THE NEW PARADIGM OF QUALITY CONTROL IN THE INDUSTRY 4.0 ERA

www.ikts.fraunhofer.de
Industrie 4.0 – Internet of Things
Motivation: Individualised Production

Individualised Production based on 6 key steps:

1. Standardized individual steps
2. Modularisation
3. Computer Based Modelling and Configuration
4. Additive Manufacturing
5. Production Networks and Order Management Platforms
6. Automated Production

Focus on high volume production (scale effects) is replaced/added by customer centric individualized production

Individualised Production close to the customer is key of Industry 4.0
Paradigm shift in industrial quality insurance and non-destructive evaluation

- Established and optimized process chains
- Statistical process control and quality management (Six Sigma)
- Testing of samples
- Tolerances for replacement

- Manufacturing „on demand“ – configured by the customer
- Additive and classical methods
- New paradigm of Quality insurance
- Integrated Intelligence, Machine Learning
The new paradigm of quality inspection
massive process data - linked to the individual component

- Quality control powders, pastes, inks, environment, logistics
- Material- and process diagnostics in-line during generation
- Anisotropic and spatially resolved strength- / stiffness- and stress data
- New understanding of interface mechanisms
- Feedback Loop to CAD-/FEA Models
- Data storage and data exchange along the value chain
- Products with integrated sensors
- 100% traceability across all the production steps
- Automated early warnings by big data Machine Learning
Spatially resolved NDE for AM components

Material parameters to look for

- Material and process based anisotropic and spatially resolved quality data
  - Internal compressive stresses – bending fatigue strength
  - Interface to “conventional” tube components
- Feedback Loop to CAD-/FEA Models – “simulate as built”
- Data as built are linked to any individual component

NDT and Additive Manufacturing
4 approaches

1. Monitoring of Feedstocks and powders

2. Integral Inspection of the component

3. In-line monitoring of critical parameters (delaminations, voids, porosity)

4. Post process inspection in critical areas (internal stresses, stiffness, cracks)

Source:
Zeiss Micrographs of steel (316L) (a, c) and AlSi10 (b, d)
Powders used for powder characterization; a, b) Light microscopy, transmitted light, bright field, 80×; c, d) SEM, SE, WD 10 mm, EHT 10 kV, 500×
Integral NDT Methods

- Visual Inspection
- X-ray inspection
- Optical transmission
- Ultrasonics
- Thermography
- Sound analysis

100% component inspection X-ray line sensor
Quelle: Fraunhofer IKTS
Acoustic analysis and pattern recognition

- Integrale Method for fast failure detection
  Sample: electrolyt tubes for Na/NiCl-cells (Project „Cerenergy“)

Optimized fixation is a key step

„normal“ fixation:

optimised fixation:
  (Signals transformed to audible frequencies)

Simple failures can be detected by listening
  tubes with fracture:

aged material:
Acoustical Process Monitoring

- Simple Sensor configuration
- Acoustical signals merged with welding specific data in time domain
- Fingerprints of typical welding failures – machine learning task
- Multiple sensors – acoustic events can be located in a surface
- Ideal approach for large structural components

Source: Fraunhofer IKTS
Machine Learning in Acoustic Analysis

Basic Process Model

Sensor Signals with known Meaning (Training Sample)
- e.g. "good"
- e.g. "bad"

Sensor Signals with unknown Meaning

- Primary Analyzer
- Secondary Analyzer
- SIGNAL ANALYZER
- Model
- Pattern Recognition
- ARTIFICIAL INTELLIGENCE
- Machine Learning

Meaning of Sensor Signals

Algorithms signal analysis pattern recognition on FPGA and DSP
Algorithms trained first
Background noise supression optionally

Hardware based autonomous voice dialogue System
Inline methods for AM process monitoring

- Optical Monitoring
- Acoustical Monitoring
- Ultrasonics (continuous monitoring of to layers only)
- Optical Coherence Tomography
- Laser-Speckle-Photometry
Optical Coherence Tomography (OCT)

- **Fourier-Domain OCT-System**
- Shortwave coherent light source (SLD)
- splitted in sample- and reference arm
- Interference $\rightarrow$ FFT $\rightarrow$ depth-reflection -profile (A-Scan)
- Cross-section (B-Scan) by a sequence of A-Scans
- Tomogramm (3D) by a sequence of B-Scans

Optical Coherence Tomography (OCT)

a) optical setup

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b) Inspection system with automated classification
OCT Data analysis (circular foil)

- B-scan data: 42 GB
- Cutting data compression: 400 MB
- Filtering: Automated classification, Failure detection: 0.4 MB
- Projection: Top view failures: 0.4 MB
- Top view protocol: 0.4 MB

High speed data processing with automated classification and failure detection
Advantages

Direct feedback → processing parameters can be adjusted during processing (geometry, position, volume)

voxel-by-Voxel generation of the 3D model as generated → safety and traceability

Certification of batch size 1 manufacturing

Manufacturing and quality inspection in a single process

OCT 3D-data of additiv manufactured ceramics
Source: Fraunhofer IKTS
Optical Tomography with ceramics

Application: green bodies based on LCM additive manufacturing

- **Layer distance**: 25µm
- **Backside signal**
- **Table reflection**

**Al₂O₃** AM test body

- *Notch at the surface*
- *Surface cracks*

**Zr₂O₃** test body

- *Layer structure visible*
- *Layer structure invisible*

*X;Y resolution: 12.5µm*

*Z (depth) resolution: 8µm*
Laser Speckle Photometry LSP

a) schematic setup

Detection Camera

Speckle pattern by laser light

Mechanical load

thermal load

Speckle pattern

rough surface

b) Speckle pattern dynamics

Speckle-pattern

Speckle-pattern dynamics through surface

time
Approach to measure stresses in materials by LSP

Stresses and porosities correlate with thermal diffusivity measured by speckle pattern movements

Ulana Cikalova, Juergen Nicolai, Beatrice Bendjus et al., "Laser speckle photometry: contactless nondestructive testing technique", Proceedings of SPIE Vol. 8413, 84130X
Application of Laser-Speckle-Photometry (LSP)

Inline-Monitoring of spot welding of gold contacts for electronics industry

Gold-contact area:

Key LSP parameter:

Mean fractal dimension: $D_F = 1.37$  
$D_F = 1.66$

Gold content: 

87 m%  
86.6 m%
Integrated NDT
Monitoring of critical parameters during AM job processing

Advantages

- limitations of penetration depths by certain methods can be overcome
- voxel-by-Voxel generation of the 3D model as generated → safety and traceability
- Certification of batch size 1 manufacturing
- Manufacturing and quality inspection in a single process
Materials Data Space

Representation of material data along the value chain (raw materials – processing – in use – Recycling)

Link between component parameters and various microstructures and compositions

Quality assurance along the value chain

Learning from data

Digitalisation of material and structural data as base for new business models (e.g. predictive maintenance, …)
Industrie 4.0 - Smart Machine Sensor
Sensors mimics the product loads and movements

Sensors mimics the product loads and movements in a packaging machine.

Focus: Optimized Machine Design, faster commissioning at customer site

Approach: Miniaturized sensor in the product form
CeraCode® using ceramic luminiscents: Product labels and process control

- Luminiscent particle inks for barcodes / QR-Codes
- Extremely robust, unforgeable labeling
- Traceability under harsh environments (high temperature, chemicals, EMV, …)
- Sensoric information of process parameters (temperature, radiation, gas pressure, …)
- Confirmed for series manufacturing after 3 month test in automotive industry

High-temperature product labeling of a component under UV light vs. daylight
Summary

1. Highly loaded or functionally critical components require individual NDT inspection

2. In-situ or inline NDT methods, in combination with other sensor signals, of the path to process based quality inspection for individual components

3. Fraunhofer IKTS develops some promising concepts for in-line NDT methods

4. The new paradigm of quality management:
   - massive process data - linked to the individual component
   - offers attractive new business models for the industry
Many thanks for your interest!

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