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The neutron micro-tomography setup at PSI and its use for research purposes and engineering applications

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ABSTRACT

A new setup for stationary neutron imaging with highest possible resolution, based on the light detection from a neutron-sensitive scintillator screen with a dedicated lens coupled to a cooled CCD was completed recently. Although, some first test results have already been reported (E.H. Lehmann, et al., Nucl. Instr. and Meth. A 576(2–3) (2007) 389), its utilization for research and industry applications in both radiography and tomography is now the topic of this paper.

It was an important step forward to extend the method towards tomography, where the 3D volume of the object is obtained from projections via a reconstruction algorithm. This enables one to study samples with 13.5 μm voxel size, when the dimensions are within a 27 mm range. In a scanning mode, even larger samples can be investigated with the same inherent resolution.

The presentation will describe the technique of the system, its performance parameters and is focused on examples of studies in several fields like wood research, biology and industrial applications.

1. Introduction

Neutron imaging is performed today with digital detection systems. These devices have replaced film-based neutron radiography methods used in the past because of the much higher performance in respect to image acquisition speed, dynamic range, linearity and the availability of the resulting information in digital format for further treatment (image post-processing, tomography, etc.). The required shorter exposure time helps limiting the probably induced activation of sample materials too.

There are three major principles for the moment in neutron detection for digital imaging: scintillation, charge excitation in semiconductors and trapped electron states in imaging plates. Some further are under consideration and testing. Despite advantages and disadvantages of the individual technique, they all have limitations with respect to the spatial resolution, which is not yet the same as film methods that have been delivered under ideal conditions. Main reason and final limitation is caused by the range of secondary reaction products during the neutron detection interaction event (see Fig. 1). Therefore, the most common imaging detectors have only about 0.2 mm spatial resolution in fields of view up to about 40 cm in diameter. However, there is the urgent demand from the research community and the industrial partners as well to provide improved performance with respect to higher spatial resolution, approaching that of X-ray imaging systems.

There are some other initiatives and options to overcome this situation by dedicated detector developments [1,2].

2. The micro-tomography setup at ICON, SINQ, PSI

The PSI approach for better spatial resolution in neutron imaging with a stationary detection system consists mainly of a dedicated optical lens viewing onto a thin scintillation screen with a large size CCD-camera [3]. That system was successfully installed and tested at the new imaging facility ICON [4], where cold neutrons are provided (see Fig. 2). Cold neutrons can deliver higher detection probability and higher sensitivity for neutron investigations than the mostly common thermal neutrons.

2.1. Principle

According to Fig. 1, the spread of capture products in ^{6}Li-based systems and the light emission from the ZnS layer give major contribution to blurring (when beam collimation effects and optical limitations are neglected).

To reduce this drawback, a thinner layer of scintillation material would be necessary even if the light output is reduced accordingly. In collaboration with a company, it was possible to

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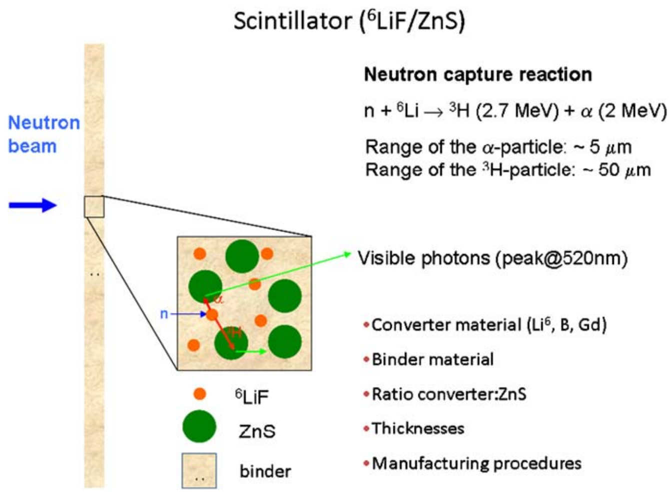

Fig. 1. Scheme how a ^{6}Li-based scintillator screen operates in the matrix of ZnS florescent material coupled with a binder.

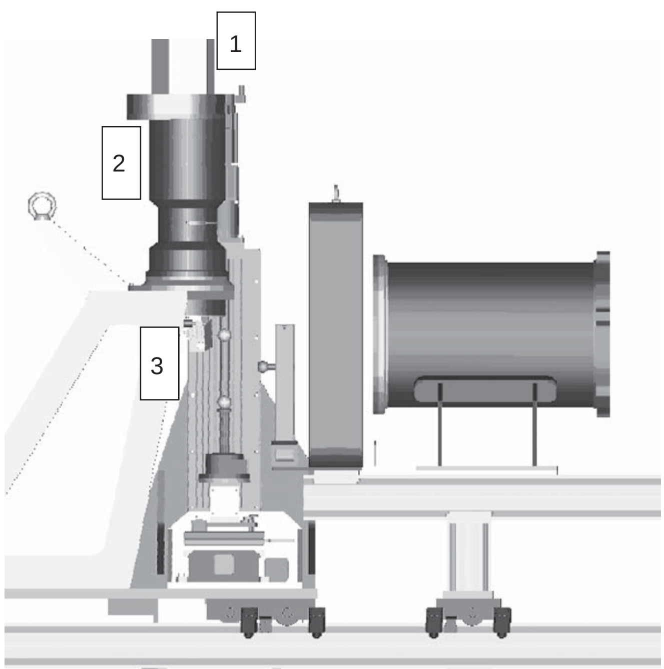

Fig. 2. The micro-tomography setup at ICON, SINQ, PSI [3]: with the cooled CCD (1) on top of the large lens system (2), the small scintillation screen and (3) is viewed in a 1:1 "magnification", when the neutron beam arrives from the right side, passing through the beam limiter (in the middle).

produce screens with at least 0.05 mm, also on commercial basis for other imaging groups worldwide [5]. However, the best option in respect to resolution was found in a Gadox screen with 0.01 mm thickness.

2.2. Performance

The active array of the used CCD (ANDOR DW 436-BV) is a 2048 × 2048 pixel matrix with 0.0135 mm per pixel, resulting in the field-of-view of 27.6 mm. With the largest aperture of the ICON beam line entry window (80 mm circular)—corresponding to a flux level of about $10^8\,cm^{-2}\,s^{-1}$—images can be taken in few seconds. This enables tomography runs of about 1000 projections within hours. For highest resolution requirements and thinnest scintillation layers, the acquisition time is extended accordingly. Twenty line pairs per mm were measured at 10% MTF as best possible for the moment.

3. Application of the system

The system with a resolution improvement by a factor of 4–5 compared to other stationary digital neutron imaging detectors enables a new category of experiments, where the detected features are close or even smaller that what the human eye can resolve. Accordingly, new options for non-destructive investigations come up, where the main advantages of neutrons (e.g. compared to X-ray) can be exploited: high transparency for metals and high visibility for hydrogenous materials.

The next few examples are only a coarse selection, the real potential and demand is seen to be much wider.

3.1. Transmission measurements (in scanning mode)

The detection system can be used for radiography purposes too, when the high image contrast by the cold neutrons and the high spatial resolution should be exploited. If the sample size exceeds the detector area in one or both directions, it can be imaged in scanning regime with the help of a remotely controlled precise *X*–*Y* table. Images can be put together with software tools easily after correction of beam uniformity (open beam). Due to the precise alignment of the system, no image gaps remain after the image combination.

An example for a quantitative investigation is given in Fig. 3 for a historical wood sample, where the information about the wood density with high spatial resolution was required. For a sample

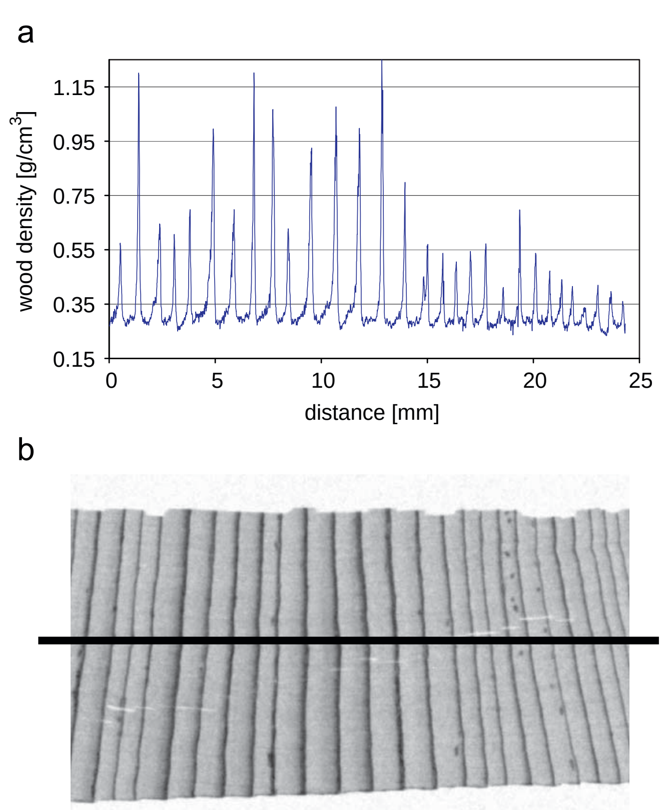

Fig. 3. Wood research: determination of wood density in non-invasive way using cold neutrons at ICON and the MT-detector in scanning mode. The results are used for dating purposes and for considerations about climate behavior of wood.