Physica B **385-386** (Part 2), 1213–1215 (2006)
Presented at the 8th International Conference on Neutron Scattering, 27.11.02.12.2005 Sydney, Australia

The new cold neutron radiography and tomography instrument CONRAD at HMI Berlin

A. Hilger [a,*], N. Kardjilov [b], M. Strobl [a], W. Treimer [a], J. Banhart [b]

[a] *University of Applied Sciences Berlin, Luxemburger Str. 10, 13353 Berlin, Germany*

[b] *Hahn Meitner Institut Berlin, Glienickerstr. 100, 14109 Berlin, Germany*

Abstract

The new cold neutron radiography instrument CONRAD is a multifunctional facility for radiography and tomography with cold neutrons at Hahn-Meitner-Institut Berlin. It is located at the end of a curved neutron guide, which faces the cold neutron source of the BER-II research reactor. The geometry provides a cold neutron beam with wavelengths between 2 Å and 12 Å. Two measuring positions are available for radiography and tomography investigations. The first one is placed at the end of the guide and it is optimized for in-situ experiments in which a high neutron flux is required. The available flux at this position is app. 10^9 $cm^{-2}s^{-1}$. The second measuring position uses a pin-hole geometry which allows better beam collimation (L/D up to 1000) and higher image resolution in the range of 100 µm in the CCD based detector system (10 x 10 cm^2). The use of cold neutrons for radiography purposes increases the image contrast and improves the sensibility for e.g. the detection of small amounts of water and hydrogen containing materials in metal matrixes. On the other hand the cold neutron beam can be modified easily by using diffraction and neutron optical techniques. This enables to perform radiography and tomography experiments with more sophisticated measuring techniques. Recent examples of research and industrial applications will be presented.

1. Introduction

Neutron tomography enables investigations of the macroscopic inner structure of large samples (up to hundreds of cubic centimeters) with a spatial resolution of up to 100 micrometers. The neutron beam can transmit some centimeters of metal but it is easily attenuated by small amounts of light elements like hydrogen, boron and lithium. This makes neutron tomography an unique tool for non-destructive testing with applications in industry, material science and various other fields [1,2]. Examples are investigations concerning quality tests of soot filters, adhesive joints, lubricate films and in-situ visualization of water management in fuel cells. Interesting applications in archeology and biology were reported recently [3,4].

The high potential of neutron tomography was the motivation to setup a neutron tomography facility at Hahn-Meitner-Institut Berlin, Germany. The facility was planned to meet the needs of high flux applications like real time imaging and high-speed tomography as well as high-resolution applications and phase-contrast tomography and to provide high flexibility for different kinds of radiographic and tomographic measurements. The cold neutron spectrum provides advantages concerning attenuation contrast due to the corresponding attenuation coefficients at these energies.

2. Instrumental parameters

The new neutron radiography beam line at HMI is placed at the end of the curved neutron guide NL1b facing the cold source of the BER-II reactor [5]. A Monte Carlo

[*] Corresponding author. Tel.: +49-30-8062-2490; fax: +49-30-8062-3094; e-mail: hilger@hmi.de.

simulation of the beam spectrum using VITESS software is shown in Fig. 1.

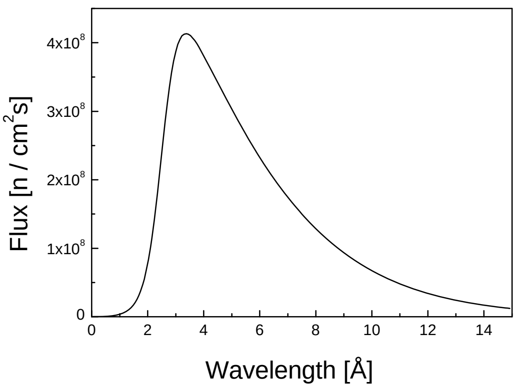

Fig. 1 Spectrum of the neutron beam at the end of the tomography beam line at HMI.

The cold neutron flux density at the end of the curved guide is of the order of approximately $3x10^9$ n/cm^{2}s with a negligible background of gammas and fast neutrons. The facility includes two measuring positions: the first one is located directly at the end of the neutron guide, taking advantage of the high neutron flux density available at this position. However, the poor beam collimation of the guide is limiting the spatial resolution that is available there. The second measuring position on the other hand uses a pin-hole geometry to increase image resolution significantly. Hence it is located downstream at a distance of app. 5 m from the end of the guide and the first position (Fig.2).

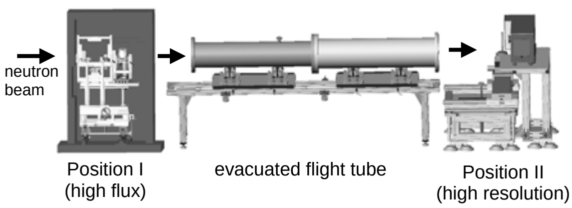

Fig. 2 Drawings of the CONRAD instrument set-up

a.)   high-flux position

The flux density at the first measuring position is approximately 3 x 10^9 n/cm^{2}s which is sufficient to perform unique real-time experiments or high-speed tomography. The beam size on the other hand is limited to the cross section of the guide which is 3 x 5 cm^2.

The *L/D* ratio, which is a measure of the beam collimation, where *D* is the diameter of an aperture and *L* the distance between aperture and measuring position [6], is defined by the guide in that case as well. The larger the *L/D* ratio the better is the beam collimation. The energy-dependant divergence conducted by a Ni coated guide in the case of a cold neutron beam has been measured to be of the order of 70 [4]. Hence the resolution which equals the geometrical blur $b = d.(L/D)^{-1}$ can be given with 300 µm at a distance of d = 2 cm between object and detector screen.

As an example, images of a real-time radiography investigation of a small model air-craft engine using a stroboscopic method [7] are shown in Fig. 3. The exposure time was 1 ms at a rotation speed of the engine of 6000 rpm. The number of accumulated images per piston position was 500.

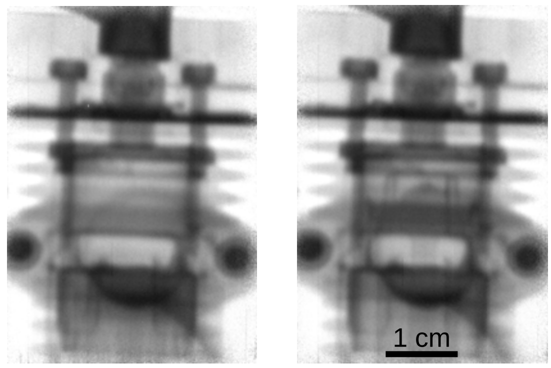

Fig. 3 Two “snapshot” images of the model air-craft engine with a time difference of 5 ms

b.)   high-resolution position

To optimize the beam for the second position an additional collimation system, consisting of a flight tube of 5 m length and a set of diaphragms, is installed (see Fig. 2). This way the L/D ratio for the second measuring position can be increased to values of about 500 and the spatial resolution improves to up to 100 µm. A pinhole exchanger, placed at Position I, with 3 circular apertures (1 cm, 2 cm and 3 cm of diameter) allows choosing the optimal L/D ratio and flux for corresponding measurements. The maximum spatial resolution for the optimum ratio L/D = 500 was measured by using the line spread function at the edge of a Gd-foil placed at a distance of 5 cm from the detector. The obtained value was 238 µm. The used detector system is based on a 16-bit cooled CCD camera (Andor DW436N-BV) with 2048 by 2048 pixels. The beam size at the second position is approximately 10 x 10 cm^2 with an intensity profile shown in Fig. 4.

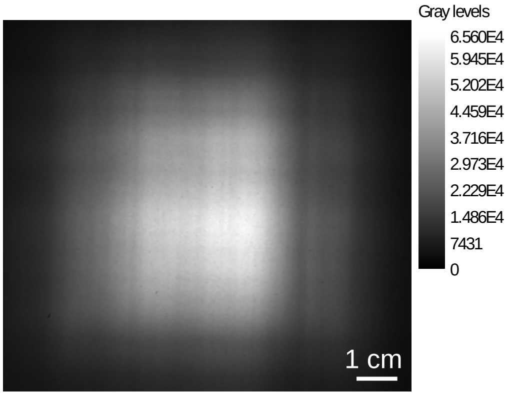

Fig. 4 Beam profile at the measuring position II at the neutron tomography facility CONRAD at HMI.

The stripe-like structure in the beam profile can be explained as a visualization of misconnections between neutron beam guide segments.

A comparison between radiography images obtained at the two described measuring positions is given in Fig. 5.

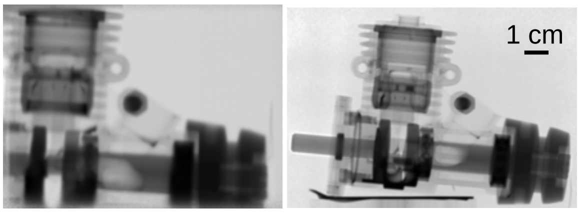

Fig. 5 Model air-craft engine measured at Position I (L/D of 70; exposure time: 0.5 s) and at Position II (L/D of 500; exposure time: 25 s).

An example of high-resolution neutron tomography at position II is the fossil sample (ammonite) presented in Fig. 6. For this experiments 300 projections were take from the sample on an angular range of 180 degree. The exposure time for a projection was 25 s resulting in a total measuring time for the whole tomography experiment of 2.5 hours.

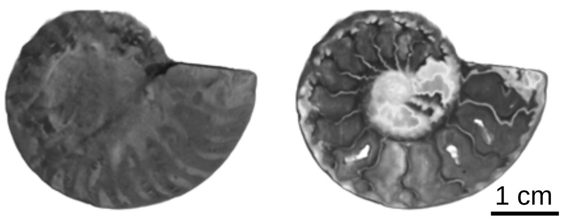

Fig. 6 High resolution neutron tomography of a fossil sample (ammonite). General view (left) and tomography slice (right). The grey scale represents attenuation values from low (black) to high (white).

References

[1] J.C. Domanus (Ed.), Practical Neutron Radiography, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1992

[2] B. Schillinger, E. Lehmann, P. Vontobel, Physica B, 276-278 (2000), p. 59-62

[3] M. Wilding, D. Y. Sumner, C. E. Lesher, K. E. Shields, D. Reap, W. J. Richards, Neutron computed tomography reconstructions of microbial structures in carbonate and silicate rocks, presented on the Second Astrobiology Science Conference, April 7-11, 2002, NASA AMES Research Center, USA, http://www.astrobiology.com/asc2002/abstract.html?ascid=133

[4] E. Lehmann, P. Vontobel, L. Tobler, L.Berger, E. Deschler-Erb, A. Voûte, Non-destructive Studies of Archaeological Objects Using Neutron Techniques, NUM Progress Report 2002, http://num.web.psi.ch/reports/2002/pdf/e-19.pdf.

[5] N. Kardjilov, A. Hilger, M. Dierik, B. Masschaele, BENSC Experimental Reports 2003, ISSN 0936-0891

[6] B. Schillinger, Nondestr. Test. Eval. 16 (2001), p. 141

[7] N. Kardjilov, A. Hilger, I. Manke, M. Strobl, W. Treimer and J. Banhart, Nuclear Instruments and Methods in Physics Research Section A, Volume 542, Issues 1-3, 21 April 2005, Pages 16-21.