Fuel cell production - possibilities of process monitoring in bipolar plate production in the stamping and forming process and inline processing of extremely large amounts of data

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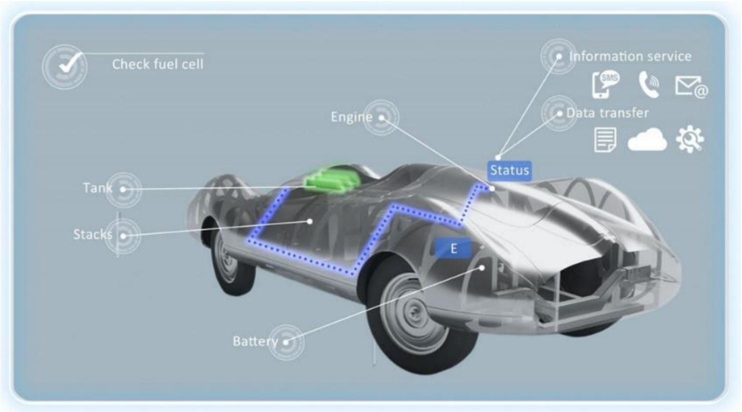
5th WORKSHOP Forming and Punching

Overview of fuel cells & electrolysers

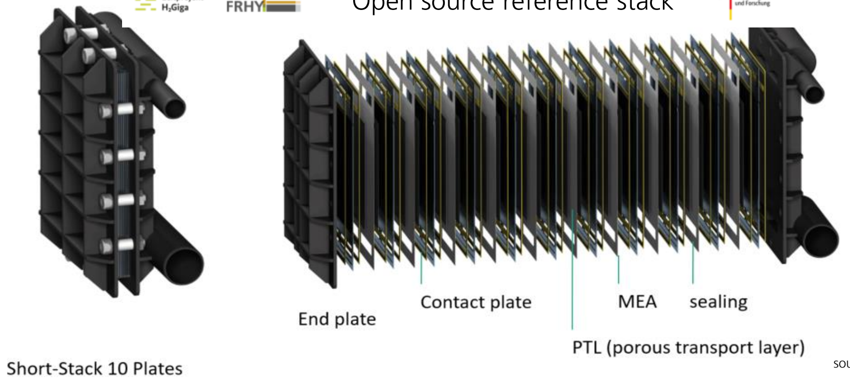
Fuel cells in mobility applications

Activities at Fraunhofer IWU – Dept. Automation

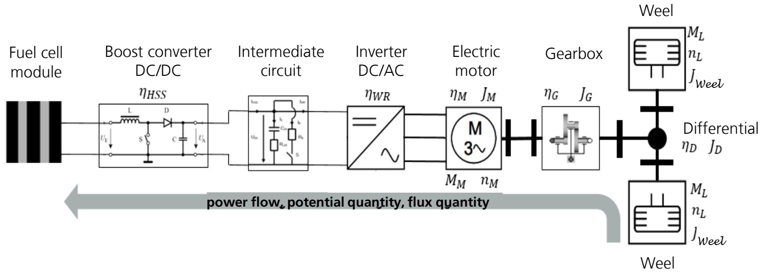


Silberhummel (Vintage car replica with fuel cell)

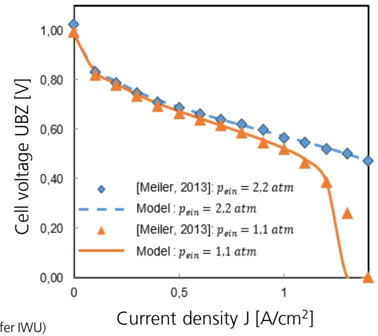
Open source reference stack



source: project FRHY



source: R.Löser (Fraunhofer IWU)



Fraunhofer IWU – Dept. Automation:

→ Simulation models of the electro-chemical behaviour and the drive system ("from the cell to traction")
→ Development of monitoring/control solutions for H2-powered vehicles
→ Testing systems for hydrogen embrittlement
→ **Inline quality monitoring**

Development goals in the fuel cell sector

The production process for fuel cells still has a strong manufacturing character

1 **Performance**

- Improving the efficiency and performance of fuel cells

2 **Costs**

- Development of cost-effective FC stacks and BOP components (peripheral systems)
- Advanced approaches for large-scale production including quality control
- Rejects as a cost driver

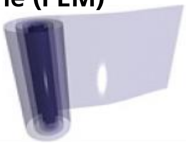
3 **Longevity and sustainability**

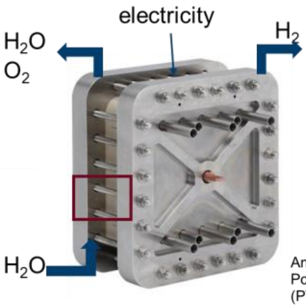
- 8,000 h light commercial vehicles, 30,000 h heavy commercial vehicles, 80,000 h power supply
- Reliability and robustness of the system under dynamic and harsh operating conditions
- Improved control systems and test procedures for resource-conserving and energy-efficient production

© Max Wei, Simon Thompson, Elizabeth Connelly, Neha Rustagi, Hossein Ghezel-Ayagh, Chris Capuano, Josh Mermelstein, DOE Hydrogen and Fuel Cells Program Record: Reversible Fuel Cell Targets, 6/23/20, Available: https://www.hydrogen.energy.gov/pdfs/20001-reversible-fuel-cell-targets.pdf

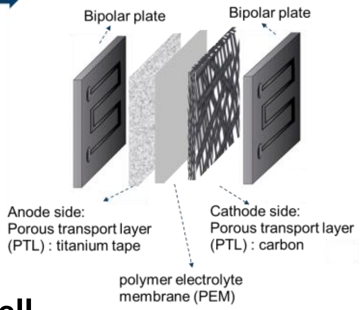
Overview of important components of fuel cells / electrolysers

Polymer Electrolyte Membrane (PEM)
(d = 50 - 150 µm)
(Nafion, PFSA, PSF, PEEK, PBI)
- Proton-conducting H^+
- Electrically insulating
- Mechanical barrier for reactants



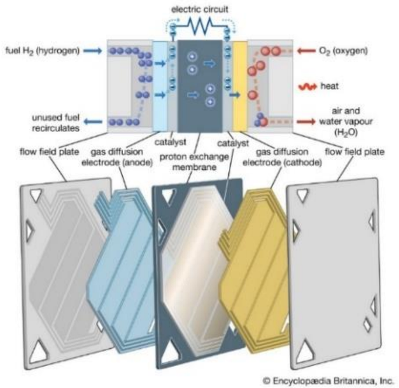


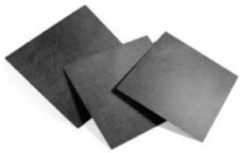
PEM Electrolyzer



Catalyst layer (CL)
(d = 10 - 20 µm)
- Reduction of the activation energy
- Platinum on carbon carrier
- Enlargement of the surface
- Corrosion resistance
- Tolerance to contamination

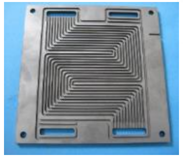
PEM Fuel Cell





Gas Diffusion Layer (GDL)
(FC: 100 - 200 µm, EL: 200 - 300 µm)
+ Microporous layer (MPL)
(d = 20 - 100 µm)
(Carbon paper/carbon fibre braid/fleece)
- Electrical conductivity
- Gas permeability
- Corrosion resistance
- Mechanical stability
- Promotion of water runoff

Bipolar plates including sealing (BPP)
(d = 1 - 2 mm)
(metal/graphite composite/polymer)
- Gas distribution
- Water drainage
- Cooling
- Electron conduction
- Corrosion resistance



End plates and mechanical stack structure
- Homogeneous pressure distribution
- Contacting the bipolar plates
- Dissipation of process heat
- Mechanical stability
- High mould fidelity
- Chemical resistance
- Weight

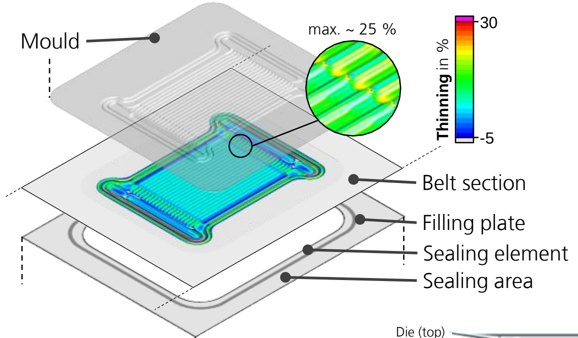
Sources: Encyclopedia Britannica, Inc., Dana, SGL, Chemours, fuelcellstore.com, KIT - IPEK, Joachim Scholta 2020

Overview of manufacturing processes for bipolar plates and single cells

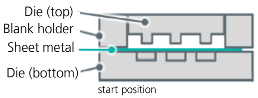
Production technologies

Process comparison

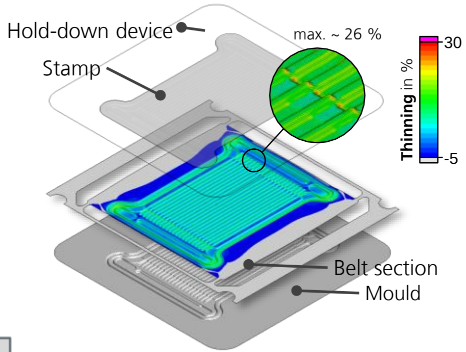
Hydroforming



Production rate: 7 BP-HP/min
(without parallelisation)

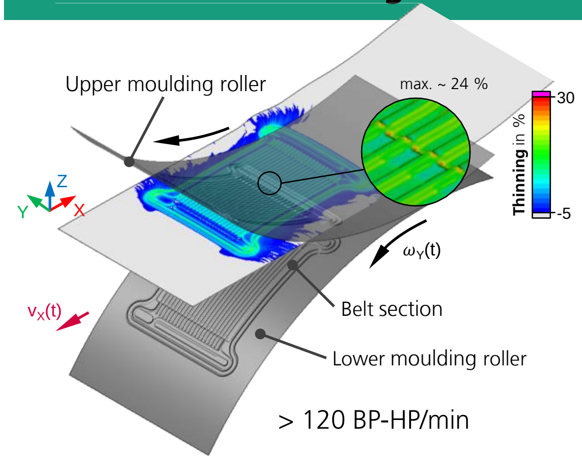


Hollow embossing

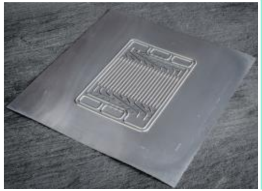


30 - 60 BP-HP/min

Hollow embossing rollers

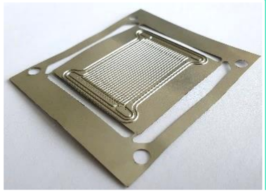


> 120 BP-HP/min



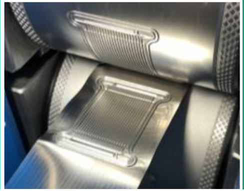
- only one mould
- high BP-HP quality
- potentials through passive hydroforming

"Smaller quantities"



- higher production rate
- most established industrial forming technology

Medium quantities

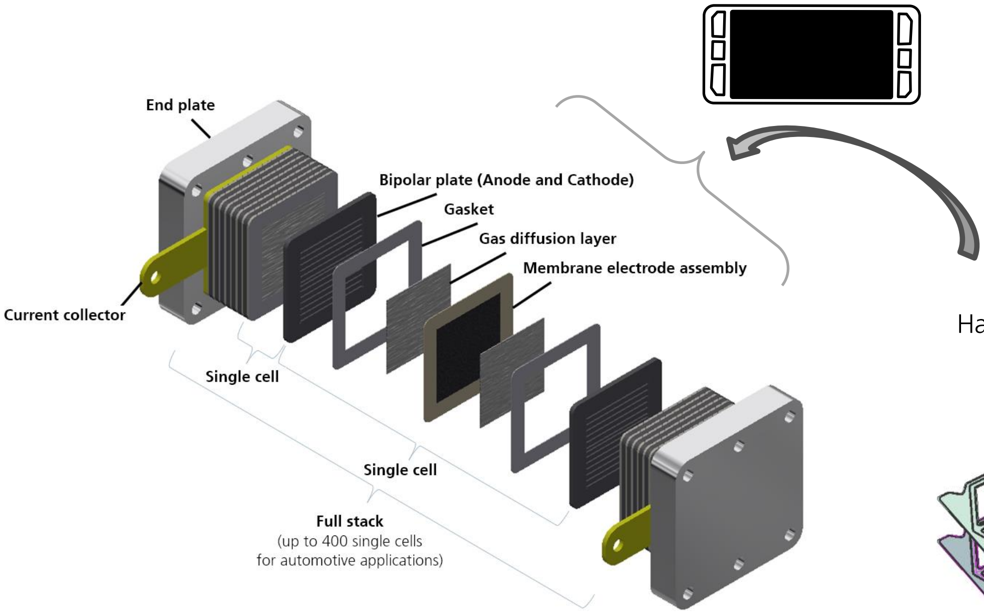


- low process forces and energy consumption
- currently low TRL

Potential for mass production

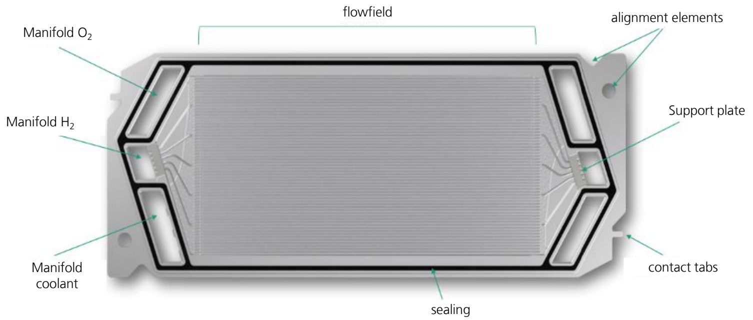
From bipolar plate to stack

Assembly overview

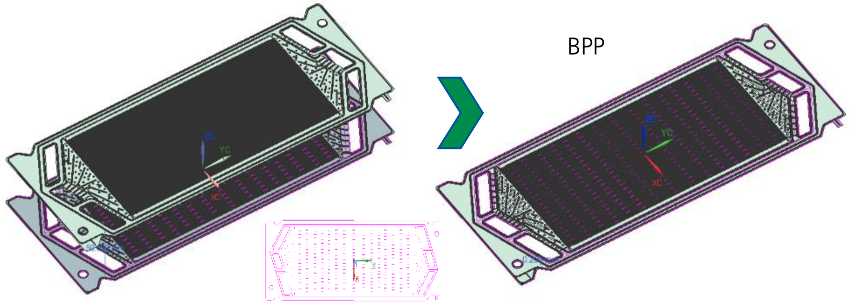


Source: Based on the diagram of DiLiCo engineering GmbH

Half plate



Half plate - cathode + anode



Inline inspection technology - 2D and 3D

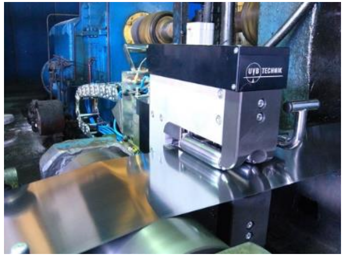
Reference test chain with quality requirements bipolar plate

Process steps and test tasks

Delivery of tape material → **Forming** → **Separating & cutting** → **Cleaning**

Delivery of tape material

- Surface quality
- Thickness tolerance of belt material
- Mechanical characteristics



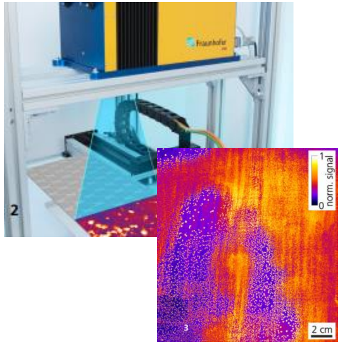
source: Coil-Monitoring UVB Technik s.r.o.

Forming / Separating & cutting

- Tool wear detection
- Crack detection bipolar half plate
- Detection of geometric deviations (especially in the flow field)
- Detection of incompletely punched-out areas
- Detection of burr formation at the cutting edges
- Breakage or deformation of components
- Detection of constrictions
- Evenness test

Cleaning

- Detection of residues on the bipolar half plates



source: UV-Fluoreszenzmessung organischer/öliger Benetzungen F-Scanner, Fraunhofer IPM

Reference test chain with quality requirements bipolar plate

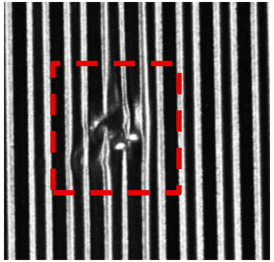
Failure characteristics and detection methods

	Dimensional accuracy errors	Surface defects	Manufacturing defects
Description	○ Deviations between actual and target geometry ○ Contour errors (inside and outside) ○ Coating (thickness)	○ Sink marks ○ Pressure marks ○ Ripples ○ Contamination ○ Trailing edges ○ Coating (homogeneous?)	○ Cracks ○ Constrictions ○ Creases
Evaluation	○ Random testing by means of optical measuring systems or mechanical measurement recordings ○ 3D shape detection (light section, fringe projection) ○ Image processing often with telecentric systems	○ (Optical) detection of deviations in the visual appearance ○ 2D image processing (classic methods + ML-based methods) ○ Lighting strategies + image processing	○ Particularly critical errors, as functionality may be impaired ○ Use of suitable lighting strategies and sensor technology

Optical inspection systems

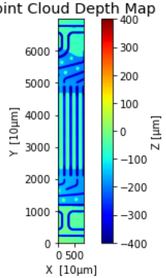
Overview of requirements and metrological boundary conditions

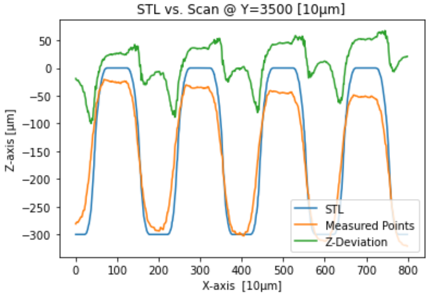
Multi-camera system - 2D surface inspection



High-resolution laser line scan - 3D geometry

source: KEYENCE





- Inline capability of the sensors and measuring principles (2D/3D)
- Determination of the suitable sensor arrangement
- Ensuring complete surface coverage with the required resolution
- Limitation of the sensors (e.g. data rate/volume, resolution, accuracy, measuring range ...)
- Loss-free data transmission (high data rates up to several GB/s)
- Fast capture and processing (multi-core/GPU)
- Is it a function-critical error or just a tolerable anomaly?
- How sensitive should the test system be set (test slip, pseudo reject)?

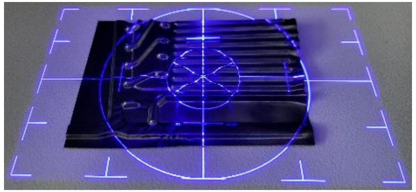
Optical 3D inspection systems

Overview of common measuring systems

Light section / laser line scan

- ✓ Detection in component movement (32 mm/s @ 16 kHz)
- ✓ Up to approx. 2 µm point spacing
- ✓ Measuring time = throughput time component (without processing)
- ? High-resolution encoder for triggering
- ✗ Distortion due to rocking, vibrations, uneven track running

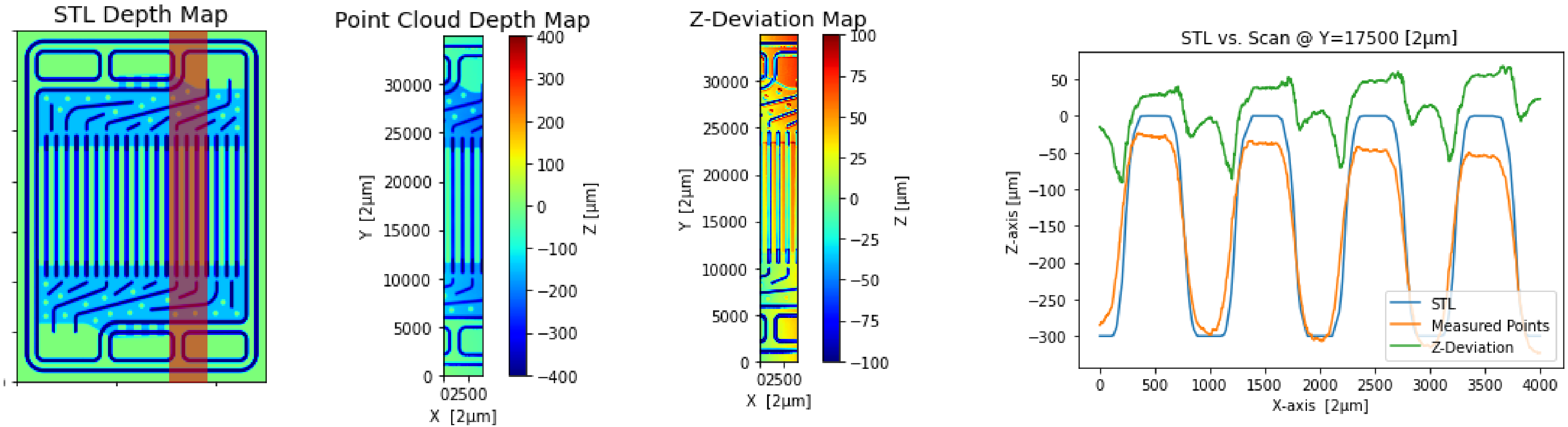
Fringe projection



- ✓ Detection of lateral measuring field (single-shot)
- ✗ Component standstill required
- ? Measuring time 0.4 s - 2 s (approx. 2,2 million points/s)
- ? Lateral point distance x/y 40 µm

Optical 3D inspection systems

Data volumes & processing times - An example ...



- Structure: Keyence LJX8020 line scanner, 130 k incr/rev encoder
- Scan field on BPP: 7.3 mm x 70 mm, 2 µm lateral resolution
- PC: Win 10, Intel i7-9700K 3.6 GHz DualCore, 16 GB-RAM

→ Data volume: 86.5 million points / file size: approx. 300 MB binary, 1.26 GB as CSV

→ Processing time: approx. 18 min (Python script)

Scan data

Name	Größe
pcd_2micron.csv	1.256.441 KB
pcd_2miron.npy	295.735 KB
stl_2micron.csv	10.614.167 KB
stl_2miron.npy	1.709.102 KB
z_diff_map_2micron.csv	985.808 KB
z_diff_map_2micron.npy	273.438 KB

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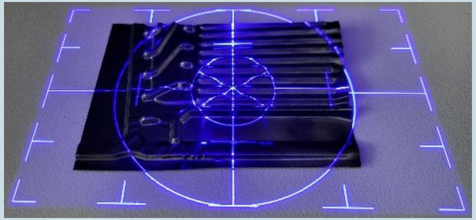
Optical 3D inspection systems

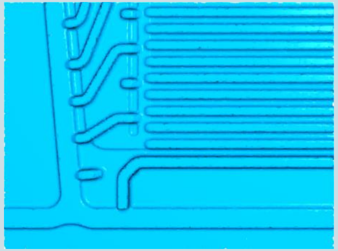
Example - Geometric deviations & flatness

- 3D scan



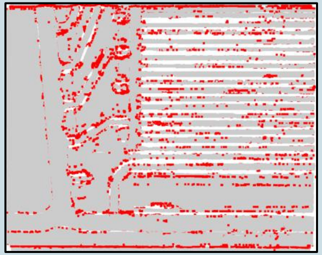
Sensor calibration

Scan of the bipolar plate

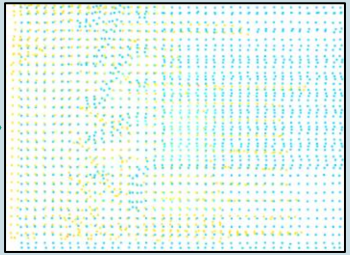


3D-CAD model as point cloud

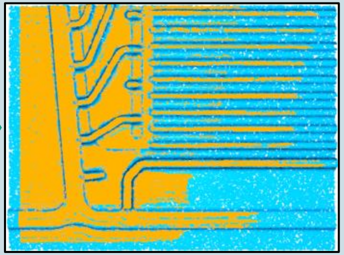
- Xeidana® + Open3D implementation



Elimination of outliers



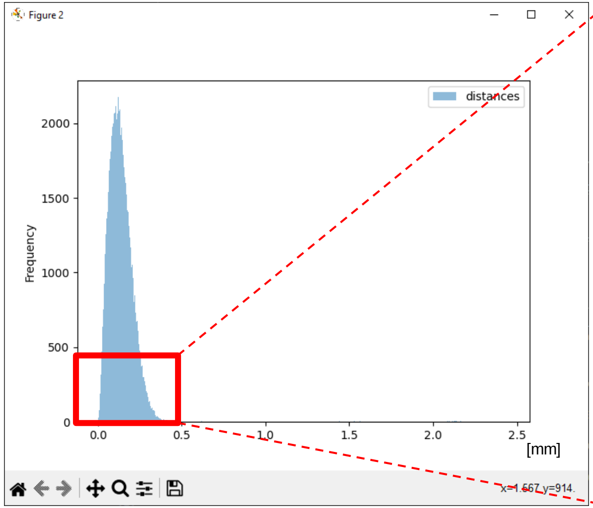
Global 3D-registration (Fitting)



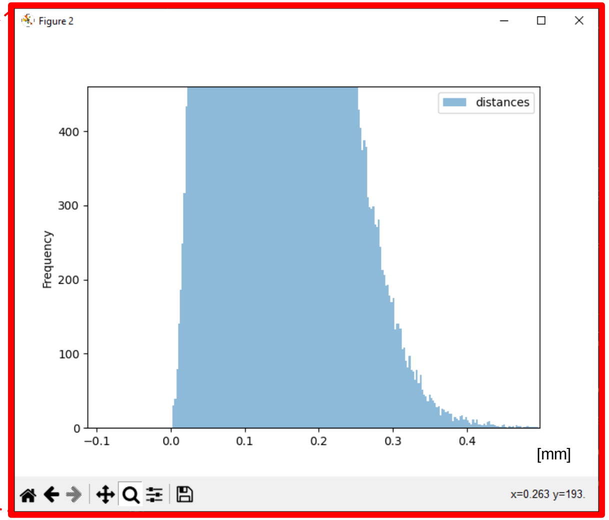
Local 3D-registration (Fitting), detection of geometric deviations, flatness

Optical 3D inspection systems

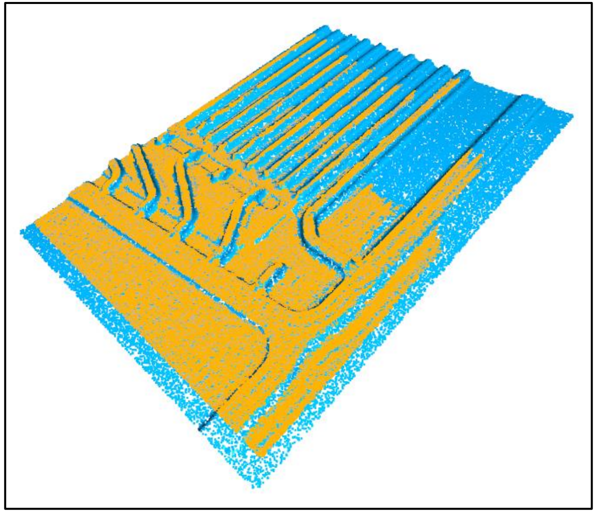
Geometric deviations & flatness



Histogram target-actual comparison between CAD and scan



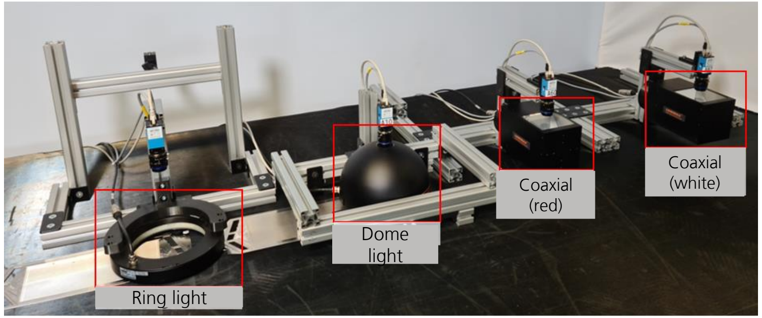
Histogram range increased



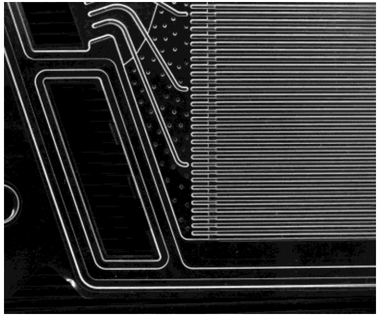
Exemplary result of the 3D registration (Fitting)

- Data quality of the point cloud incomplete on steep slopes or due to high reflection

Comparison of different lighting concepts for highlighting geometrical, production-related, (forming process) and welding defects with optical 2D sensors



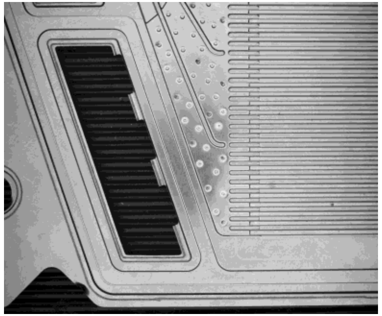
Darkfield



Suitable for manufacturability defects

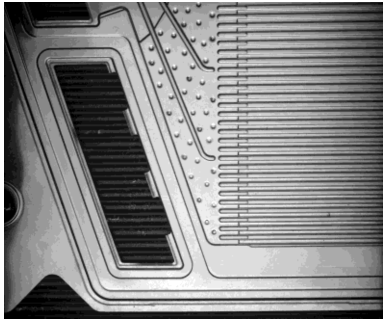
Not suitable for weld seam or surface testing

Diffuse light illumination (dome light)



Well suited for weld seams

Coaxial



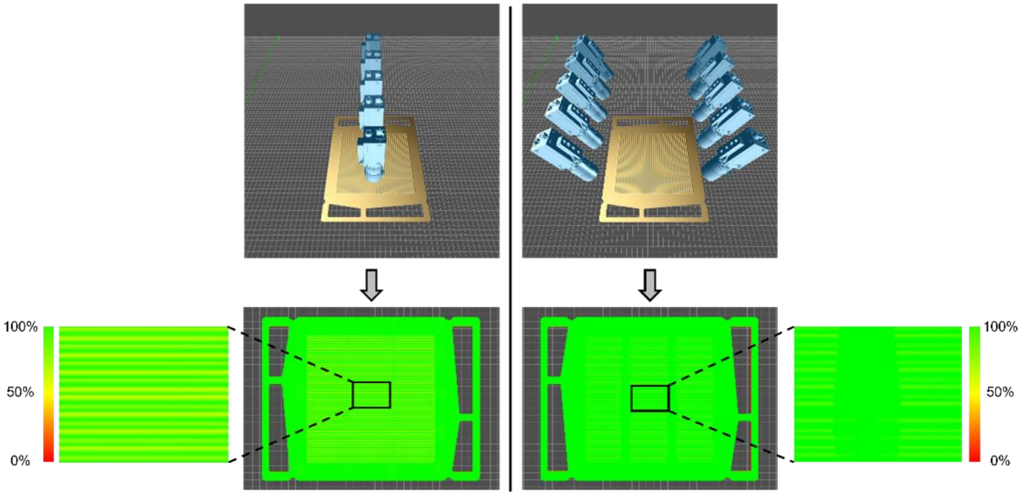
Well suited for weld seams & surface anomalies

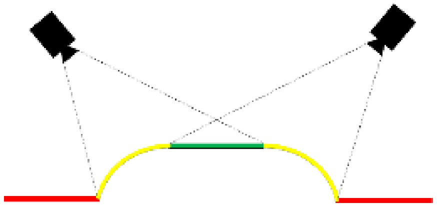
Optical 2D inspection systems

Coverage analysis

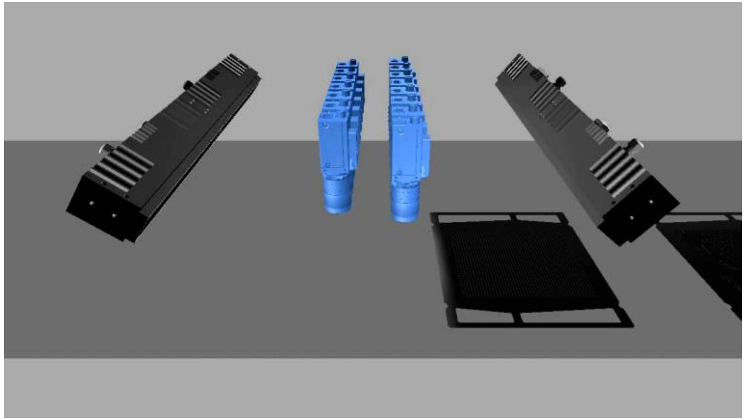
Coverage simulation of multi-camera systems:

Orthogonal arrangement V-arrangement





Example with required double camera redundancy:
green = ok, yellow = low redundancy, red = no coverage



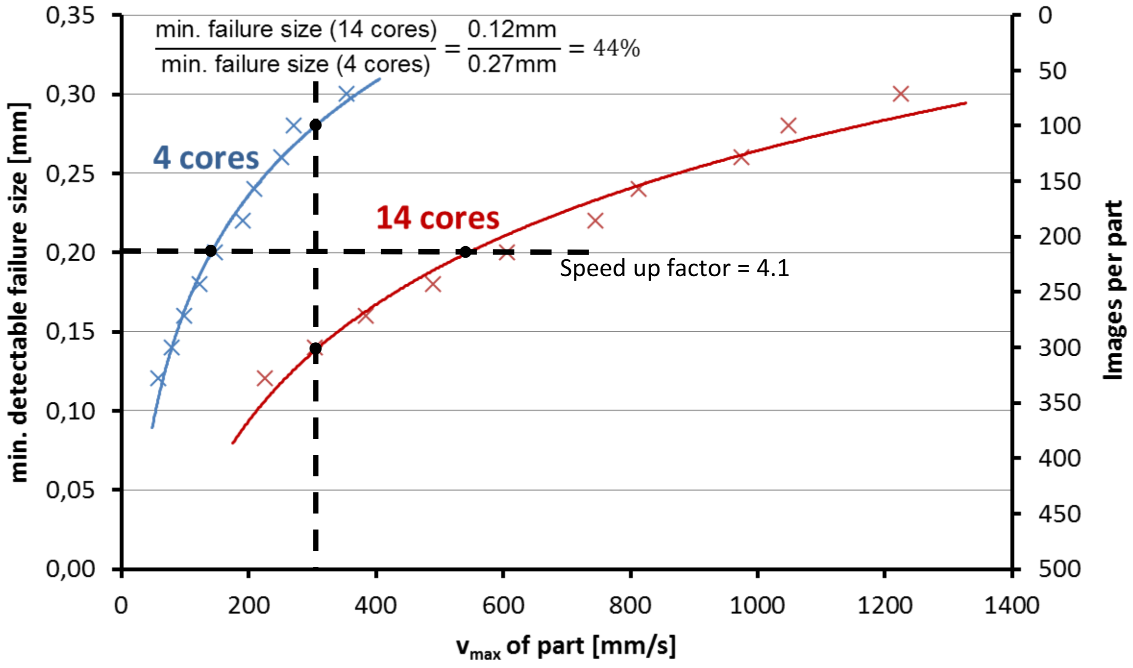
source: L.Gjakova (Fraunhofer IWU)

Processing programme for each camera:

1. Image acquisition
2. Correction of lens distortion
3. Compensation of placement tolerances
4. Edge detection and segmentation
5. Comparison with the good status model (anomaly detection) or (error) feature evaluation

Optical 2D inspection systems

Resolution, speed and computing time - always a compromise ...



Conclusion

Conclusion

- 3D measuring systems generally generate very large amounts of data, which often cause problems when processed inline
- 3D measuring systems require component standstill or low-disturbance component movement
- 2D measuring system easier to master in inline applications
- 2D measuring systems only provide indirect information on 3D features depending on the camera lighting arrangement
- Complete and possibly redundant coverage of the monitoring areas must be observed and can be simulated
- Detectable minimum defect size, component speed and computing power are linked to each other. If ever finer defects are to be detected at the same speed, the required computing power increases disproportionately