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The micro-setup for neutron imaging: A major step forward to improve the spatial resolution

E.H. Lehmann[a,*], G. Frei[a], G. Kühne[a], P. Boillat[b]

[a]Spallation Neutron Source Division (ASQ), Paul Scherrer Institut, CH-5232 Villigen, PSI, Switzerland
[b]Electro-Chemistry Laboratory, Paul Scherrer Institut, CH-5232 Villigen, PSI, Switzerland

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Abstract

To overcome present limitations of the spatial resolution in neutron imaging a newly designed setup was realized at the ICON facility [G. Kühne et al., ICON—the new facility for cold neutron imaging at the Swiss spallation neutron source SINQ, Swiss Neutron News 28 (December 2005), pp. 20–29, 〈http://sgn.web.psi.ch/sgn/snn/snn_28.pdf〉], which is installed at the cold neutron beam line 52 at the Swiss spallation neutron source SINQ [G.S. Bauer, Nucl. Instr. and Meth. A 463 (2001) 505] since 2005.

It was found by dedicated performance measurements, that the inherent spatial resolution of this locally fixed neutron imaging device is better than 50 μm, corresponding to 20 line pairs/mm in spatial frequency at 10% of the modulation transfer function (MTF). Therefore, the system has the potential to perform neutron tomography investigations with a resolution better than that previously achieved.

This article describes the design features, details of the installation and the results from first test measurements. It gives an outlook for the further potential of this technique in both radiography and tomography applications.

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Keywords: Neutron imaging; Spatial resolution; Tomography; Scintillator; CCD-camera

1. Introduction

Neutron imaging has been developed as a powerful complementary technique for non-destructive testing with alternative features compared to X-ray applications [1–3]. Using the high attenuation ability of hydrogenous materials and the high penetrability for even heavy metals, neutrons are very valuable for many technical and scientific investigations.

Modern digital neutron imaging devices are established in several labs [4], linked to strong neutron sources like research reactors or spallation neutron sources. Compared to X-rays at synchrotron sources, the intensity of neutron beams will always be limited by orders of magnitude.

Therefore, the efficient use of neutrons for scientific and technical applications depends very much on the detector performance. This holds with respect to spatial resolution and time resolution in particular, as demonstrated for existing neutron imaging detectors in Table 1. A gain in time resolution Δt will be accompanied by a loss in spatial resolution Δx and vice versa. In this way, a qualitative ‘‘uncertainty relation’’ can be defined as sketched in Eq. (1):

$$\Delta x\,\Delta t \propto n \qquad (1)$$

where n is the number of neutrons or their intensity in the beam, respectively.

This number of neutrons n will be the limiting factor for spatial resolution Δx and time resolution Δt in a similar way. As indicated in Table 1, an easy way to improve the time resolution of existing systems is to increase the

*Corresponding author. Tel.: +41 56 310 2963; fax: +41 56 310 3131.
E-mail address: eberhard.lehmann@psi.ch (E.H. Lehmann).

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Table 1
Properties of neutron imaging systems in comparison

Detector system	X-ray film and transmission light scanner	Scintillator + CCD-camera	Imaging plates	Amorphous silicon flat panel	CMOS pixel detector
Max. spatial resolution (μm)	20–50	100–500	25–100	127–750	50–200
Typical exposure time for suitable image (s)	5 min	10	20	10–0.03	~10
Detector area (typical) (cm × cm)	18 × 24	25 × 25	20 × 40	25 × 20	3 × 8
No. of pixels per line	4000	1000	6000	2000	256–400
Dynamic range	10^2 (non-linear)	10^5 (linear)	10^5 (linear)	10^3 (non-linear)	Unlimited
Digital format (bit)	8	16	16	12	Counts

Principle numbers in orders of magnitude, no specific device is characterized.

neutron intensity n, corresponding to a shift to left in the diagram. This can be done by using a stronger initial source, larger apertures or experimental positions closer to the source. However, in the same way, the spatial resolution will become more limited.

It is much more difficult to improve the spatial resolution while maintaining the performance with respect to a reasonable exposure time. Here, some new developments are needed, as shown with the micro-setup in this article.

2. Status of neutron imaging detection systems

In the past 15 years, a dramatic development has taken place with respect to digital imaging systems. Neutron imaging took profit from inventions such as imaging plates (IP), amorphous silicon flat panels and also CCD cameras. By the adaptation of suitable conversion modules, neutrons could be directly measurable as direct digital information, which is in most cases directly proportional to the neutron intensity across the beam.

As stated earlier [3], there are now several neutron imaging systems available with different performance properties. In addition to the spatial and time resolution, the dynamic range, the signal-to-noise (S/N) ratio and the size of the sensitive area (field-of-view, FOV) are also important parameters to take into account. These parameters can vary widely for the individual detection system. The applicability of a specific detection system depends much on the needs from the particular investigation task to be performed.

Although the film technique has been considered as the best one with respect to spatial resolution, there are many drawbacks, for example:

- The exposure time to obtain valid information is two to three orders of magnitude higher than modern digital systems. In addition, the development time has to be also considered.
- In the case of neutron exposure, the risk for activation of the sample material is an important issue today. Therefore, long exposure times for film investigations should be avoided to limit the activation risk.

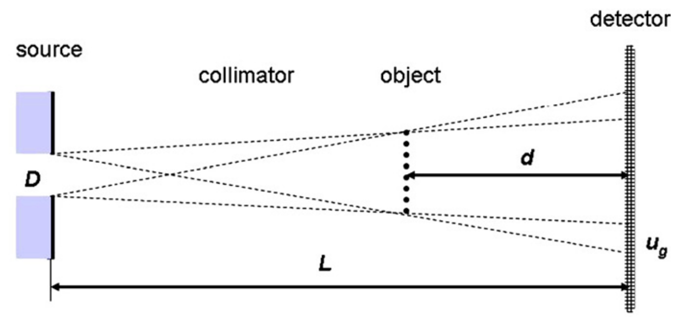

Fig. 1. Principle setup of a neutron imaging installation: the collimator length L and the aperture diameter D are the main parameters responsible for the geometrical image sharpness.

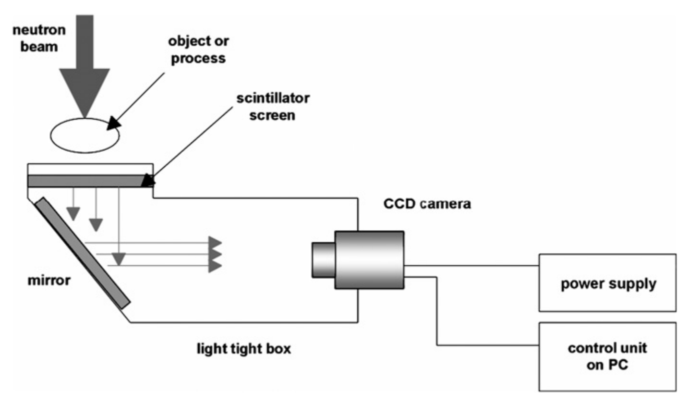

Fig. 2. Components of a neutron imaging device based on a CCD-camera system.

- The exposed film has a limited dynamic range and is strongly not linear in its response.
- As a non-stationary detector, film cannot be used for neutron tomography and other advanced methods.

There is however a need to have a neutron imaging device, which has about the same inherent spatial resolution as films and yet overcomes all the limitations and drawbacks mentioned above.

Before we describe our new approach in detail, a rough overview about existing digital neutron imaging systems is given in order to understand the progress.