PAUL SCHERRER INSTITUT

Materials Science at Large Scale Facilities

Neutron imaging - Exercises

Detecting Microstructural Damage in a Composite

Scenario:

A fiber-reinforced composite has undergone thermal cycling and may contain micro-cracks and fiber/matrix debonding. The features are too small for direct spatial resolution, and X-ray contrast between matrix and fibers is very poor.

Questions:

- Which neutron imaging technique can detect microstructure below the spatial resolution limit?
- What contrast mechanism enables this?
- What are the limitations?

Detecting Microstructural Damage in a Composite

Neutron grating interferometry (dark-field imaging).

Contrast mechanism:

- Sensitivity to small-angle scattering from micro-cracks, porosity, and fiber structures.

Limitations:

- Long exposure times due to interferometer losses.
- Sensitive to vibrations and sample motion.
- Quantitative interpretation requires modeling.

Detecting Blockages in Internal Cooling Channels

Scenario:

A thick metallic component (e.g., a turbine blade prototype) contains internal cooling channels that may be partially blocked. X-ray CT gives almost no penetration because the alloy is very absorbing. The engineers want to know whether blockages exist and how extensive they are.

Questions:

- Which neutron imaging technique would you use and why?
- What advantages does this method offer for this sample?
- What are the key limitations?

Detecting Blockages in Internal Cooling Channels

Use neutron absorption radiography or tomography. It directly visualizes internal structure based on neutron transmission.

Advantages:

- Neutrons penetrate dense metals like Ni-based alloys much better than X-rays.
- High contrast between metal walls and small amounts of debris (oxide flakes, organic residues).
- Tomography gives a 3D map of channel blockage.

Limitations:

- Spatial resolution (~20–50 µm) may miss extremely fine deposits.
- Neutron scattering can blur edges in thick components.
- Long exposure times for thick/high-Z metals.

Identifying Microcracks in a Dense Alloy

Scenario:

A thin slab of a high-density alloy shows signs of microcracking after thermal cycling. The cracks are very small and lie close to the surface. X-ray microscopy is problematic due to strong absorption contrast from the alloying elements. The team wants an alternative method to assess crack geometry at high resolution.

Questions:

- Which neutron technique can provide higher spatial resolution than conventional pinhole imaging?
- What advantages does it offer?
- What practical challenges do you expect?

Identifying Microcracks in a Dense Alloy

Neutron microscope (using focusing optics).

Advantages:

- Micron-scale resolution achievable.
- Neutrons penetrate the dense alloy without severe artifacts.
- Sensitive to cracks near the surface.

Challenges:

- Limited field of view.
- Lower flux through focusing optics → longer scans.
- Alignment demands and sensitivity to vibrations.

Visualizing the Motion of a Fast Mechanical Component

Scenario:

A mechanical device contains a moving internal component (e.g., a valve or actuator) whose motion needs to be visualized inside a sealed metal housing. The motion is fast and repeats continuously, but direct optical access is impossible. The engineers want a time-resolved image of its movement.

Questions:

- Which neutron imaging method is suitable for fast, repeatable motion?
- Why is neutron imaging useful in this situation?
- What are the main limitations?

Visualizing the Motion of a Fast Mechanical Component

Stroboscopic neutron imaging synchronized to the motion cycle.

Why useful:

- Neutrons penetrate the metal housing and show internal moving parts.
- Stroboscopic accumulation provides high temporal resolution for repeatable cycles.

Limitations:

- Motion must be strictly periodic.
- Acquisition time can be long because only a fraction of frames contribute.
- Requires good synchronization hardware.

Checking the Water Distribution Inside a Fuel Cell

Scenario:

A polymer electrolyte membrane (PEM) fuel cell is being tested under different operating conditions. Performance drops at high current, and the team suspects water accumulation or uneven water distribution inside the gas diffusion layer and flow channels. Direct access is not possible during operation.

Questions:

- Which neutron imaging technique would best reveal the water distribution?
- Why is this method particularly suited to this kind of sample?
- What limitations should you be aware of?

Checking the Water Distribution Inside a Fuel Cell

Neutron absorption radiography, ideally time-resolved.

Why suitable:

- Neutrons have very high contrast for hydrogen-containing water.
- Can directly visualize water distribution inside operating fuel cells, even with metal casings.
- Possible to capture time-dependent behavior (flooding, dry-out).

Limitations:

- Temporal resolution depends on beam intensity; may require compromises.
- Condensation or evaporation during measurement can complicate interpretation.
- Limited spatial resolution for very thin channels.

Visualizing Internal Magnetic Fields in a Superconductor

Scenario:

A bulk high-temperature superconductor is being magnetized and demagnetized, and the team wants to see how magnetic flux penetrates and is trapped inside the bulk material. Surface-sensitive techniques have not given enough information.

Questions:

- Which neutron imaging technique allows visualizing internal magnetic fields?
- What information does it provide?
- What limitations exist?

Visualizing Internal Magnetic Fields in a Superconductor

Polarization-contrast neutron imaging using polarized beams.

Information provided:

- Internal magnetic field distribution inside the bulk.
- Flux penetration, trapping, and inhomogeneities.
- Insight into current paths and magnetic shielding.

Limitations:

- Reduced flux due to polarization optics.
- Sensitive to stray magnetic fields.
- Interpretation can be ambiguous without modeling.

Mapping Residual Stresses in a Welded Component

Scenario:
A welded steel structure exhibits unexpected distortion in service. The manufacturer suspects strong residual stresses around the weld seam. Cutting the part for diffraction measurements is not acceptable, and they want a spatial map of the strain field inside the intact component.

Questions:

- Which neutron imaging technique gives spatially resolved strain information?
- What can be learned from the data?
- What are the limitations?

Mapping Residual Stresses in a Welded Component

Bragg-edge imaging (energy-resolved neutron transmission).

Information obtained:

- Elastic strain maps from Bragg-edge shifts.
- Texture gradients and phase variations across the weld.
- Insights into heat-affected zones.

Limitations:

- Requires TOF or monochromatic beam with good energy resolution.
- Spatial resolution lower than conventional radiography.
- Model-dependent interpretation.