Part and Process Design for Additive Manufacturing

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Assistant Professor
Faculty of Engineering Technology
Presentation outline

- Introduction
- Part design for additive manufacturing
  - Design rules
  - Design tools
- Process design for additive manufacturing
  - Melt pool modeling
  - Smart scan strategies for SLM
- Quality control for additive manufacturing
  - Destructive vs. non-destructive testing
- Conclusions
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Introduction

Myself

- **Dr. ir. Wessel W. Wits**
- Assistant Professor Mechanical Engineering
- Group of **Design, Production & Management**

Research areas

- Design Engineering (Physics in Design)
  - Additive manufacturing
  - Thermal management (two-phase principles)

Affiliations

- Teacher & Researcher **Faculty of Engineering Technology**
- Coordinator of the Master track **Design Engineering**
- Core lecturer **University College Twente (ATLAS)**
Introduction

Faculty of Engineering Technology, University of Twente

3 programmes
~350 staff members
~1800 students
Introduction

Our research group **Design Engineering**

- Make the design (engineering) process more efficient and effective
  - Research methods & methodologies
  - Develop tools & techniques

- Optimize the relation between Design & Production
  - **Feature-based design**
  - Computer aided process planning
  - Computer aided design (synthesis)
Goal: To align research activities in the area of AM

Research groups
- Design, production & management
- Applied laser technology
- Applied mechanics

Current work
- Numerical analysis tools
- Design tools & methodology
- New and faster processes
- Application research (design studies)
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Additive manufacturing for space applications

Case study together with NLR

**Goal**
- Next generation of pump systems for satellites

**Drivers**
- Reduce weight, increase reliability

*Single pump* → *Micro pump assembly*
Design of “no moving parts” valves

- Operate by pressure difference
  - **Diodicity**

\[ Di = \frac{\Delta P_{\text{backward}}}{\Delta P_{\text{forward}}} \]

- Very reliable
- Optimized for Reynolds value
Design rules for additive manufacturing

- Part orientation influences part quality
  - Avoid down-facing surfaces
  - Surface roughness
  - Use of support structures

![Diagram showing part orientation and build axis](image)

- **Best**
  - Build axis
  - Baseplate
- **Poor**
  - Steep angles
  - Low angles
  - "Down facing" surface
  - Bad surface
  - Impossible
  - Support structures required
Prototype no-moving-part valve for aerospace application
Prototype no-moving-part valve for aerospace application

X-ray image

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Pump assembly for aerospace application

- Surface roughness \( [Ra = \sim 5.1 \, \mu m \, \& \, 4.6 \, \mu m \, (hor. \, \& \, vert.)] \)
- Laser beam welding of AM parts

3D reconstruction of surface (250x magnification)


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Design tools for additive manufacturing

Industry needs

- Focus on **smart** design tools that (really) aid with applying design rules

- Optimize build orientation for
  - Minimum overhang & support
  - Minimum stress & deformation
  - Minimum (layers &) time
  - ...

  Meeting part quality requirements

- And one level deeper: optimize each layer towards the same goal(s)
Design tools for additive manufacturing

Our approach

- Capturing process physics to analyze the impact of design choices
  - Feedback of process knowledge to the designer (DfX-methodology)
- Setting up a software architecture to support this
  - Implementing feature-based design algorithms
Prototype design support for build orientation

Algorithm steps:

- Tessellation (discretization)
- Detection of outer surfaces (convex hull)
- Overhang (feature) is recognized by ray tracing
Prototype design support for build orientation

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A good design tool should:
- Map the solution landscape
- **Give insight** into the solution landscape
  - E.g. rank candidate solutions
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Melt pool modeling

Understanding the physics behind the process

- Modeling laser interaction with the powder bed
- Lessen the number of experimental trials
- Predict melt pool size and quality of printed tracks
Melt pool modeling

Optimizing the process

- Vary laser power, spot size, laser speed, hatch distance, ...
Melt pool modeling

Optimizing the process

- Vary laser power, spot size, laser speed, hatch distance, ...

- Identify process windows for (new) material(s)


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Smart scan strategies for SLM

- Short vs. longer scan vectors
- 5 test parts (Ti6Al4V)

In collaboration with PPS project by TNO, NLR, M2i and industrial partners
Smart scan strategies for SLM

- Thermomechanical modeling of adjacent scan vectors
  - Temperature, deformation, strain & stress
  - Vectors are ‘activated’ stepwise in time

\[
\begin{array}{|c|c|c|}
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4 = \Delta t & 8 = \Delta t & 12 = t_{\text{cooling}} \\
\hline
3 & 7 & 11 \\
\hline
2 & 6 & 10 \\
\hline
1 & 5 & 9 \\
\hline
\end{array}
\]

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Longest vector

Shortest vector

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Smart scan strategies for SLM

- Deformation measurements
- Long longitudinal vectors increase deformation

In collaboration with PPS project by TNO, NLR, M2i and industrial partners
Smart scan strategies for SLM

- Deformation measurements
- Long longitudinal vectors increase deformation
- Other vectors show minor differences

Results should feedback into (part &) process design tools

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Quality control for additive manufacturing

2D microscopy

- Typical SLM defects
- Pore morphology and location are important for quality control

**Overheating**  **Scan strategy defects**  **Insufficient melting**
Quality control for additive manufacturing

3D X-ray computed tomography (XCT) – CAD Comparison

- Comparing to part, sections, internal features, …
- Deformation due to sagging of layers (max. 0.2 mm)
- Roughness and irregularities near part features

Less material
Voids
High surface roughness
Quality control for additive manufacturing

3D X-ray computed tomography (XCT) – Porosity detection

- Inhomogeneities
- Threshold >46 μm (>0.0001 mm³)
- Max. volume 0.005 mm³
- Void vol. 0.1848 mm³ (0.2109%)

Higher porosity near internal features?
Quality control for additive manufacturing

3D X-ray computed tomography (XCT)

- Analyzing 2D sections of interest after XCT investigation
- Better calibration of various porosity/density testing methods
  - Archimedes, pycnometry, microscopy & 3D XCT

W.W. Wits, et al., to be published soon…
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Conclusions

- Part & process design for AM is essentially different
  - We need to train/educate engineers differently
  - **New design & support tools are required**

- CAD to Part is too good to be true (for now)
  - Process design (and optimization) research is essential

- Real products require predictable quality
  - Quality control, standardization and certification are essential
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