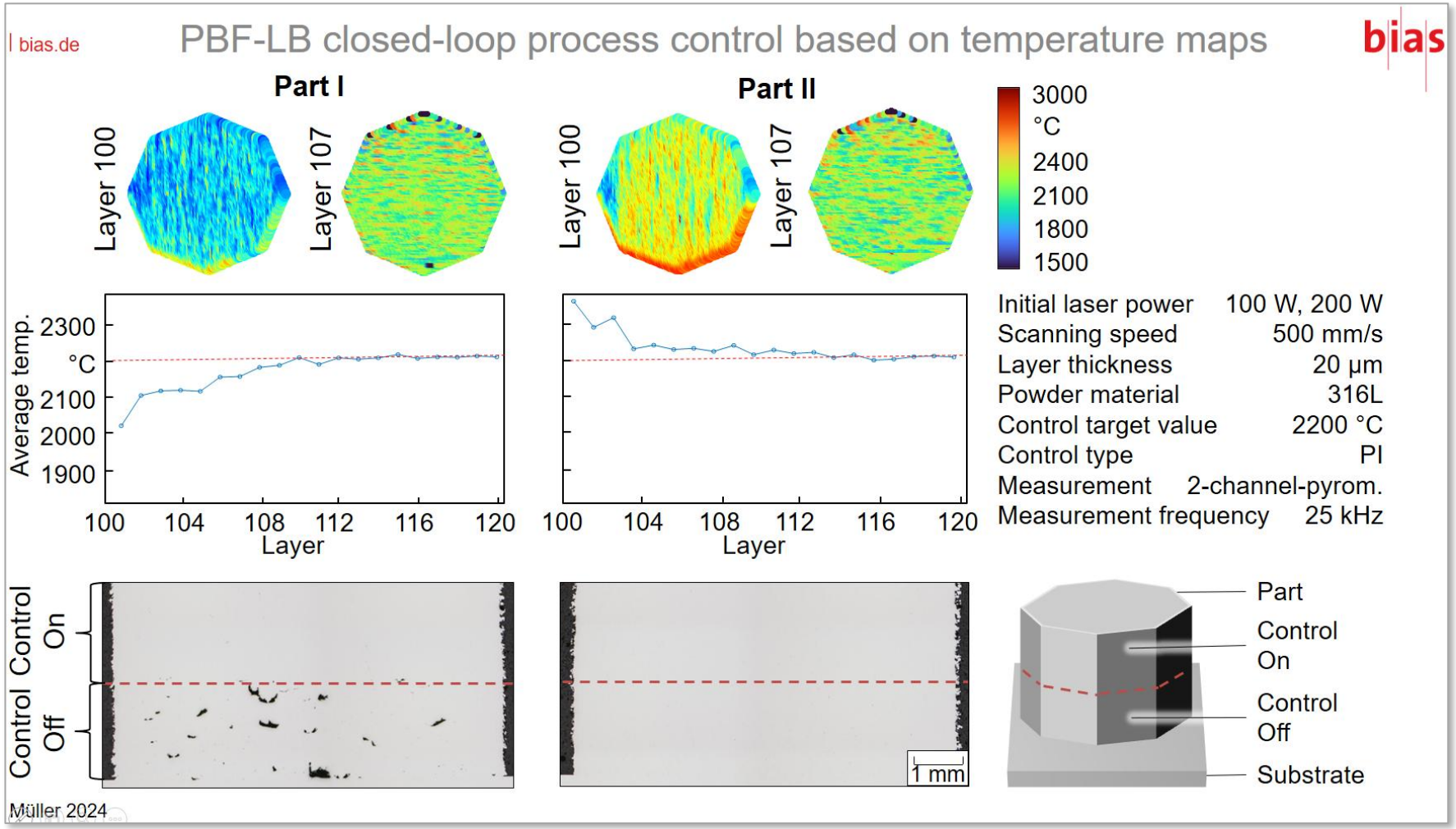
Layer wise Laser Power Control



Research project

- Pixel definiton, e.g. 150 µm x 150 µm
- Average temperature value of every pixel
- Pixel wise modulation of laser power
- Recalculation during recoating
- Source Code will be open sourced

Layer wise Laser Power Control



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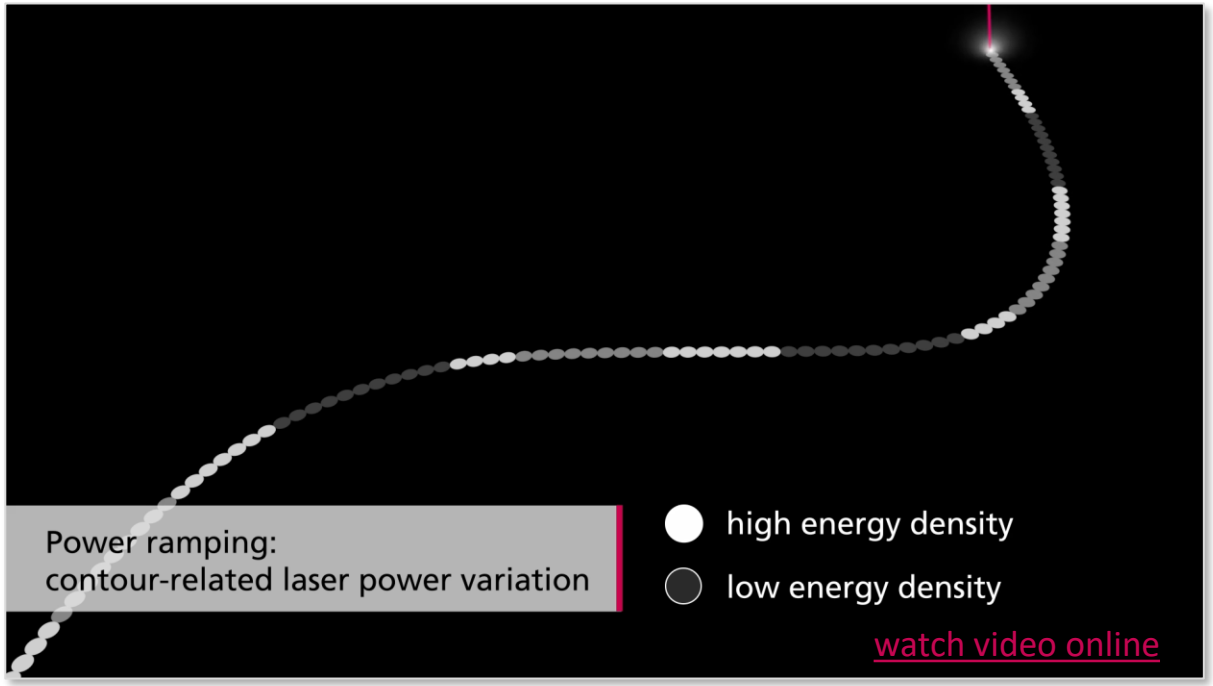
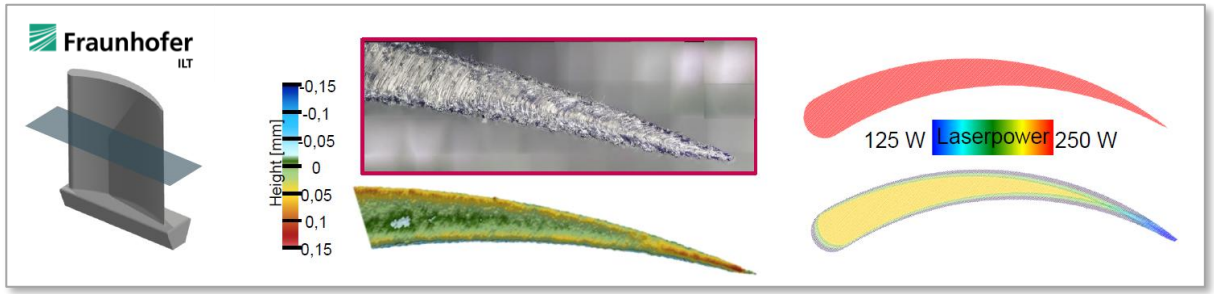
Point cloud based parameter assignment

LPBF specific advantage of SCANmotionControl





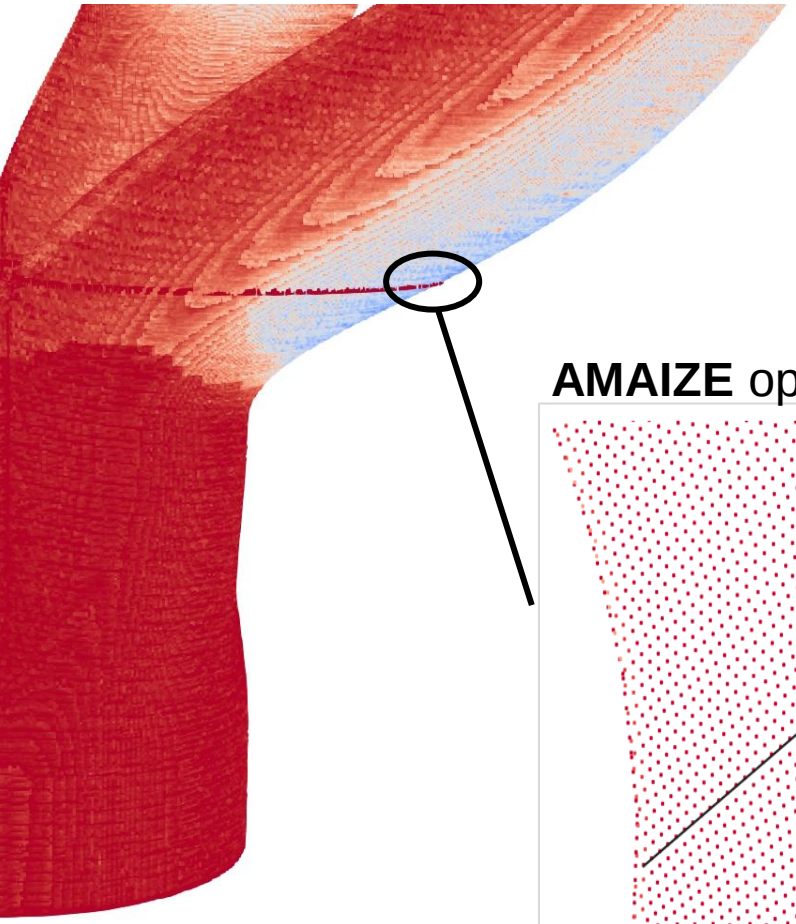
SCANmotionControl

- 100 kHz power assignment -> @ typical LPBF speed of 1 m/s
  –> 10 µm point cloud parameter grid.
- Variation of speed at the same time

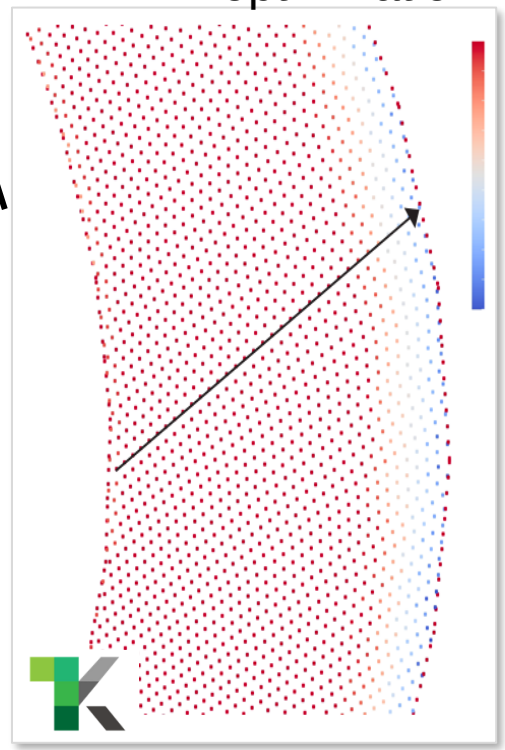
LPBF: Geometry adapted process control

- Project with Fraunhofer ILT
- Suppression of edge bulging
- Rampings as a function of vector length

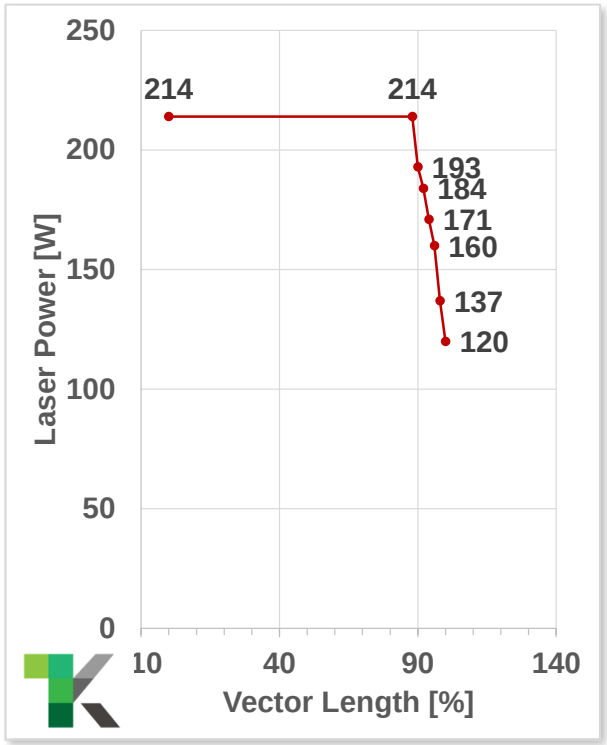
Seamless end-to-end parameter transfer



AMAIZE optimization



Exemplary vector



Integration in **3MF** file

```
<hatch x1="100" y1="15890" x2="19900" y2="15" f1="0.5350" f2="0.3000">
    <sub t="0.88000" f="0.5350"/>
    <sub t="0.90000" f="0.4825"/>
    <sub t="0.92000" f="0.4600"/>
    <sub t="0.94000" f="0.4275"/>
    <sub t="0.96000" f="0.4000"/>
    <sub t="0.98000" f="0.3425"/>
</hatch>
```

.3MF

Execution with ***SCAN*motionControl**

```
double initialPower[1];
initialPower[0] = 0.5350;

slsc_ParaSection powerRamps[7];
powerRamps[0] = { 88.0, 0.5350 };
powerRamps[1] = { 2.0, 0.4825 };
powerRamps[2] = { 2.0, 0.4600 };
powerRamps[3] = { 2.0, 0.4275 };
powerRamps[4] = { 2.0, 0.4000 };
powerRamps[5] = { 2.0, 0.3425 };
powerRamps[6] = { 2.0, 0.3000 };

slsc_MultiParaTarget multiTarget;
multiTarget.m_nNumTargets = 7;
multiTarget.m_pTargets = powerRamps;

m_pSDK->slsc_job_jump(contextHandle, point1.data());
m_pSDK->slsc_job_para_enable(contextHandle, initialPower);
m_pSDK->slsc_job_multi_para_line(contextHandle, point2.data(), &multiTarget);
```

Case Studies

ETH Zurich Rapture

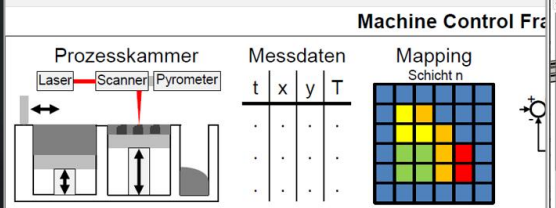
Rotational recoating system tailored for specific use cases

University of Aalen

Real-time closed loop control

BIAS Bremen

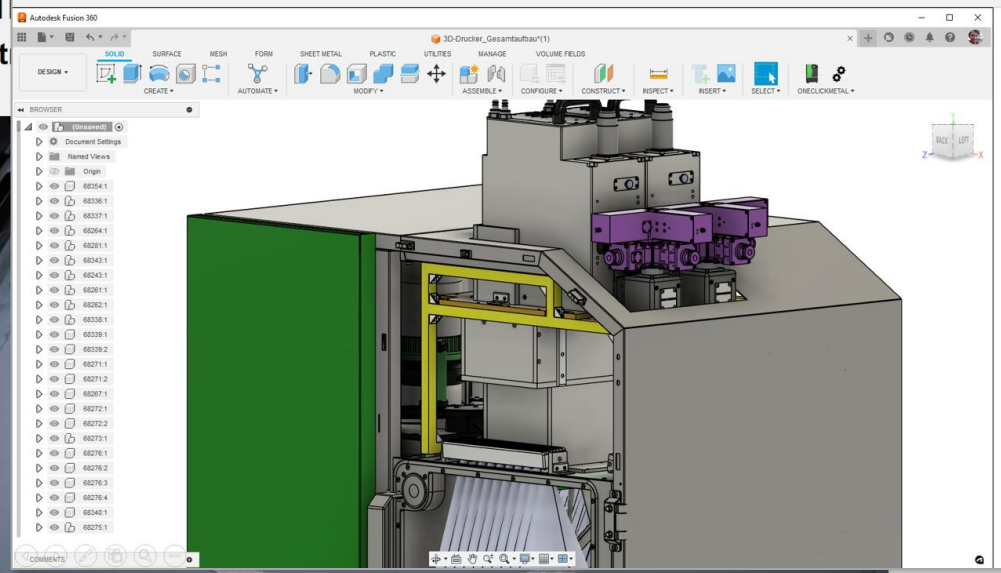
Layer wise temperature control



3D-Scanner

Scanning Engine

Technology Demonstrator



- Commercial base machine
- 1000W Lasers
- State of the art Scan System
- Reference software implementation (Open Source)

In collaboration with

ONE CLICK METAL

Universität Stuttgart - M. Fitzlaff, M. Käß

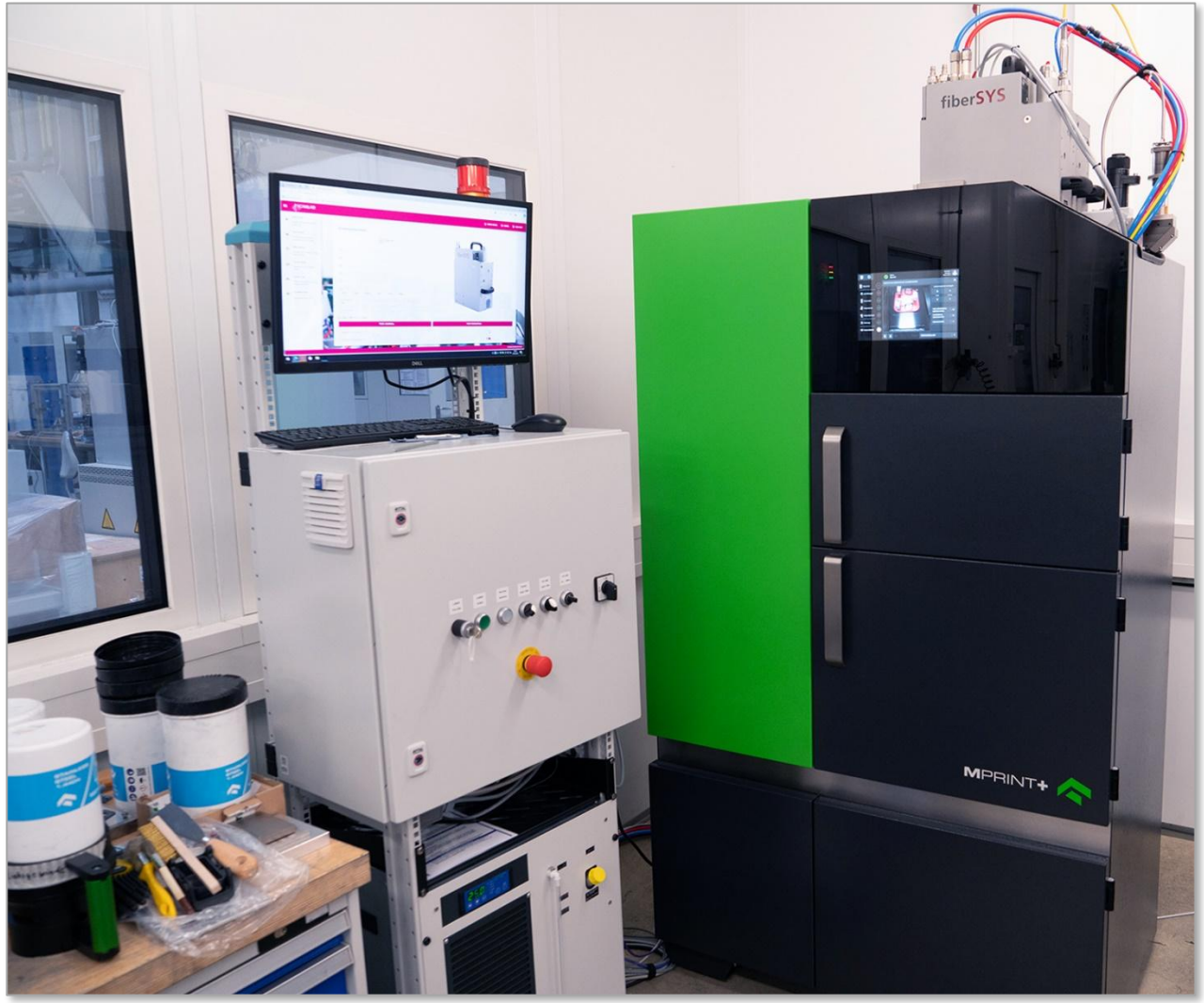
- 1 Application Developer
- 6 Months time-to-market

generously supported by

B&R A member of the ABB Group

DVS FORSCHUNG
01IF22039N

LPBF Scanning Engine



- **Off-the-shelf Scan Head and Electronics**
  - fiberSYS Scan heads
  - RTC6 Scan control cards with Open Interface Extension
- **Open Access End-to-End Software Stack**
  - Autodesk Machine Control Framework
  - Input file format: 3MF
  - High Level Interface to base machine
- **Features**
  - Open toolpath, open laser timings
  - 100 kHz point cloud based parameter setting
  - 100 kHz process and laser path monitoring
  - 100 kHz closed loop control
  - Complete insight into plus ownership of source code

Virtual AM machine

Input:

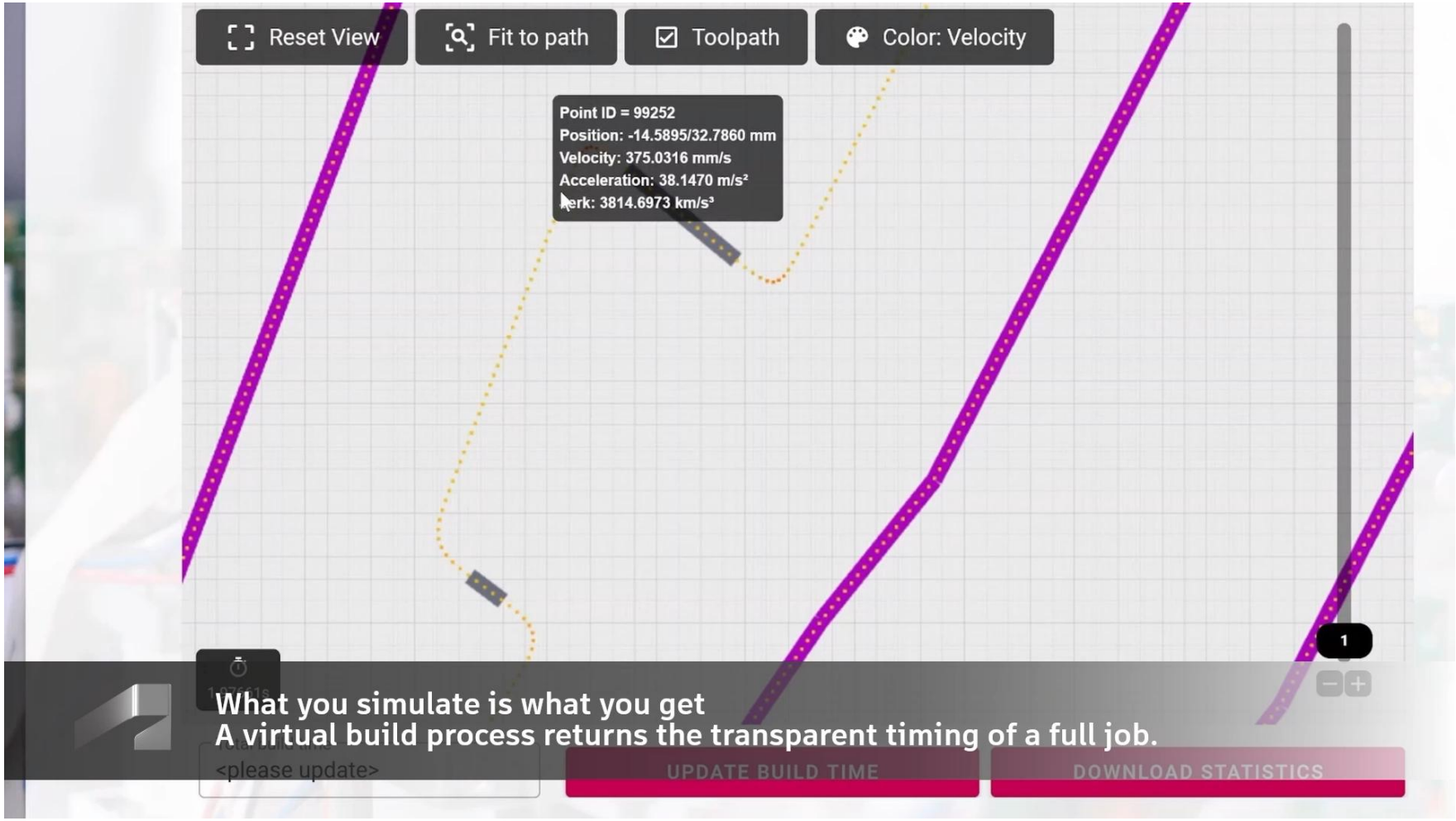
Build processor output including SmC parameters

- Marking speed in m/s
- (Minimum mark speed)
- Corner tolerance

Output:

Build process simulation

- Simulation programmed geometry vs. executed scan path in 10 µs steps
- Build time calculation with 10 µs accuracy



watch video online

Conclusion

End-to-end process control with standardized off-the-shelf components

Off-the-shelf machine components available for

- The complete optical bench for multi Laser Machines
- 100 kHz point cloud based parameter setting
- 100 kHz process and laser path monitoring
- 100 kHz closed loop control

End-to-end process control by

- Open Access Closed Loop Application Stack
- Complete insight into plus ownership of source code
- Commercially usable under BSD license
- Open Toolpath

→ **Fast Access to beyond state-of-the-art LPBF technology**

→ **Open**

→ **Customizable**

→ **Commercially usable**