Nondestructive Characterization and Quality Control of Lightweight Materials and Assemblies
(Advanced Joining Technologies)

R&D and Applications in Automotive and Transport Industry

OUTLINE

- Introduction to Fraunhofer IZFP & Mission
- NDE of the future: Life Cycle Monitoring & Materials Data Space
- NDE for Product Development
- Production-Integrated NDT for In-Situ Process Control
- NDT for Quality Control of Products
- Outlook
Fraunhofer-Gesellschaft at a Glance

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

- **24,000** staff
- **67 institutes and research units**
- **€2.1 billion**
- **€1.8 billion**
- **Almost 30%** is derived from contracts with industry and from publicly financed research projects.
- **More than 70%** is contributed by the German federal and Länder Governments.

Fraunhofer-Gesellschaft : Applied Research

New Business Models

Universities and research organisations

Fraunhofer Mission

Industry and companies

Market readiness (Technology Readiness Level)

- **TRL 1**: Basic principles observed and reported
- **TRL 2**: Technology concept and/or application formulated
- **TRL 3**: Analytical and experimental critical function and/or characteristic proof of concept
- **TRL 4**: Component and/or validation in laboratory environment
- **TRL 5**: Component and/or validation in relevant environment
- **TRL 6**: System model or prototype demonstration in a relevant environment
- **TRL 7**: System prototype demonstration in an operational environment
- **TRL 8**: Actual system completed and qualified through testing and demonstration
- **TRL 9**: Actual system proven through successful operations
FRAUNHOFER IZFP …

... develops sensor & system technologies and evaluation tools to be used for non-destructive monitoring along the complete product life-cycle

Location Saarbrücken

Saarbrücken: app. 200 personnel / scientific staff (app. 115 full time equiv.)

Budget SB ~ 16 Mio €
Industry Contracts SB ~ 7,5 Mio €

EZRT Fürth: ~ 100 pers.

Budget Fürth ~ 14 Mio €
FRAUNHOFER IZFP
Mission / future NDE

Fraunhofer IZFP uses the competences
- of intelligent data acquisition based on complex, nondestructive sensor systems / sensor physics
- in order to generate information (smart materials information) by means of intelligent data analytics
- for the optimization of process models along the entire life cycle with the goal of optimum safety, efficiency and quality

Fraunhofer IZFP
Business Fields / Industry Segments for Life Cycle Monitoring Applications

- Automotive
- Rail(way)
- Aviation & Space
- Energy
- Agriculture / Bio Engineering
- Infrastructure / Construction
- Security
- Sports/ Leisure Goods

New products need modern NDE!

No airplane would be flying, no car would be driving without non-destructive monitoring!
FRAUNHOFER IZFP
Customized Competencies – Product Life Cycle (PLC)

- Development of system solutions for:
  - Characterization (raw materials | materials)
  - Definition of parameters (product development)
  - Monitoring and control (production process)
  - Quality control (product)
  - Condition monitoring (trade | operation)
  - Sorting of materials (recycling)

- Intelligent Crosslinking
  - Within a single stage of PLC
  - Between different PLC stages

- Optimization
  of reliability, cost effectiveness and sustainability of new materials and products

Future NDT 4.0
System Design from Data Acquisition / Sensor Physics up to Data Evaluation & Analytics within the Digital Product Space
**FRAUNHOFER IZFP**

**Strategic Competences**

**Scientific Competencies** (core competencies)
- Data acquisition – development of sensors for different nondestructive technologies
- Data evaluation – “3D imaging” and “3D image processing”
- Application and material know-how – data analytics, smart materials information
- System development – subsystems, lab systems, industrial systems

**Technological Competencies**
- Acoustics, Ultrasound
- Electromagnetic Methods
- Thermographic Imaging
- Eddy Current
- X-Ray
  
**Customized Competencies** (Product Life Cycle)
- Raw Material Analysis
- Material Characterization
- Process Monitoring
- Quality Assurance
- Condition / Operation Monitoring
- Recycling / Material Sorting

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**Data Acquisition, Transport & Processing into Smart Materials Data for Optimization of any kind of Process (**→ **NDE 4.0 + IoT**)**

Source: https://www.bitkom.org/industrie40/
NDE 4.0: Digital Data Processing and Analytics → Transfer into Information for Optimization & Process Design

- **Business Intelligence**
  - "diagnostic"
  - Descriptive Analytics

- **Data Science**
  - "forecast"
  - Predictive Analytics
  - "pre-planning"
  - Prescriptive Analytics

- **Optimization**
  - Design

**Complexity**

**Asset / Benefit**

**DB** (Data base) with training data sets (object + opt. parameter)

- Training Algorithm
- Artificial Neural Network, Deep Learning, Machine Learning

**GUI**

**Source:** Fraunhofer EZRT / IZFP
FRAUNHOFER IZFP
Certified Systems for NDE 4.0

The Fraunhofer IZFP quality management system is certified in accordance with DIN EN ISO 9001.
The certification encompasses “the research, development, qualification and application of nondestructive testing technologies”.

Fraunhofer IZFP also operates a flexible test lab that is accredited in accordance with DIN EN ISO/IEC 17025.
The accreditation is internationally accepted under the “ILAC-MRA“ agreement.

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Lightweight Design
→ Multi-Material Use
→ Innovative Joining Techniques

Hybrid construction
Multi-Material Design

Steel/Aluminium
mixed construction

Opt. Steel
shell construction

Steel/FRP
mixed construction

Steel-Spaceframe

FRP-Structures
“Body in Black”

Biennet (incl. 2K bonding) made of Aluminum:
10.3 kg + 1.0 kg (2K bonding) = 11.0 kg

Trunk Lid (thermosetting mat.):
-2.0 kg

Reef Carbon Fiber:
ca. -0.3 kg

Doors made of Aluminum:
-10 kg

Aluminum Front End:
-20 kg

Fender (thermoplastic resin):
-4 kg

Source: Böllhoff / Volkswagen

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Product development
Definition of parameters of the production process or the product itself

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Monitoring along the Product Life Cycle: XXL-CT

Fraunhofer EZRT
XXL-CT ➔ Validation & Improvement of design for optimal crash performance
FRAUNHOFER IZFP
Nondestructive Monitoring along the Product Life Cycle

- Data analysis and geometric data extraction from XXL crashed CTs
- Validation of crash-simulations CT for Ground Truth
Monitoring in Production: In-Process Screw Control

Control of Correct Clamp Load for optimized screwing process

Monitoring in Production: In-Process (real-time control)

RIVTAC-Technology

Process Monitoring with Airborne and Structure Borne Ultrasound
Monitoring in Production: In-Process (real-time control)

Signal Amplitude (y) as a function of process time (x) for RIVTAC

Monitoring in Production: In-Situ Control of Welding Process

Laser Welding
- Welding penetration with acoustic emission
- Welding defects with acoustic emission
- Hardness and residual stress with 3MA
- Process monitoring and control
- Process optimization with power ultrasound

Friction Stir Welding, FSW
- Inline testing (e.g. with EMAT, thermography)
- Process monitoring (e.g. acoustic emission)
- Process control (e.g. MonStir®)
- Process optimization with power ultrasound (UltraSound Enhanced – USE FSW)

Resistance Spot Welding
- Hardness and residual stress with 3MA
- Nugget size with 3MA and ultrasound
- Process monitoring and control
- Process optimization with power ultrasound

SLM (Selective Laser Melting)
- Process monitoring with acoustic emission
Monitoring in Production: In-Process (real-time control)

Process Control Loop (Real-Time Control) using In-Situ Airborne Ultrasound

Friction Stir Welding of Aluminium

- no pores, no cracks
- homogeneous mixing
- pores & cracks
- inhomogeneous mixing

FSW tool

Sonotrode

Butt joint

US oscillation

Retreating Side

Weld Direction

Joint

Shoulder

Pin

Advancing Side

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Monitoring in Production: In-Process Control of Spot Welding

Spot Welding

Physical Principle (Ultrasound Transducer)

Spot Welding Tool with integrated ndt control

Monitoring along the Product Life Cycle: Welding & Bonding
Production Monitoring and Control

Ultra-Highstrength Steels (Presshardening)

Body and Frame Requirements:
Yield Strength, Hardness, Toughness ....

Elongation (%)

Flat product grades:
- IF-steels
- Deep drawing steels
- High Strength IF steels
- BH-steels
- Isotropic steels
- CRM-steels
- High Strength Low Alloysed steels
- DP-steels
- TRIP-steels
- Martensitic steels
- Air quenched steels
- Press hardening steels

Body Parts:
- B-pillar
- Floor panel
- Side intrusion beam
- Crash zones
Complex Production Chain (Presshardening)

Basic material:
- Steel 22MnB5
- Evtl. AlSi coated

Roller furnace:
- Austenitization
  - $T = 880 - 930 \, ^\circ C$

1. Hot forming:
- $T = 770 - 830 \, ^\circ C$
- Good formability

2. Quenching:
- $dT/dt > 27 \, K/s$
- High strength
- Up to 1,500 MPa

Welding:
- Coating properties
- Weldability!

Crash test:
- Steel properties
- Crash safety!

Close quality monitoring is necessary
- Enormous time and costs with destructive testing
- Production Integrated NDT

Production Monitoring and Control
Ultra-Highstrength Steels (Presshardening)

Micromagnetic Inspection Device (3MA)

Nondestructive Measurement
- Hardness
- Yield strength, Rp0.2
- Ultimate tensile strength, Rm
- Elongation, A50
Monitoring along the Product Life Cycle

Automated Inspection of lightweight aluminium castings
Novel X-ray technology DRAGONFLY is reducing the analysis time by 50%

Automated Inspection of Polymer Composite Products

Battery Crashbox (e-car)

Structure CFRP Layer

GFRP base material

Structure Metal Mesh

complex multi-material body with GFRP base material
Automated Inspection of Polymer Composite Products

Battery Crashbox (e-car)

Thermography: Pulse-Phase-Analysis @ 0.05 Hz

Reference defects in 2 mm depth

6 mm
5 mm
4 mm
3 mm
2 mm

Delamination at metal inlay (mount support)

Automated Inspection of Polymer Composite Products

Air-Coupled Ultrasound for automated inspection of Battery Crashbox (e-car)

customized transducers (IZFP patent)

Defects

Microstructure

465 kHz
260 kHz
Automated Inspection of Polymer Composite Products

Sampling-Phased Array Ultrasound (TF, FMC) of CFRP Wheel (3D Inspection)

C-Scan (Projection)
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FRAUNHOFER IZFP: Optimized Product Lifecycle-Management
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Non-Destructive Monitoring in the Product Life Cycle by Smart Sensors and NDE 4.0

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