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Recent applications of neutron imaging methods

E. Lehmann*, D. Mannes, A. Kaestner, C. Grünzweig

Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Abstract

The methodical progress in the field of neutron imaging is visible in general but on different levels in the particular labs. Consequently, the access to most suitable beam ports, the usage of advanced imaging detector systems and the professional image processing made the technique competitive to other non-destructive tools like X-ray imaging. Based on this performance gain and by new methodical approaches several new application fields came up – in addition to the already established ones. Accordingly, new image data are now mostly in the third dimension available in the format of tomography volumes. The radiography mode is still the basis of neutron imaging, but the extracted information from superimposed image data (like for a grating interferometer) enables completely new insights. In the consequence, many new applications were created.

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Keywords: attenuation contrast, digital neutron imaging systems, phase contrast, micro-tomography, engineering diffraction, energy related materials

1. Introduction

The penetration of neutrons through considerably thick structures of materials enables the inspection of objects, assemblies and processes in a nearly non-invasive manner. The transmitted component of the neutron beam is registered with a suitable two-dimensional neutron detector. In comparison to the initial beam distribution, information about content, structure and their development can be derived on the macroscopic scale.

The method of neutron radiography has been initialized since first (radioactive) neutron sources were available (about 1938). First inspections were done already with film using some converter materials (e.g. Ag) [1].

* Corresponding author. Tel.: +41-56-310-2963; fax: +41-56-310-2963.
E-mail address: Eberhard.lehmann@psi.ch

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Since then, both the sources and the detection systems have been developed further and were dramatically been improved. Modern neutron imaging facilities can be found at beam ports of dedicated research reactors or spallation neutron sources now.

On the other hand, digital neutron imaging detectors enable highest efficiency and highest resolution in space, time and contrast/dynamics. Based on the digital output of neutron imaging data, modern image processing tools (including the reconstruction of tomography projection data into the volumes) can be applied. The quantification of the sample content can be performed on higher methodical level, also taking into account the comparison to tabulated cross-section data and by using simulation tools.

While the majority of applications of neutron radiography has been focused in the past to non-destructive testing in complement and as alternative to X-ray methods, the modern approaches also intend to push forward more scientific usages. Nevertheless, also common industrial applications can profit from the methodical progress and the increase in the performance of the neutron imaging systems.

This paper will give an overview with respect to facilities, methods and data acquisition with the aim to focus to best possible applications with scientific and more applied background. It is based on the experience at Paul Scherrer Institut, Switzerland, but can easily be translated to similar facilities at other places.

2. Facilities

In a survey about neutron imaging facilities around the globe, performed by ISNR [1] and IAEA [2], there are currently 48 installations registered. Among them, only about 15 ones can be seen to be “state-of-the-art”, still with differences in the individual performance. All neutron imaging stations have their individual layout and specification and some certification and standardization is required for comparison in the future.

The majority of facilities is situated at research reactors, where the access and usage is dominated by the neutron scattering community, isotope production or irradiation technology. In many cases, not the optimal beam port was given for neutron imaging and compromises needed to be accepted in the beam line layout. Most of the beam lines use thermal neutrons with a Maxwellian spectral distribution around 25 meV, corresponding to 1.8 Å. Since the begin of this century, beamlines with a colder spectrum were also set into operation for neutron imaging purposes (ANTARES, CONRAD, ICON, …). The suit of installations is completed by such for fast (fission) neutrons in the keV and MeV range. Given by the beam properties with respect to size, spectrum, intensity and homogeneity the kind of application is already predefined since the attenuation properties limits the sample thickness with respect to transmission and visibility. With a exposure time of a few seconds at a neutron flux intensity of about 10^7 cm^{-2} s^{-1} it can be extrapolated which application can be performed with respect to time resolution (real-time, tomography, energy scans, …). It depends on the individual problem which dynamic range in the images is really required, means which acquisition time should be used.

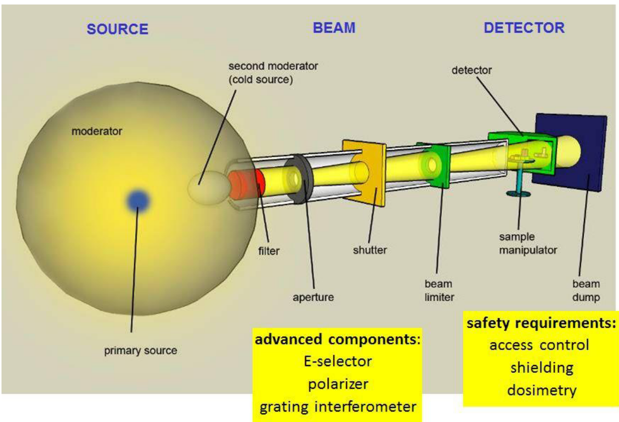

Fig.1: Schematic layout of a generic neutron imaging facility: the degree of complexity and the particular layout depend very much on the budget and other boundary conditions