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A method for neutron scattering quantification and correction applied to neutron imaging

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Abstract

Either the composition, the thickness or the density of a sample can be derived, given the other two are known, by measuring the attenuation of a given incident radiation intensity through the sample. However, in the case of neutron imaging, the separation of the transmitted intensity from the scattered intensity using scintillator-based detection systems is yet to be solved. Several methods have been proposed for the correction of disturbing neutron scattering, but they are only applicable to specific materials or require some a-priori knowledge of the sample. Here we present a method for white beam neutron imaging which compares transmitted neutron images at different distances from the scintillator to improve the quantification capabilities of neutron imaging.

Keywords: neutron; radiography; transmission; imaging; quantitative; quantification; scattering; artifacts; correction; filter;

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1. Introduction

All imaging techniques have a common struggle: the improvement of the geometrical resolution they can provide. In the particular case of transmission neutron imaging, one has to take into account the type of detection system, the collimation of the beam and the distance from the sample to the detector, as shown by Lehmann et al. (2007) and Trtik et al. (2015).

Because neutron beamlines start with a neutron aperture of several square millimeters to have a reasonable neutron flux, the source cannot be modeled by a point. The geometrical unsharpness of a neutron setup is directly proportional to the pinhole diameter of the source and the distance between the sample and the detector. To reduce this unsharpness, neutron imaging is usually performed with the sample as close as possible to the detection system. Unfortunately this comes at a cost: The visible amount of neutrons scattered from the sample is higher the closer the sample is to the detector. The detection of scattered neutrons in the transmitted image creates artifacts which prevent the correct quantification of the samples investigated.

The scattering disturbance has been previously tackled by Tremsin (2011) using collimators, by Hassanein (2005) using iterative scattering correction tools, and Peetermans (2012) using energy selection. Collimators take a long time to be aligned and they might create features in the image. Iterative scattering correction tools require some a-priori knowledge of the sample, and the correction parameters can bias the measurement. Energy selection past the Bragg cut-off does not remove incoherent scattering and utilizes exclusively the coldest neutrons of the beam.

We present here a method for the estimation of the scattering intensity coming from the sample. Two images are obtained for every measurement: the neutron radiography in close contact with the scintillator and a second image with the sample at a certain distance from it. From the “close” image, the highest achievable resolution is obtained, while the “far” image provides information only about the transmitted neutrons. By means of these images, the scattered distribution over the detector area can be quantified.

This scattering is then assimilated to 2D functions using robust numerical fitting tools. Once the parameters of these functions are known, a 2D mask containing only the scattering signal is generated. This mask is then subtracted from image A to obtain an image with the highest achievable resolution and quantification.

Nomenclature

r	radius of the sample
t	thickness of the sample
I_T	Transmitted neutron intensity
I_S	Scattered neutron intensity

2. Theory

The Beer-Lambert law relates the attenuation of a neutron beam travelling through a material with an exponential law, which depends on the density of the material and the attenuation coefficient.

$$I = I_0 e^{-\Sigma x} \tag{1}$$

Where I is the transmitted intensity of the beam, I_0 is the incident intensity, $\sum$ is the attenuation coefficient of the radiation through the material and x is the effective thickness of material. By evaluating (1) for every pixel using the transmission image as I and the open beam as I_0 one should be able to estimate the attenuation coefficient and/or the thickness of the traversed material.

Because we often use a polychromatic neutron beam to perform imaging, using a single attenuation coefficient is a simplification, as its value changes with the energy of the incident particle. This phenomenon is not exclusive to neutron radiography; actually its magnitude is higher in the case of x-ray imaging. White beam neutron imaging has a spectral distribution comprising wavelengths in a single order of magnitude, compared to polychromatic x-ray imaging which often comprises three orders of magnitude. Due to this, cross section values along the spectrum stay