Development and Quality Assurance of Additive Components at MAN Energy Solutions

MPA Stuttgart
44th MPA-Seminar, October 17th - 18th, 2018

Dr. Roland Herzog, Markus Ernsberger, Dr. Sven Wiers, Claudius Wurm, Matthias Schneck, Christoph Korbmacher, Dr. Markus Röhner
Strategic business areas

- Engines & Marine Systems
- Power Plants
- Turbomachinery

Aftersales MAN PrimeServ
# Member of the Volkswagen Group

MAN Energy Solutions is part of a brand family

<table>
<thead>
<tr>
<th>Volumen</th>
<th>Premium</th>
<th>Super Premium</th>
<th>Truck &amp; Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>VW</td>
<td>Audi</td>
<td>Porsche</td>
<td>MAN Truck &amp; Bus</td>
</tr>
<tr>
<td>Skoda</td>
<td>Lamborghini</td>
<td>Bentley</td>
<td>Scania</td>
</tr>
<tr>
<td>Seat</td>
<td>Ducati</td>
<td>Bugatti</td>
<td>Power Engineering</td>
</tr>
<tr>
<td>VWN</td>
<td></td>
<td></td>
<td>RIO</td>
</tr>
<tr>
<td>MOIA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Financial Services**

![Volkswagen Financial Services Logo](image)
Key figures 2017

14,300 employees worldwide

2.8 bn € revenue
MAN has released the first metallic component for serial production with Laser PBF

**Current Additive Production Part**

**Industrial Gas Turbine MGT6100, 6-7MW**

- Last stage of gas turbine compressor
- Guide vane segment (OGV)
- 12 x
Current Additive Production Part

MAN has released guide vane segments for AM production of gas turbines
Additive Components

Outlet Guide Vane Segments for Gas Turbine Compressor

Weight: 270 g
Material: IN718

Integration of inner shroud
Integration of junctions
Conventionally not producible
Advantage: no extra diffusor inlet structure

Integrated design has been developed for AM

144 → 12
Less parts
What drives us towards additive manufacturing?

Additive Manufacturing enables **new and innovative designs**…
…and thus improves our products for our customers.

Additive Manufacturing speeds up innovation cycles …
…by **fast prototype manufacturing**.

Additive Manufacturing helps to **reduce costs**.

MAN Energy Solutions has established Additive Manufacturing for **serial production**…
…by successful **cooperation with excellent development partners and suppliers**.
The additive production volume shall be increased.

Many parts are technologically feasible.

But only some are reasonable from a business point of view.

Wow can we identify and select them?
Cost Comparison of Manufacturing Processes

Laser PBF is an expensive additive manufacturing process
AM - Level of Industrialization for Metallic Parts

Aspects of Value Creation

- Technological & Cost Benefits
  - Airbus A320
  - Large Diesel Engines
- Technological Benefits
- Cost Challenge
  - Tooth Crown
  - Hip Implant
  - Additive Manufacturing (SLM)
Where is the technical know-how?

What are the challenges?
Challenges

Material properties, dimensional accuracy and surface quality are major challenges and development targets. They have significant influence on technical feasibility and manufacturing cost.

Material Properties
> Laser PBF is not a flawless process.
> How can flaws and defects be detected and controlled reliably?
> Material properties are frequently sufficient, but for some applications not.
> Which limitations prevent successful application?
> Which benefits can be utilized?

Dimensional Accuracy
> Process induced internal stresses limit dimensional accuracy.
> Support structures are required, but increase the costs.
> How can the dimensional accuracy be controlled efficiently?
> Empirically? Simulation?
> Other AM processes?

Surface Quality
> Machining and/or surface finishing is most often required.
> Which surface quality is achievable at which costs?
> Alternative and cost competitive finishing processes are required.
Quality Requirements, Material Defects

How can material defects be detected and controlled?

Influencing parameters and measures

Powder
- Chemical Composition
- Inclusions
- Porosity
- Residual moisture
- Gases (N₂, O₂, H₂)

Process
- Various parameters (not detailed here)

Current defect detection and control
- Qualification by microstructural analysis and process freeze
- 100% volume test with NDT at finished parts is not feasible
- Online process monitoring (thermal deviations of metal pool) is required as indirect defect control

Flaws and Defects

Pores
Cold weldings
Cracks
Material Properties - Tensile

Alloy 718, tensile properties at 500°C
AM material shows small anisotropy, but acceptable properties

Mechanical Properties at 500°C
- In Plane: Rp0.2 = 1110 MPa, Rm = 1283 MPa, A5 = 9.7%
- Out of Plane: Rp0.2 = 989 MPa, Rm = 1207 MPa, A5 = 15%

Minimum Requirements
- Rp0.2 min. = 860 MPa
- Rm min. = 1027 MPa
- A5: 12%

Heat treatment according to AMS 5663:
- Solution annealed at 980°C / 1hr / open furnace cooled
- Precipitation hardened in two stages
  1.) 720°C / 10 hr / furnace cooled
  2.) 620°C / 8 hr / open furnace cooled
Materials for Additive Manufacturing

Future Potential

AM material innovation landscape\(^1\) (serial production)

> Two major fields of AM technology development are currently discussed by the industry:

- **Materials with new/improved functionalities**, e.g., amorphous metals, new super alloys for turbine hot section or even alloys of basic metals which allow for a better process ability like Titanium-Aluminides for aero turbine blades or Aluminum alloys with better weld ability like Scalmalloy®

- **Materials with improved process ability**, e.g., printing with higher pre-heating temperatures for creation of directional microstructure for increased creep resistance

> **Powder management** along the entire lifecycle with Industrie 4.0 technologies will further gain relevance

---

1) Not exhaustive, based on expert estimates

---

MAN Energy Solutions

Internal/Public

MPA Stuttgart - 44th MPA-Seminar – MAN Energy Solutions - ©2018
Materials for Additive Manufacturing

Advantages, Limits, Risks, Challenges

**Positive**

> Static material properties at moderate temperatures can be equal to / better than cast & forged qualities
> Cyclic material properties at moderate temperatures can be equal to cast & forged qualities
> New materials with improved properties (e.g. Scalmalloy, High Entropy Alloys, ODS, Metallic Glasses…)

**Limits / Risks / Challenges**

> Defects need to be monitored, detected and controlled!
> Limited material resistance at high temperature (creep, TMF)!
> Materials need to be qualified, new materials data and materials models/parametrizations are required!
Drivers and Challenges

Drivers
- Flexible and innovative design (complex, integral, lightweight, hybride)
- Low volume parts (small lot size)
- Faster prototyping (shorter time-to-market)
- Shorter lead times for spare parts and stock reduction (print-on-demand)
- Material flexibility and new materials / functionality
- Reduced costs for selected components

Challenges
- High manufacturing costs for Laser PBF
- Limited process stability, process monitoring and particular QA required
- Defects / limited material properties at HT / materials data required
- Internal stresses / distortions / shape accuracy
- Surface finishing is expensive
- Few field experience
Thank you very much!