



Welcome to the
THE NEXT LEVEL
of Additive Manufacturing.



Feedforward Process-parameter Optimization for Control of LPBF Melt-pool Size

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*PanOptimization

**The Pennsylvania State University

***DMG MORI

PanOptimization

Founded by Pan Michaleris

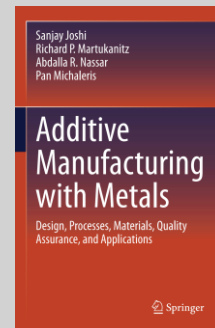
- Penn State ME Professor (1997-2016)
- Previously founded Pan Computing
- Core team has a combined 50+ years experience in AM/welding sim and HPC

Inventors of PanX

- We wanted to do something that would have maximum impact on the industry
- A novel and unique architecture for thermomechanical AM simulation/optimization at any scale



BOOTH 829



Issues with parameter development

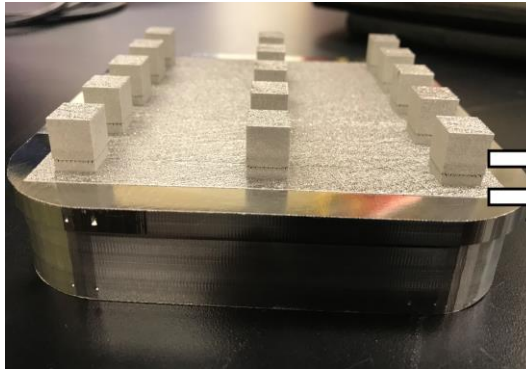
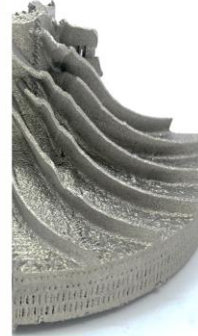


Expectation

- Machines are capable of producing any part
- Parts have homogenous material properties
- Part production is reliable

Reality

- Process conditions change depending on part geometry
- Parts exhibit non-homogenous material properties
- Conditions can differ when repeating the same part

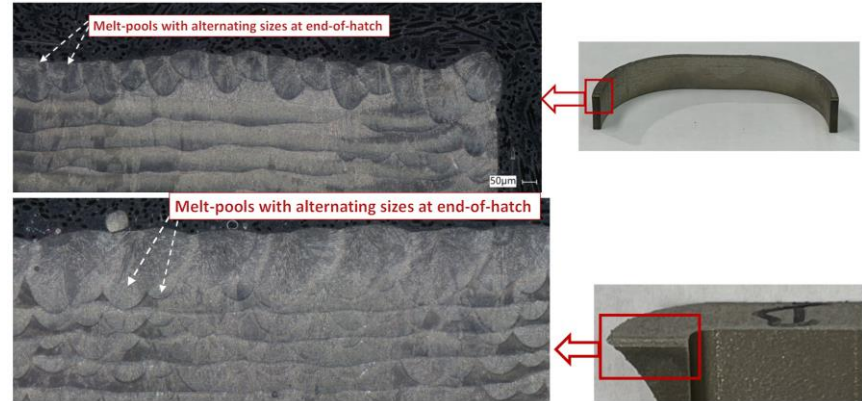


Background:

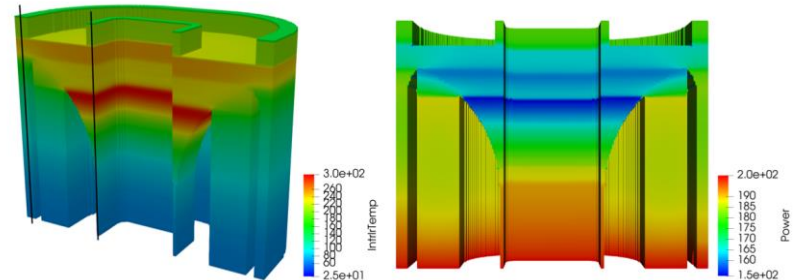
- Recent studies show that melt-pool size and material properties are strongly correlated to interlayer temperature
- Some groups are working to modulate laser power on a feedback basis

Objective:

- *Feedforward* modulation of laser power via predicted interlayer temperature
- Ability to have “locked down” process files for regulated industries
- Scale to any geometry



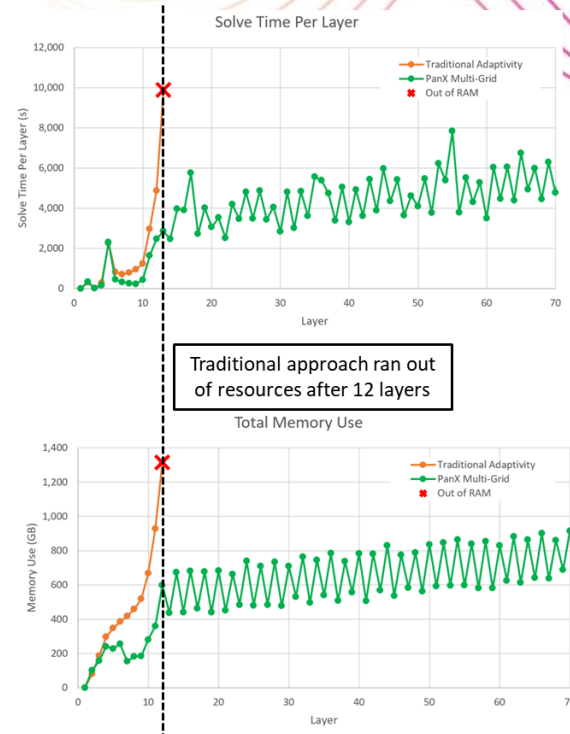
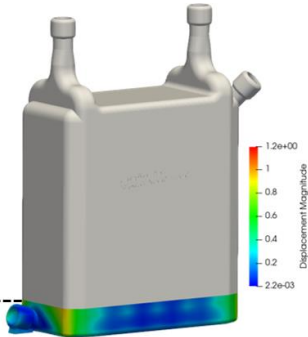
Wang, Qian, et al. "Effect of interlayer temperature on melt-pool morphology in laser powder bed fusion." *Additive Manufacturing Letters* 7 (2023): 100169.



Multi-Grid Modeling (MGM) is available only in PanX and achieves:

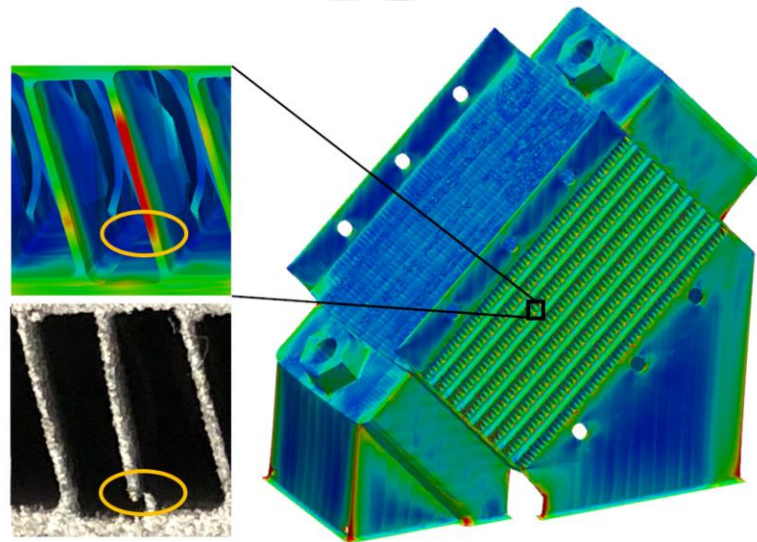
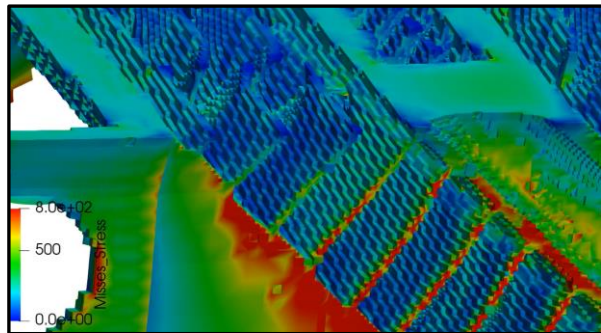
- High accuracy and resolution
- Scalability to any build size or complexity
- Computational speed and efficiency (no expensive GPUs)

Legacy approach can get about this far (12/128).



By using Multi-Grid Modeling (MGM) PanX can...

- Resolve even the finest features (300 micron)
- Scale to the full build volume
- Simulate this HX in 14hrs (compared to 160hr print time) w/ 206GB RAM

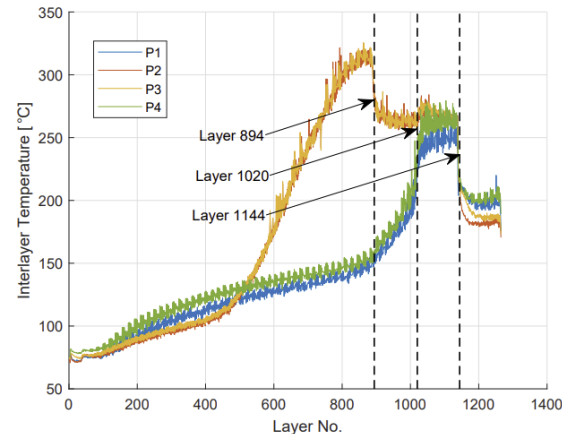
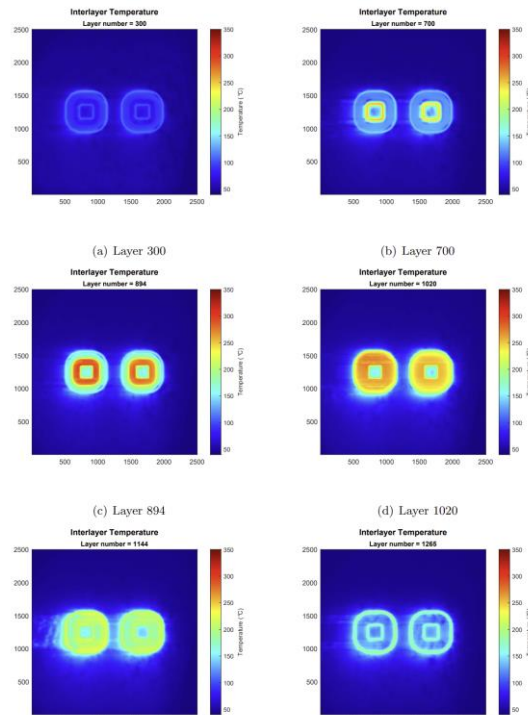
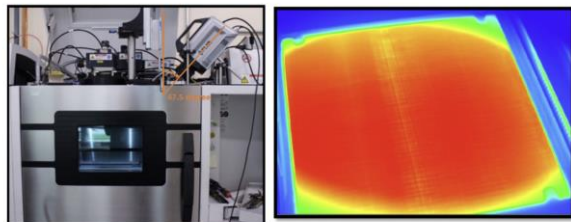
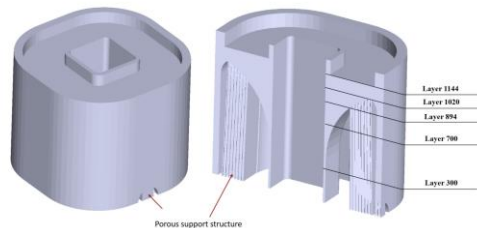


This heat exchanger and cracked vane are featured in Saltzman, David, et al. "Design and evaluation of an additively manufactured aircraft heat exchanger." *Applied Thermal Engineering* 138 (2018): 254-263.

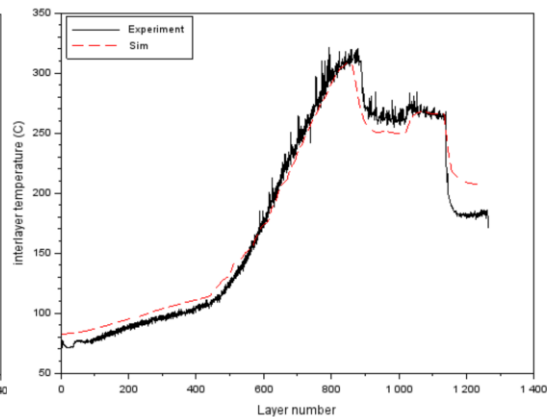
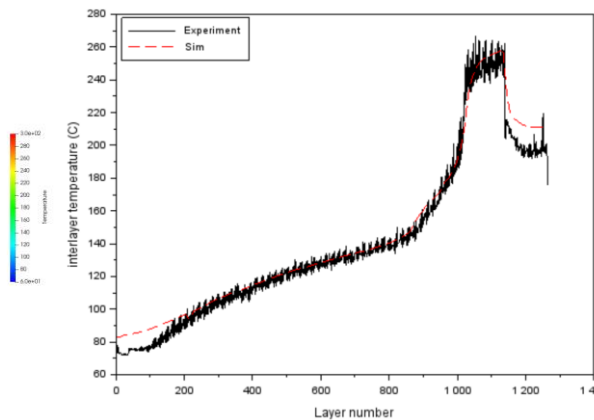
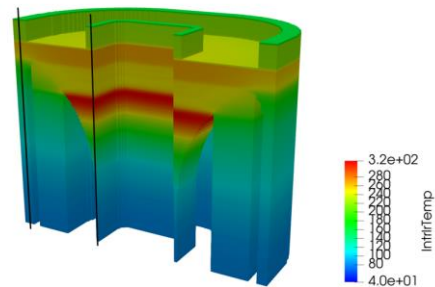
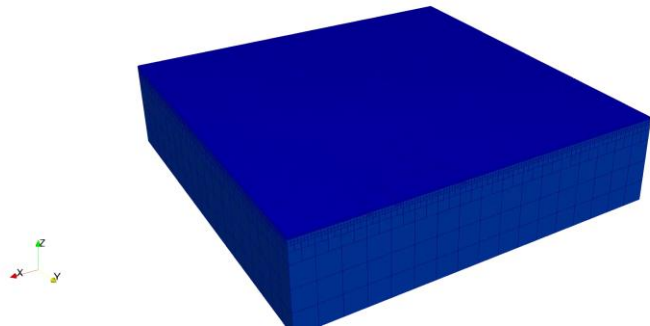
PanX integrates directly with machine OEMs

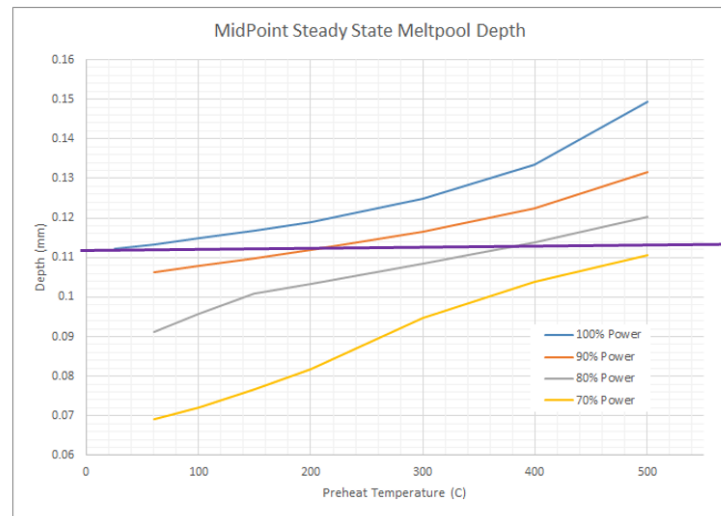
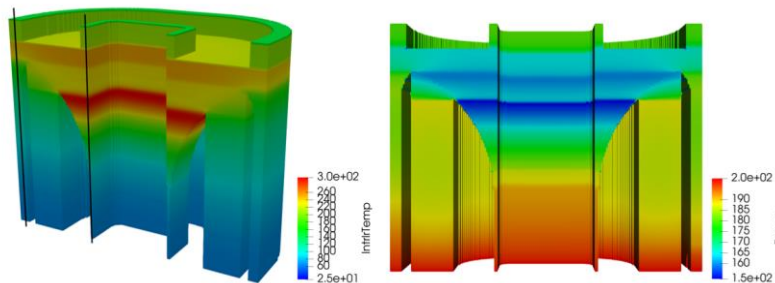
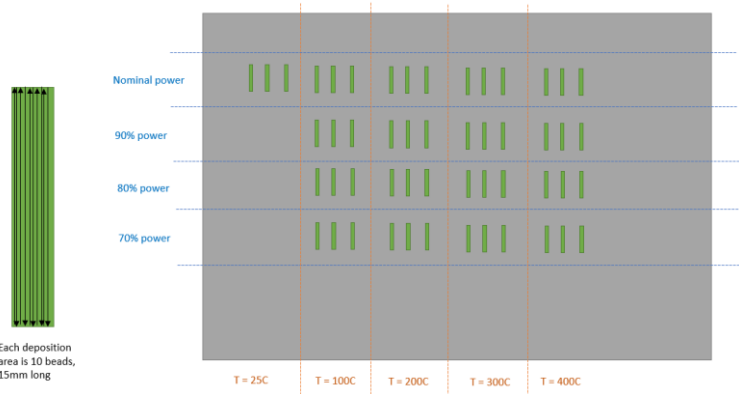
- PanX API interfaces directly with OEM's print prep software
- Energy input passed to PanX on a voxel-by-voxel basis + upskin/downskin
- Exact processing time and dwell time passed to PanX layer-by-layer
- High fidelity modeling of machine-dependent boundary conditions

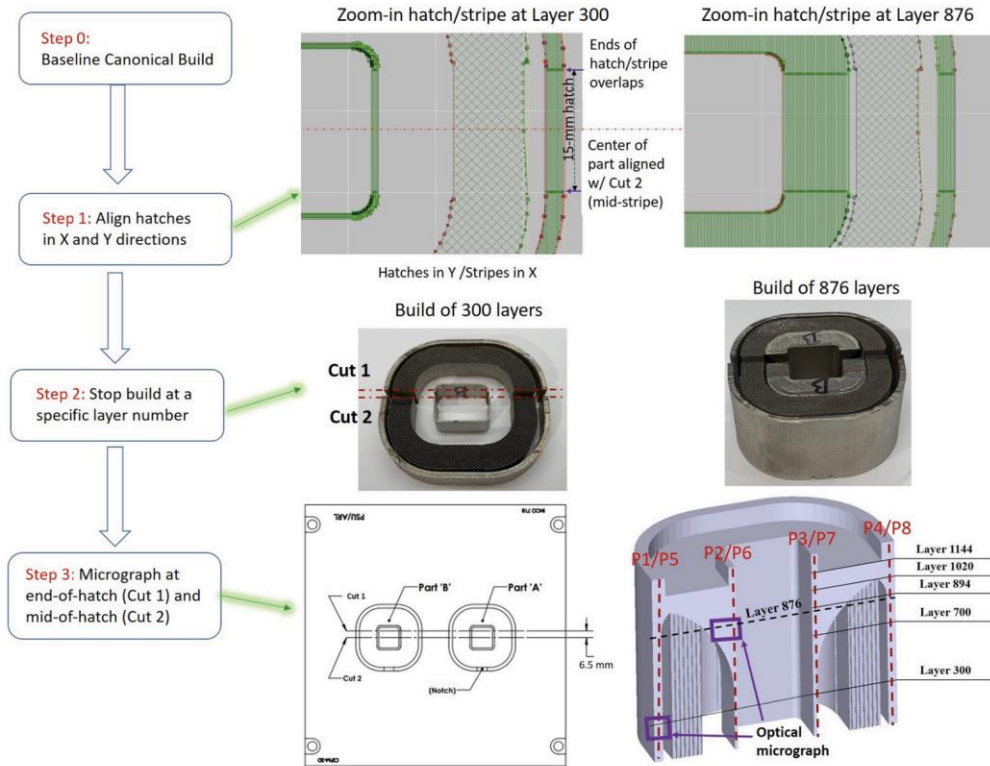




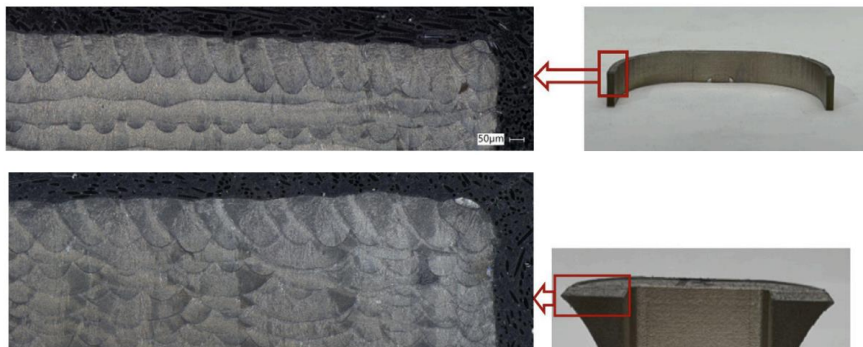
Wang, Qian, et al. "Part-scale thermal evolution and post-process distortion of Inconel-718 builds fabricated by laser powder bed fusion." *Journal of Manufacturing Processes* 81 (2022): 865-880.



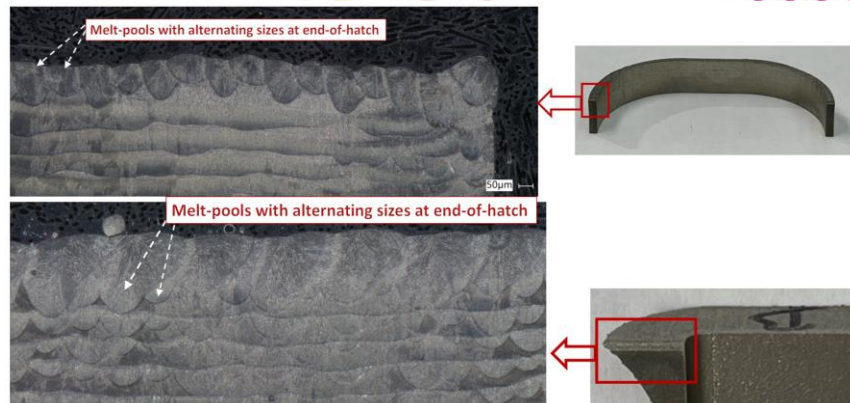




Middle of hatch



End of hatch



Build ID	Melt-pool half-width (micron)	Melt-pool depth (micron)
Baseline-300	89.6 ± 5.5	173.9 ± 13.4
Baseline-876	125.7 ± 11.7	167.1 ± 12.0

Build ID	Melt-pool half-width (micron)	Melt-pool depth (micron)
Baseline-300	76.4 ± 7.2	161.8 ± 14.8
Baseline-876	179.3 ± 14.6	220.2 ± 27.4

Middle of hatch

Baseline-300*



Baseline-876*

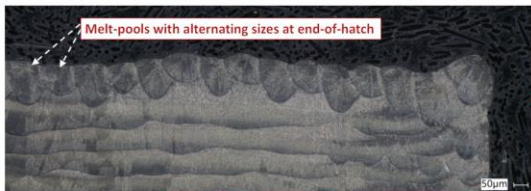


Optimized-876



Build ID	Melt-pool half-width (micron)	Melt-pool depth (micron)
Baseline-300	89.6 ± 5.5	173.9 ± 13.4
Baseline-876	125.7 ± 11.7	167.1 ± 12.0
Optimized-876	83.7 ± 6.9	154.4 ± 16.7

Baseline-300*



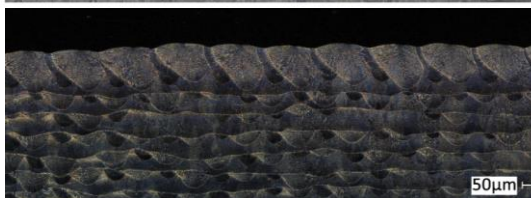
End of hatch



Baseline-876*

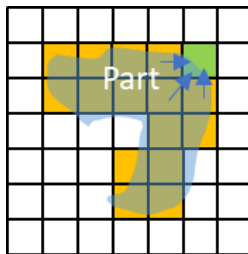


Optimized-876



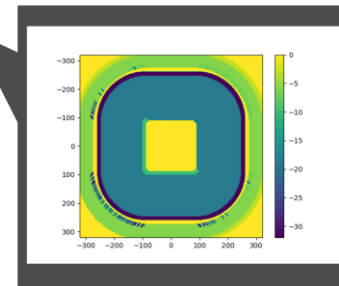
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Baseline-300	76.4 ± 7.2	161.8 ± 14.8
Baseline-876	179.3 ± 14.6	220.2 ± 27.4
Optimized-876	162.4 ± 11.9	174.4 ± 13.4

- FEA Mesh may not cover entire cross-sectional slice
- Correction must be padded/expanded
- Moving average (ignoring uncorrected cells) is used
- Repeated until desired padding is achieved (default 1mm)



Correction Files

mm	Filepath
0	---
0.03	---
0.06	---
0.09	---
0.12	---
0.15	---
0.18	---
0.21	---
0.24	---
0.27	---
0.3	---

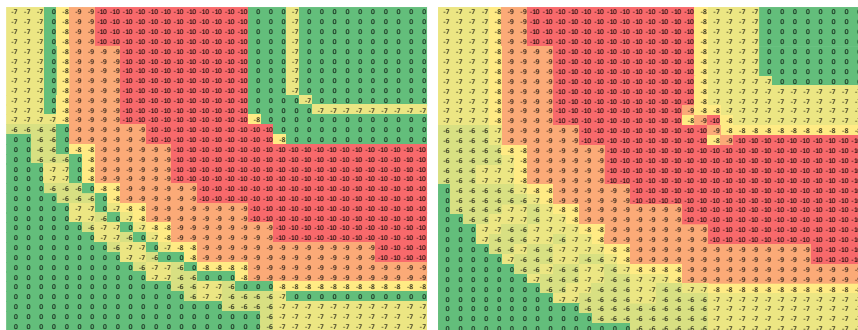
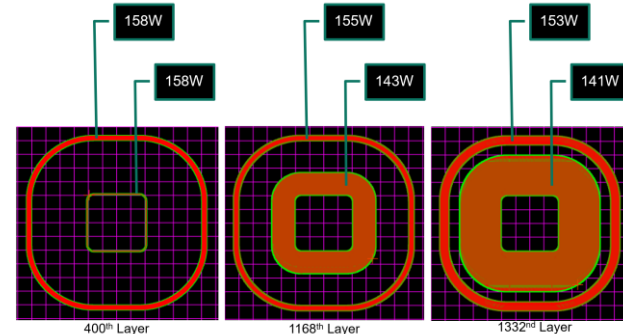


+ File loading in job preparation software

+ Single layer power correction CSV reading

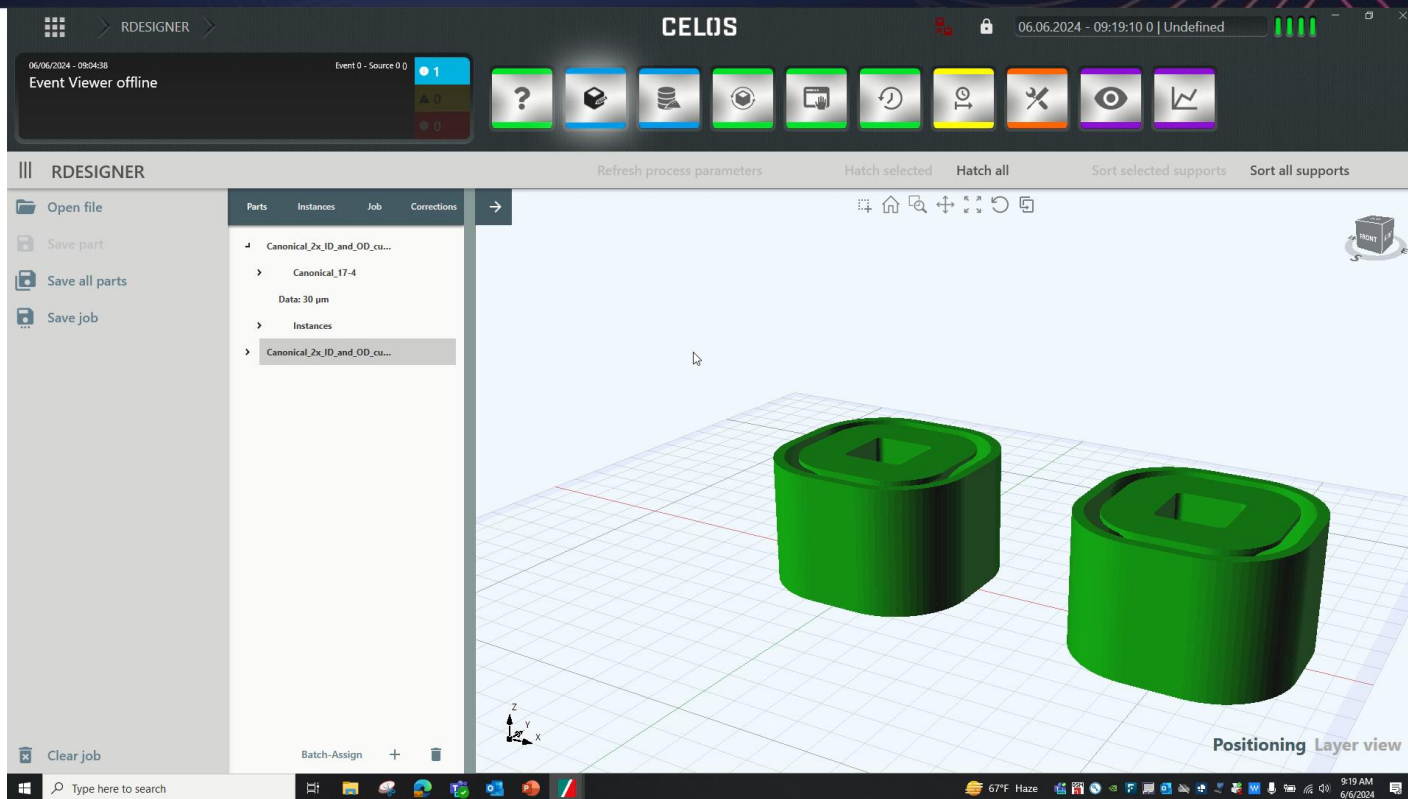
+ Single CSV per layer

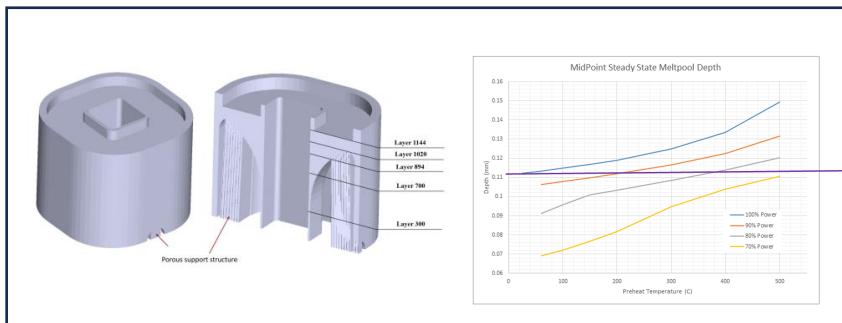
DMG MORI



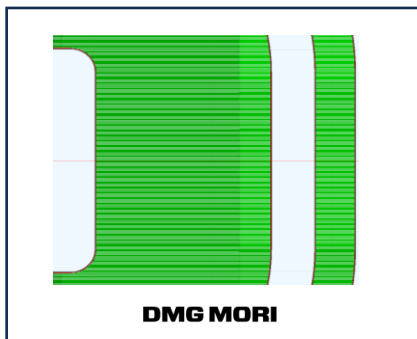
Mapped Result with no padding

Mapped Result with padding

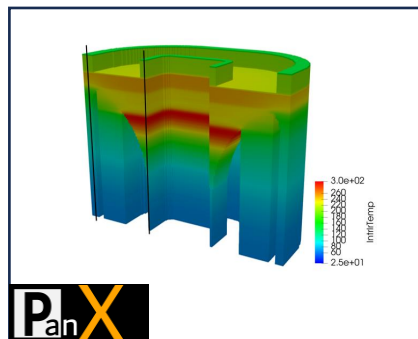




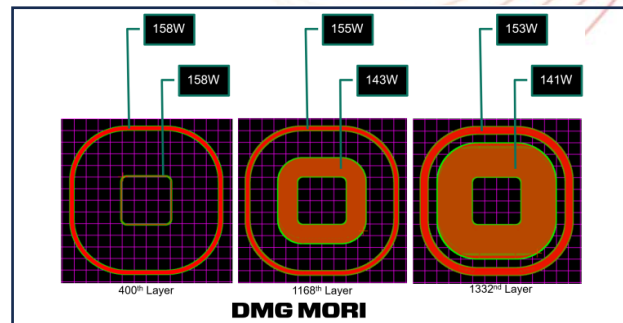
1. CAD geometry & look-up table generation (empirical, analytical, or numerical)



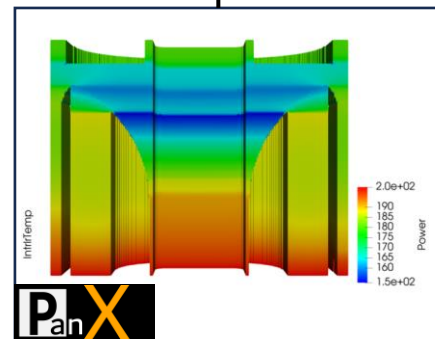
2. Build-prep (slicing and toolpathing)



3. FEA meshing and simulation



5. Read spatially corrected laser powers into build-prep

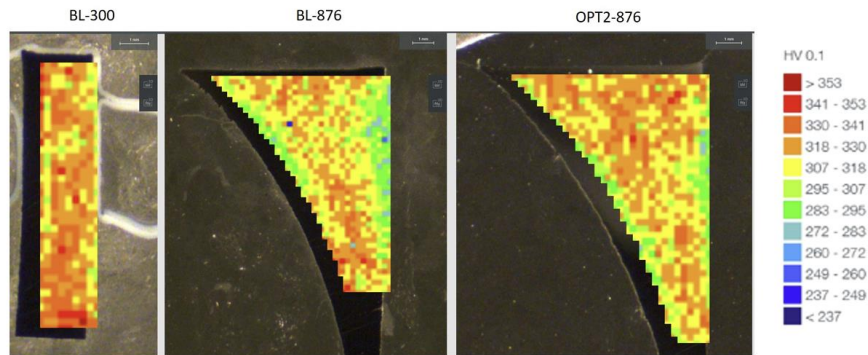
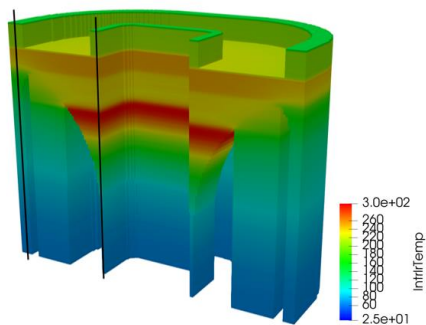


4. Output spatially corrected laser powers



6. Optimized build

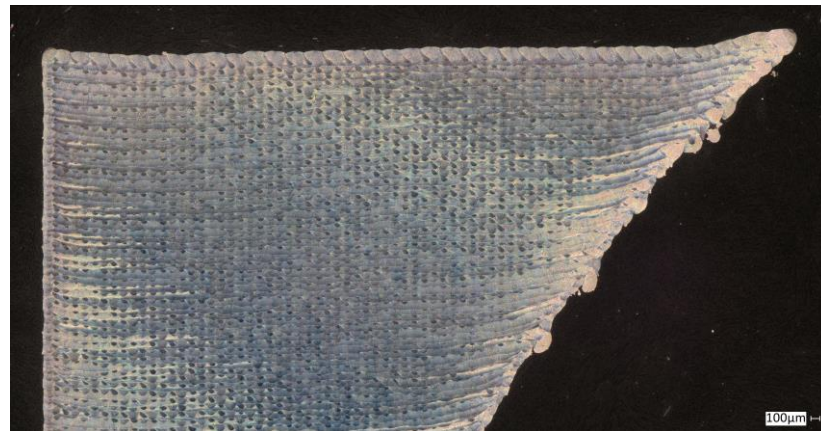
- Investigate impact of power optimization on microstructure and material properties
- Vector level optimization based on exact scan path



Q. Wang et al., Control of interlayer temperature through laser power optimization in powder bed fusion to improve build quality. In review.

- PanX accurately simulates interlayer temperatures and accounts for actual machine parameters and timing
- The approach scales to parts of any size and complexity including those with features spanning microns to meters
- Spatially optimized laser powers result in more uniform melt quality compared with baseline process parameters
- DMG MORI integration with PanX results in an end-to-end parameter optimization workflow

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THANK YOU!



THE
NEXT
LEVEL

