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Efficient Post-machining of Additively Manufactured Components

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BCT’s core know-how: Software solutions for automated manufacture and repair of individually shaped parts

ADAPTIVE MACHINING
Where we come from

Manufacturing & repair applications
- Tip repair
- NGV repair
- Combustion chamber repair
- Vane fillet & platform milling
- Composite repair

Technologies used
- On machine probing
- On machine scanning
- External scanning
- Software

Customised modules

OpenARMS BCT

Bespoke solutions
References

**Turbine**
- ABB, Switzerland
- AirFrance-KLM/Safran, F
- Aviadvigatel, Russia
- AVIC, China
- BTL, Israel
- Chromalloy, USA
- GE/Alstom, Switzerland
- Holy, China
- Honeywell, USA
- IHI, Japan
- Leistritz, Germany
- Lufthansa Technik, Germany
- MTU Aero Engines, Germany
- MTU Maintenance, Germany
- Rolls Royce, UK
- SAESL, Singapore
- Siemens, Germany
- Safran MRO, France
- TACR, Germany
- Safran Aero Boosters, BE
- Safran Helicopter Engines, F
- TOS (P&W), Singapore
- XAE, China
- …

**Composites**
- Airbus, Germany
- Boeing, Australia/USA
- German Army
- MotorSich, Ukraine
- …
Adaptive Machining of AM Components

- What is Adaptive Machining?
- Why do AM parts require machining?
- How can Adaptive Machining support the processing of AM parts?
Adaptive Machining Technology
BestFit vs. Adaptation

**BestFit**
- Starting condition
- Capture position/orientation
- Calculate BestFit Frame

**Adaptation**
- Starting condition
- Capture pos./orientation & shape deviation
- Calculate BestFit & Adaptation

**CAD/CAM planning**
**Machining**
Example: Using **BestFit** for blade manufacturing

Blade “Final geometry” to be manufactured by milling

Precision casted or forged blank part with stock material

NEW position calculated by BestFit (translation/rotation)

Use original NC program within another frame
Example: Using Adaptation for blade tip repair

1. Individual shape does not require to scrap the part! Consider shape during subsequent processing, instead!

- Measure individual shape of each blade, in-process
- Adapt NC milling programs based on measuring results
- Send new programs to machine for processing

Cycle time: probing plus re-contouring = 2 - 2.5 min

Reprofiled Tip
Example: Using Adaptation for linear friction welded blisks

Linear Friction welded parts (test sample shown)

Measuring program defined within the software

Probing

Probing

Rough milling process

Fillet milling
Adaptive machining: Principle of BCT’s software OpenARMS

- Consider as-is position
- Consider as-is shape
- Consider predefined technology
- Generate adjusted NC-program for each individual part
Connection of OpenARMS with NC equipment

Standard PC

- Windows operating system
- OpenARMS software
- Ethernet port

Machine tool

- Standard NC controls
- Ethernet port

Standard ethernet connection
Why Machining of AM Components
Machining, why?

- Prepare fittings
- Provide functional surfaces
- Blending
- Improve surface finish
- Prepare holes
- Remove support structures
Adaptive Post-machining of AM Components
Automated processing of AM parts using Adaptive Machining Systems

- Connected to measuring devices to capture as-is situation
- Connected to machine controller
- BestFit/Adaptation
- Parameter handling
- Automated processing

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Process flow and feedback for the user

- Capture as-is position and shape
- Use improved best fit capabilities
- Adaptation of NC programs
- GO!
- User check

CAD  AS-IS
Milling tasks of a lightweight structure

- Pocket milling/drilling holes
- Provide functional surfaces
- Pocket milling
- Drill holes to nominal dimensions
Removal of SLM supports: Blending by automated measuring and milling process

- Capture surrounding geometry
- Calculate adapted NC programs for removal of support
- Blend surface
Hybrid manufacturing approach: Conventionally manufactured base component

- Add feature by LMD
- Provide a smooth transition
  - Measure the surrounding area after LMD
  - Calculate adapted NC programs for final machining of AM feature and smooth transition into base component
Total impeller/blisk repair using hybrid machines

1. Capture of position and shape of each blade
2. Removal of worn-out section (best-fit)
3. Adapt LMD process
4. LMD process
5. Adapt LMD process
6. Adapt re-contouring
7. Re-contouring
Conclusions & Lessons-learnt

+ Deviations from nominal shape play a decisive role in additive manufacturing

+ Many geometrically critical post-machining processes can be automated using adaptive machining

+ Don’t focus on Design for Functionality only
  Although 3D printing seems to be limitless, most of the parts need post-processing

+ Design for Manufacturing is key to efficient 3D printing based production
  Foresee elements which can be used to reference and to fix the part during post-processing

+ Look at traditional manufacturing processes
  Try to adapt solutions from casting etc.