MULTIFUNCTIONAL TOMOGRAPHY INSTRUMENT WITH COLD NEUTRONS AT HMI

N. Kardjilov[1*], A. Hilger[1], I. Manke[1,2], M. Strobl[1,3], W. Treimer[3], J. Banhart[1,2]

[1] *Hahn Meitner Institut Berlin, 14109 Berlin, Germany*
[2] *Technical University Berlin, Berlin, Germany*
[3] *University of Applied Sciences Berlin, 13353 Berlin, Germany*

[*]Corresponding author E-mail: *kardjilov@hmi.de*

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 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 hydrogenous 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 like energy dispersive and phase-contrast imaging.

INTRODUCTION

The high penetration of neutron radiation through matter and the high interaction probability with light elements like hydrogen, lithium and boron 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. 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 cover a large number of experimental methods like high flux application (e.g. 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. In addition the cold neutron spectrum provides advantages concerning increased attenuation contrast, larger energy band for dispersive measurements and stronger phase contrast effects.

1. INSTRUMENTAL PARAMETERS

The new neutron radiography beam line at HMI is placed at the end of bended neutron guide facing the cold source of the BER-II reactor [3]. The spectrum at the end of the guide was measured by TOF method using a single chopper synchronized with a ^{3}He counting tube, Fig. 1. The drops in the spectrum are due to monochromator inserts of instruments staying in front of the radiography station as well as Bragg edges of materials used for holders and beam windows (stainless steel and aluminum).

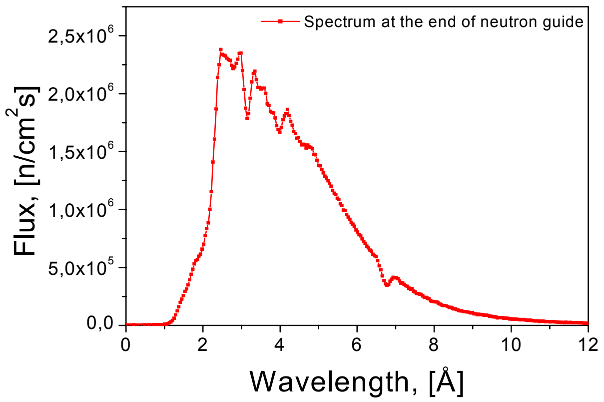

FIGURE 1. Spectrum of the neutron beam at the end of the tomography beam line at HMI.

The cold neutron flux density at the end of the bended guide was measured by gold foil activation analysis to be 2.8×10^8 n/cm^{2}s with a negligible background of gammas and fast neutrons. This relatively high flux is a precondition for real-time imaging or high-speed tomography. Dedicated detector system based on fast shutter CMOS camera was setup at the end of the neutron guide. This allows for measurements with exposure times from 1 ms up to 500 ms in a filed of view of 3 cm x 12 cm (WxH) determined by the size of the guide. The achieved spatial resolution at this measuring position was approximately 500 µm due to the large beam divergence coming from the ^{58}Ni coated guide (L/D ~ 70). The image quality at different exposure times of a small combustion engine can be compared in Fig. 2.

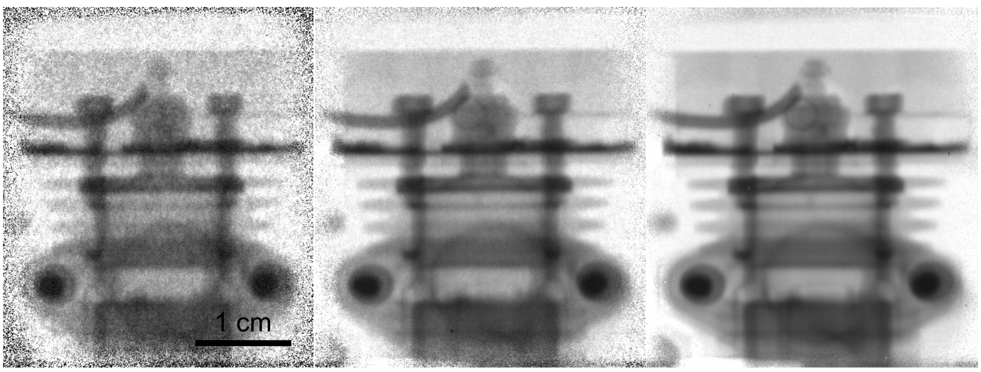

FIGURE 2. Single snap shots of a small combustion engine at exposure times of 4 ms (left), 40 ms (middle) and 400 ms (right).

In order to improve the spatial resolution a second measuring position was setup using pinhole geometry. For this purpose a collimation system, consisting of a flight tube of 5 m length and a set of diaphragms, was installed. This way the L/D ratio for the second measuring position was increased to values of about 500 and the spatial resolution was improved down to 100 µm. A pinhole exchanger, with three circular apertures (1 cm, 2 cm and 3 cm of diameter) allows for choosing the optimal L/D ratio and flux for the corresponding measurement. The spatial resolution for the optimum ratio L/D = 500 was measured by a Gd-test pattern (Siemensstern) placed at a distance of 5 mm from the detector. The obtained result is shown in Fig. 3.

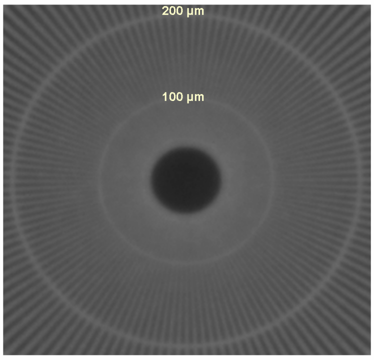

FIGURE 3. Resolution test using Gd-pattern (Siemensstern). The lower limit of 100 µm was achieved.

The used detector system is based on a 16-bit cooled CCD camera (Andor DW436N-BV) with 2048 by 2048 pixels.

2. EXPERIMENTAL OPTIONS

The neutron tomography instrument CONRAD at HMI can be modified very easily due to its flexible shielding (boron plastic + 5 cm lead) and this allows for simple preparation of experiments requiring special beam modulation or complicated sample environment. Some of the successfully installed experimental options will be presented here.

2.1. SCANNING OPTION

The beam size at the second position is approximately 8 x 8 cm^2 which is a limitation factor for tomography investigations on larger samples. Therefore a scanning setup was considered where the sample and the detector were fixed together at their transversal scan through the beam. At this the exposure time increases as well as the spatial resolution suffers due to the slightly cone beam geometry. Comparison between radiographic images taken with and without scanning setup is presented in Fig. 4.

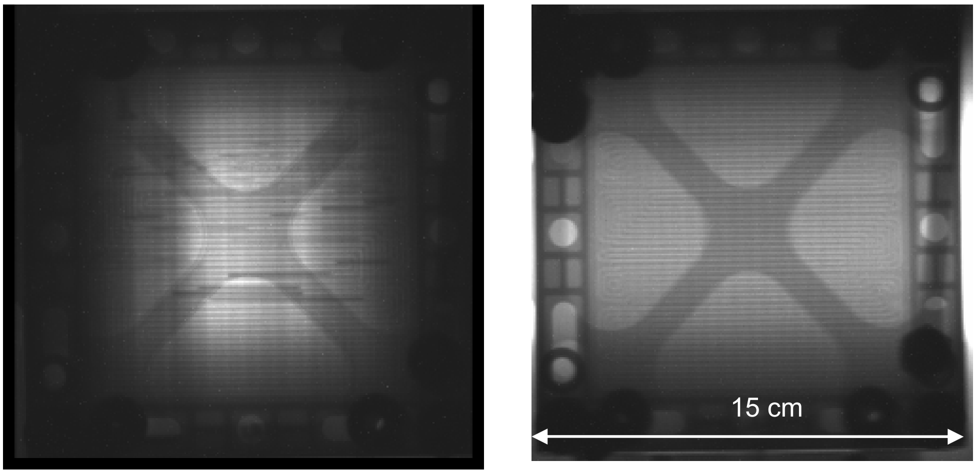

FIGURE 4. Neutron radiography of PEM fuel cell without scan otion (left) and with scan option (right). The measuring times were 10 s and 36 s correspondingly.

The scanning setup allows for increasing of the available sample dimensions up to 20x20 cm^2 limited by the size of the active area of the detector system.

2.2. ENERGY-SELECTIVE OPTION

The advantage of the cold neutron spectrum was used for setup of tunable energy selective option. It was based on a double crystal device providing monochromatic neutron beams between 2 Å and 6 Å. The energy resolution was determined by the mosaicity of the used pyrolytic graphite crystals as for 0.8° mosaicity the energy band $\Delta\lambda/\lambda$ was estimated to be 3 %. Details about the construction and the performance of the monochromatic setup installed at CONRAD are given elsewhere [4]. An example of radiographic images below and above the Bragg-cut-off for iron and copper are presented in Fig. 5.

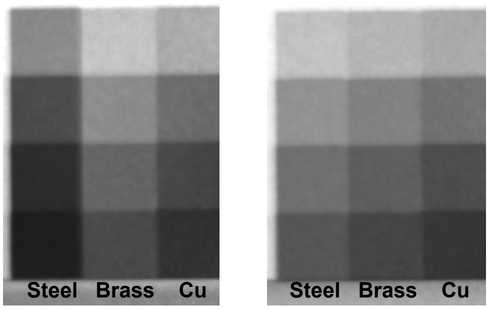

FIGURE 5. Energy despersive radiographic images on test samples (step wedges – steps from 0.5 cm to 2.0 cm) from steel, brass and copper. The left image is recorded at 3.7 Å – below the Bragg-cut-off for the three materials while the right image shows better transmission at 4.3 Å – above the Bragg-cut-off.

2.3. PHASE CONTRAST OPTION

The low contamination of the beam by high energetic neutrons and gammas allows for good signal-to-noise ratio in low flux experiments where large exposure times are required. For instance the phase contrast technique requires high spatial coherence of the beam which can be realized by utilization of a small pinhole at a large distance to the sample position. This leads to a dramatically flux reduction which makes the beam spectrum an important factor for the successful performance of such kind of experiments. In addition the useful phase-contrast signal is proportional to the neutron wavelength λ [4] which means that the cold spectrum will enhance the effect. For phase contrast experiments the tomography station CONRAD is equipped with pinhole exchanger (apertures of 1 mm, 3 mm and 5 mm) providing variable spatial coherence length from 0.3 µm to 1.5 µm at the spectral maximum of 3 Å. Comparison between conventional and phase tomography sections on a human tooth surrounded by D_2O is shown in Fig. 6.

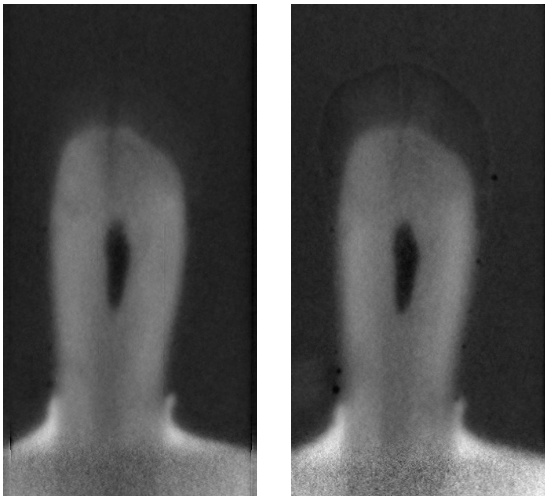

FIGURE 6. Comparison between conventional (left) and phase-contrast (right) tomography section of a human tooth. For the phase contrast experiment a pinhole of 5 mm and a distance of 5 m to the sample was used. The number of projections was 200 for the both experiments.

Evidently the phase contrast tomography provides much more details about the structure of the tooth where the border between the dentine and the enamel is clearly visible. Even small cracks in the enamel and bubbles in D_2O can be resolved.

CONCLUSIONS

The new neutron tomography instrument at HMI provides good conditions for test and development of new experimental methods due to its flexibility. The use of innovative techniques allows for overcoming of the limits in conventional neutron tomography and extending the field of applications. In addition the cold neutrons can be used very effectively with neutron optical components for optimization of the experimental performance. The future development of the instrument is connected with further tests of dedicated optical arrangements (neutron guides, benders and polarizers) which will help to establish new experimental techniques.

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