A double detector set-up for simultaneous transmission and diffraction neutron imaging

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Abstract

For the first time, a set-up was developed to allow neutron imaging of sample transmission and scattering simultaneously, making optimal use of available neutrons. Additional microstructural sample information can thus be obtained about the sample under investigation. A technical overview of the set-up is presented, followed by encouraging first application experiments on neutron grain imaging and single crystal Laue imaging.

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1. Introduction

Neutron imaging studies the variation in transmission of a neutron beam through a sample of interest. Neutrons removed from the direct beam through absorption and scattering, both coherent and incoherent, are disregarded.

However, joint access to transmitted and scattered neutron data could provide additional sample information and aid the interpretation of observed image contrast, particularly for coherent elastic scattering on mono- and polycrystalline materials. Though it has already been suggested in [1] and realized successfully for synchrotron radiation [2], it has not been performed so far in neutron imaging.

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In this work, a double detector set-up for neutron imaging is presented. The set-up allows for simultaneously recording of transmitted and scattered neutrons, making optimal use of available neutrons. Technical details of the set-up are presented together with first results showing a wide range of potential applications. These include e.g. sample scatter imaging, grain diffraction imaging, single crystal investigations, Laue pattern recording, etc.

Moreover, the double detector set-up can also be seen as an exciting precursor and/or relatively inexpensive alternative to the future time of flight imaging beamlines as IMAT (ISIS, UK) that will include detector banks for recording diffraction signals as well as ERNIS (JPARC, Japan) and ESS (Sweden) holding it under consideration.

2. Technical overview

The double detector set-up (DDS) combines two camera systems present at the ICON cold neutron imaging beamline of the Paul Scherrer Institut (Switzerland) [3] to allow for simultaneous transmission and scattered neutron imaging. The transmission image is recorded with the so-called micro set-up imaging system for high-resolution imaging [4], while the scattered neutron image is recorded with the midibox imaging system. Here, several combinations of scintillators and lenses are available to optimize desired resolution, field of view and exposure times. Main parameters are listed in Table 1 below.

A camera signal processing box combines camera triggering and feedback signals to emulate one virtual camera and interface it to existing beamline operating software. As such, both camera’s can be triggered and start measuring simultaneously. The exposure times can be set independently and the camera with the longest acquisition time (exposure plus read-out time) will determine when the next trigger is sent.

Table 1. Main parameters of the DDS imaging system

|                     | micro set-up          | midibox               |
|---------------------|-----------------------|-----------------------|
| Camera              | Andor DV 436          | Andor DW 434          |
| Available pixels    | 2048 x 2048           | 1024 x 1024           |
| Field of view       | 27mm x 27 mm          | 40mm x 40mm           |
|                     | 160mm x 160mm*        |                       |
| Pixel resolution    | 13.5ȝm               | 37ȝm - 156ȝm         |

* 100mm x 100mm with scintillator adapter

As most coherent scattering of interest occurs sideways in the cold ICON beam spectrum (illustrated in Table 2), the midibox is mounted on a separate stage aside from the direct beam. The angle with which the detector faces the sample can be set with the user friendly Labview-based beamline operating software. A set of rails allows for easy manual positioning parallel and perpendicular to the beam direction. The set-up is schematically depicted in Figure 1.
Table 2. Angles of diffracted neutrons with respect to the incoming neutron beam for some engineering materials at the ICON mean wavelength of 3.1Å.

|     | 1st reflection | 2nd reflection | 3rd reflection |
|-----|----------------|----------------|----------------|
| Al  | 83.1°          | 99.9°          | -              |
| Cu  | 95.9°          | 118.1°         | -              |
| αFe | 99.8°          | -              | -              |
| Ni  | 99.3°          | 123.2°         | -              |
| Pb  | 66.0°          | 77.9°          | 125.6°         |

Figure 1. Schematic overview of the double detector set-up.

Due to geometrical constraints in camera system housing and beamline lay-out, the spatio-angular range that can be reached is limited to the one depicted in Figure 2a. To allow for smaller sample to detector distance, a 180mm long adapter of 100mm x 100mm FOV was produced to bring the scintillator as close as 8cm from the sample (Figure 2b). When solely performing scatter imaging, these geometrical constraints can be relaxed and the midibox can even be brought into contact with the sample.

The DDS is fully integrated in the ICON beamline lay-out. It can thus make optimal use of its sample stage, allowing sample translation in vertical, side and beam direction as well as sample rotation and tilt. The beam spectrum can easily be manipulated with present beryllium filter (acting as high-pass wavelength filter), mechanical neutron velocity selector (offering a monochromatic beam of $\Delta \lambda / \lambda = 15\%$) and future crystal-based monochromator TESI ($\Delta \lambda / \lambda = 2-5\%$) [5].
3. First applications

Many possible applications are conceivable for simultaneous imaging of sample transmission and – coherent or incoherent – scattered neutrons. Two are investigated more deeply in this section: imaging grains in a sample by the neutrons they diffract and imaging of a single crystal nickel-based superalloy by Laue diffracted neutrons off the sample bathed fully in a white beam. Further use of the double detector set-up can be seen in recording Laue patterns, scattered neutron imaging of amorphous and polycrystalline samples using collimators, verifying simulated sample scattering in light of quantitative neutron imaging, etc.

3.1. Grain imaging

A coarse-grained as-cast bronze sample (90w% Cu – 10w% Sn) was examined, with the sample size illuminated by the neutron beam measuring 7mm x 10mm x 5mm. The velocity selector [6] was used to perform energy-selective neutron imaging at 3Å, for which neutrons are diffracted off (111) crystal lattice planes towards the midbox at 90° with respect to the incoming neutron beam and 94mm distance to the sample. Exposure time was 150s for both micro set-up and midibox. Transmission and diffraction imaging results are depicted in Figure 3. As the diffraction image is formed by detecting more (diffracted) neutrons than the surroundings’ background level, it has a typical white sample on dark background contrast, as opposed to the transmission image where the sample is observed through a decrease in observed neutron beam intensity.

The double detector set-up allows to visualize simultaneously sample transmission, exhibiting area’s of reduced transmission where grains are in diffraction condition with their (111) planes, as well as the image formed by these diffracted neutrons. Additional microstructural information can thus be gained (e.g. grain orientation). Moreover, tomographic reconstruction of grains based on the combination of transmission and diffraction images or even solely the latter are now coming into reach for neutron beams, having already been performed with synchrotron radiation [7].

Figure 2. Spatio-angular range covered by the DDS imaging system (a) and with scintillator adaptor(b).
3.2. Laue imaging

A single crystal nickel-based superalloy turbine blade has been examined with the DDS. This type of turbine blades is used in modern gas-turbines and aircraft engines that require high mechanical strength under high temperatures.

White beam imaging has been performed with the double detector set-up. Monocrystalline in nature, a Laue pattern is formed on the side detector, though in this case the full sample is illuminated by the neutron beam and no longer Laue spots, but Laue sample projection images formed by Laue diffraction off the whole sample are captured on the side detector. An example of a combination of transmission and diffraction image is presented in Figure 4. A photograph of the sample under approximately the same angle as seen by the side scatter detector is provide as well, illustrating the interpretation of the diffraction image as a sample projection formed by the diffracted neutrons on the side detector. Moreover, in the top left corner another Laue image of the sample can be distinguished.

For this measurement, the 40mm beam entrance aperture was used and exposure times amounted to 11s for the microbox transmission imaging and 15s for the midibox (the former having longer read-out times, resulting in similar acquisition time of 17s for both camera systems). The sample to midibox detector distance was 88mm, large enough to avoid overlap with sample projections formed by diffraction off other lattice planes.
It is clear that this Laue imaging of monocrystalline materials has great potential, supplying spatially resolved information on crystalline properties at short acquisition times. One can even foresee 3D reconstruction of scattered neutron images by means of algebraic reconstruction techniques [8] using multiple Laue diffraction projections of the sample and the transmission data as initial estimate.

4. Conclusion and outlook

A set-up was successfully developed to record simultaneously transmitted and scattered neutron images. After a technical overview, some potential applications were listed. Encouraging results were obtained for grain imaging and single crystal imaging, demonstrating the feasibility of using diffracted neutrons for imaging. Future work will focus on a better understanding of diffraction images in light of the samples crystalline properties, actively combining transmission and diffraction information and developing proper reconstruction schemes for 3D rendering of sample scattering properties.

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