Einsatz eines hochgenauen Roboters zur Probenmanipulation in der Eigenspannungs- und Texturanalyse mit Neutronen

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Typical Applications
• Residual Stress determination
• Texture measurements

Method = DIFFRACTION
\[ 2d \sin \theta = n\lambda \]

Peculiarities of the measurements
• spatial resolved
• small gauge volumes (GV)
• sample needs to be measured at the same GV position in different orientations
Why using a 6-axis industrial robot for sample positioning?

- Suitable for small sample geometries
- High precision
- Proven technology

XYZ- and rotation-tables, eulerian cradle,…

Robot system
- High flexibility
- Automation possible (sample changer)
- Complex and larger parts
- Free choice of rotation center
Robot positioner @ STRESS-SPEC

- in operation since 2012*
- mainly used for texture measurements so far

* C. Randau et al. (2015), *Nucl. Instr. Meth.*, 794, p. 67-75,
DOI: 10.1016/j.nima.2015.05.014
Since 2020: New project to further enhance robot capabilities

**Motivation:** Measurements in complex shaped samples from advanced manufacturing processes

- Make robot ready for high spatial resolution strain determination
- Increase measurement efficiency by improved alignment procedures
- *In-situ measurements at temperatures up to 1300 °C* (e.g. recrystallization texture,...)
- .....
The Robot Positioning – Challenges

- Residual strain measurement is complicated because…
  - Position accuracy at the same pose (repeatability) < 50 µm
  - …but absolute position accuracy >= 500 µm

- TO STRESS AGAIN: We have to measure the sample at the same spot at least in 6 different directions to derive a complete strain tensor – always an absolute positioning job!

Aim: Absolute position accuracy < 50 µm

Ramadhan et al. (2021), *Nucl. Instr. Meth.* A, 999, 165230
Complex Shaped Parts - Example Measuring Task

**Turbine blade**
- Measure the residual stress state at several points along the blade
- 2 mm sub-surface
- Following the curvature of the surface
- No CAD data is available

**Challenges**
- No flat surfaces
- Measuring points are along an „undefined“ curved line
- Principal stress directions are most likely unknown
Measurement Process Chain – From Sample to Data

1. Markers applied
2. Sample mounted on robot holder
3. 3D-Scan Digital model + marker positions Sample COSY
4. Define measuring points and directions
5. Matching robot and sample COSY

Real experiment

- Optical Tracking system
- Position correction
- Collision detection

Future:
Data and analysis results can be projected on digital sample (online evaluation)

Definition of Measurement Points & Directions

Sample

Scan to point cloud

Meshing and markers

2 mm
Simulation & Control Environment for Measurement Kinematics

- ...includes the robotsystem, the actual sample, the walls,...
- Provides
  - Interface to the robot controller hardware
  - Path-planning
  - Collision avoidance
  - Alignment to measurement vectors
- OpenSource!

This is what the users sees!
Results - Feasability Studies of Sample Tracking
Optical Tracking System at our diffractometer - triangulation

Robot position correction - planned

Left image

Right image

... in commissioning
Optical Tracking System at our diffractometer - compensation

Camera 1
Camera origin
Robot arm
Sample
Gauge volume center

Camera 2

Camera system
S_target
F_target

Sample
Gauge volume center
Measurement point
> 500 µm

Robot Base

C
S_0
F_0

…2-3 iterations

Measurement point
> 500 µm

< 50 µm
Sample Environment – Laser Furnace

- Temperatures up to 1300 °C in vacuum or inert gas atmosphere
- Heating with IR-Lasers
- Mounted at the robot
- Cupola design for texture measurement

Laser furnace concept

Laser diode with housing
Sample Environment – Laser Furnace
Conclusion and Outlook

• Current state of the project
  • Proof-of-concept is made: **Accuracy better than 50 µm!**
  • Experiments can be planned and simulated in advance with less effort
  • Communication between NICOS > ROS/Movelt > Robot controller > Robot hardware established
  • Collision detection avoids damage on the instrument
  • Dedicated sample environment and neutron optics for the robot system are available

• Future tasks – what’s next?
  • User friendly workflow and assisted measurement
  • Automated choice of best measurement direction (intensity based)
  • Automated neutron optics alignment
  • Markerless pose estimation
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