Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 69 (2015) 67 – 70
Physics Procedia

10 World Conference on Neutron Radiography 5-10 October 2014

IMAGINE: a cold neutron imaging station at the Laboratoire Léon Brillouin

Frédéric Ott[a,*], Camille Loupiac[a,b], Sylvain Désert[a], Arnaud Hélary[a], Pascal Lavie[a]

[a]*Laboratoire Léon Brillouin UMR12 CEA/CNRS, Centre d'Etudes de Saclay, 91191 Gif sur Yvette,France*
[b]*Equipe PAPC, UMR PAM, AgroSup Dijon-Université de Bourgogne, 21000 Dijon, France*

Abstract

A second cold neutron imaging station has been open to users at the Laboratoire Léon Brillouin. The station is designed for high resolution neutron imaging and tomography. The typical field of view is 100x100 mm² with a spatial resolution of 100µm. Better spatial resolutions (~50µm) can be achieved when reducing the field of view down to 30x30mm². The L/D ratio can be varied from 200 to 1000 with pinhole sizes ranging from 20 to 7 mm. Future upgrades will provide capabilities for energy resolved measurements using either a velocity selector or a double crystal monochromator. The possibility to perform polarized neutron experiments will also be provided next year.

Selection and peer-review under responsibility of Paul Scherrer Institut

Keywords: neutron radiography, neutron imaging, cold neutron

1. Introduction

In order to provide an easier access to neutron imaging for users, a second cold neutron imaging station has been installed at the Laboratoire Léon Brillouin on the reactor Orphée. While the first station is dedicated to radiography screening (~4000 pieces per year), the aim of this second station is to offer a flexible facility with versatile ancillary equipment so as to be able to perform in-situ measurements (controlled atmosphere, temperature, pressure) as well as tomographic measurements. The station shall eventually provide a spatial resolution as good as possible, in the range of 10-20µm. The IMAGINE station is part of the users program and can be accessed via the usual proposal system of the Laboratoire Léon Brillouin.

Selection and peer-review under responsibility of Paul Scherrer Institut
doi:10.1016/j.phpro.2015.07.009

2. Technical specifications

The station is installed on the Orphée reactor at Saclay, France. The neutrons are provided by a highly curved guide (G3bis), which looks at a H_2 cold source (20K). Due to the strong curvature of the guide, the wavelength spectrum distribution starts at λ= 3A°. The peak flux is at 4A° and above this wavelength the flux decreases roughly following a $1/\lambda^3$ law. The strong guide curvature also ensures that there are neither fast neutrons nor gammas originating from the reactor core. The background level on the experimental area is very low. No difference can be observed on the sCMOS camera detector with the shutter closed or open (in the latter case a B4C beam trap is hiding the scintillator). The signal to noise ratio is on the order of 2000 and is limited by the dark current of the sCMOS camera. In practice, absorption contrasts with a 0.1% resolution can be measured.

The instrument is using a classical pin-hole configuration. The guide size is 25x50mm². The pin-hole size can be varied between 6 and 25mm². After the pin-hole a shielded casemate is available. It enables setting up either a velocity selector, a double crystal monochromator or a time-of-flight chopper (in the future). The sample can be set at a distance of 4m up to 8m from the pinhole exit. All the elements of the spectrometer are on air pads so that the experimental set-up can easily be reconfigured depending on the specific need of an experiment. The flux at the instrument is $2x10^7$ n/cm²/s for an L/D = 200 and D=20mm.

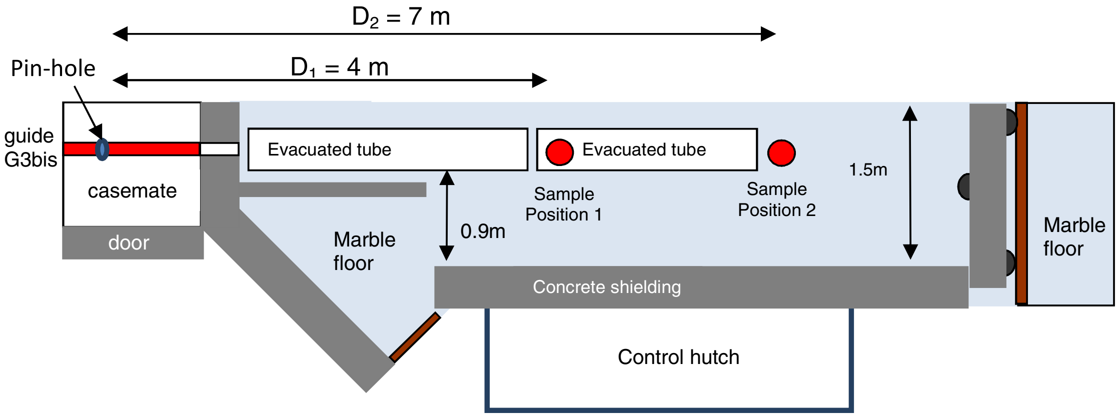

Figure 1: Implantation of the spectrometer IMAGINE on the guide G3bis at the Laboratoire Léon Brillouin.

The detector systems are based on scintillators from (RC Tritec, 2014) coupled to sCMOS cameras. A box with a 100x100mm² field of view coupled to a sCMOS camera from (Photonics Science, 2014) is available. The objective is a Voigtlänger NOKTON 25mm F/0.95 MFT. A second camera box optimized for high resolution imaging is available with a field of view of 30x30mm². This detector uses a sCMOS NEO camera from (ANDOR, 2014) coupled to a Canon EFS 60mm F/2.8 Macro USM. Both camera systems offer fast readout systems of up to 25fps. In practice however, acquisition times of at least 1s are required to achieve an acceptable signal/noise ratio. In case a very large field of view is required, a FUJI image plate 200x400mm² is available with a spatial resolution of 50µm. The reading of the image plate has however to be done off-line with a scanner which prevents performing time resolved experiments or tomographic measurements with this system.

Due to the strong curvature of the guide, the beam homogeneity across the guide exit is poor. Both horizontal and vertical structures are observed corresponding to various reflections on the mirrors of the curved guide. In order to improve the beam homogeneity, we use alumina membranes Anodisc from (Whatman, 2014). These membranes are very strong small angle scatterers. The size of the holes in the membranes can be chosen between 20nm, 100nm or 200nm. Thus the small angle scattering can be tuned to match the characteristic length-scales on the instrument. The beam homogeneity fluctuations over the detector area are on the order of 20% without membranes. With 2 membranes, the fluctuations are reduced to 5%. With 4 membranes, the fluctuations are reduced to 2.5% and the beam intensity by 14%.

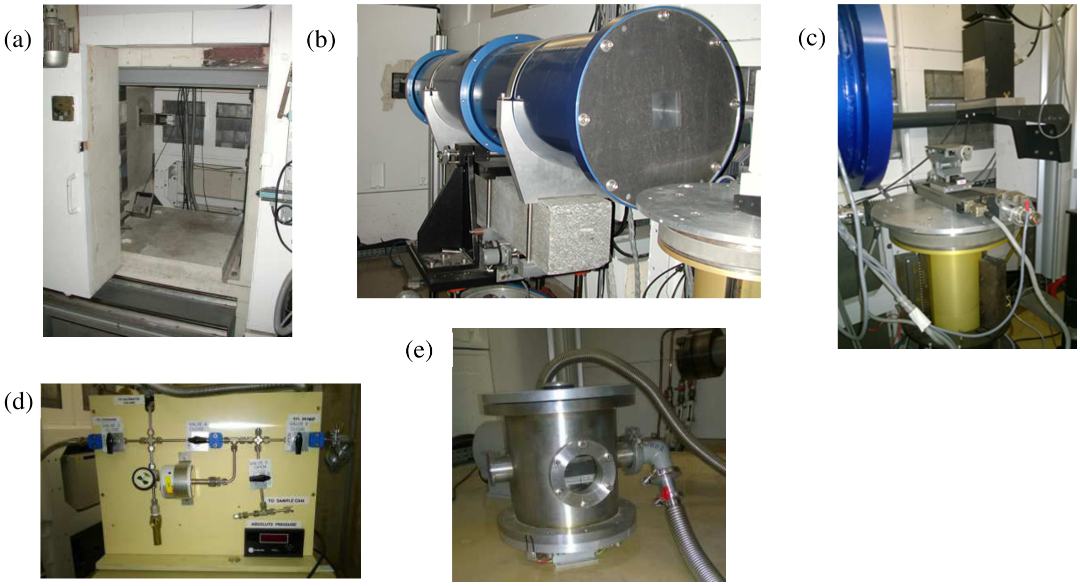

Figure 2: (a) The casemate where the velocity selector will be installed, (b) The evacuated tube (blue) for the neutron flight path, (c) The heavy load sample table (200kg). The large round table can rotate to perform tomographic measurements. The camera box is very compact and can be brought very close to the sample, (d) The control bench for the humidity chamber, (e) A furnace to perform measurements up to 200°C.

Figure 2abc show different elements of the spectrometer. The sample stage can accommodate any sample environment provided by the user (up to 200kg). The vertical travel is 260mm and the top table (400mm in diameter) can rotate by 360° to perform tomographic measurements.

Sample environments such as a humidity chamber and a furnace (up to 200°C) can be provided to the users (Figure 2de).

Data handling and processing are performed with ImageJ/FIJI or Matlab. For tomographic reconstructions the users may use (*Octopus, 2014)* or *(TomoJ, 2007, 2014)*. The tomographic reconstructions can be performed very quickly (<5minutes) on a workstation equipped with a GPU card (GTX 580). For 512^3 data sets, a simple weighted back projection (WBP) reconstruction calculation takes less than 3 seconds when using *TomoJ*. More complex algorithms (ART, SIRT) are however more time consuming. In practice, neutron tomographic data set are complete (typically 200 pictures over 180°) so that the simple WBP algorithm provides very good results.

3. Recent studies

The initial scientific focus for the internal research at the LLB was around food applications such as the study of milk powders dissolution in water (figure 3a), or the meat cooking process. The instrument was open for close collaborators in April 2014 and the calls for proposals are now open twice a year (April and October). Friendly users' experiments covering a wide range of fields have already been performed: hydrogen loading in Zr tubes, water distribution in fuel cells, in-situ following of the opening of a thermal fuse, the diffusion of surfactant in model rocks, the diffusion of water in soils, or the grapevine root growth. Figure 3b shows measurements performed on cork stoppers for wine bottles to study their quality grading (Lagorce, 2014).

4. Current upgrades

Several upgrades of the imaging station are under way. A velocity selector is presently being installed in the casemate. A double crystal monochromator will be installed in winter 2015. When these upgrades are working properly, polarized neutrons will be implemented. A high resolution setup using a Micro Channel Plate detector will be tested in spring 2015. It should enable to achieve spatial resolution in the range of 10-20µm together with the capability to perform Time-of-Flight measurements.

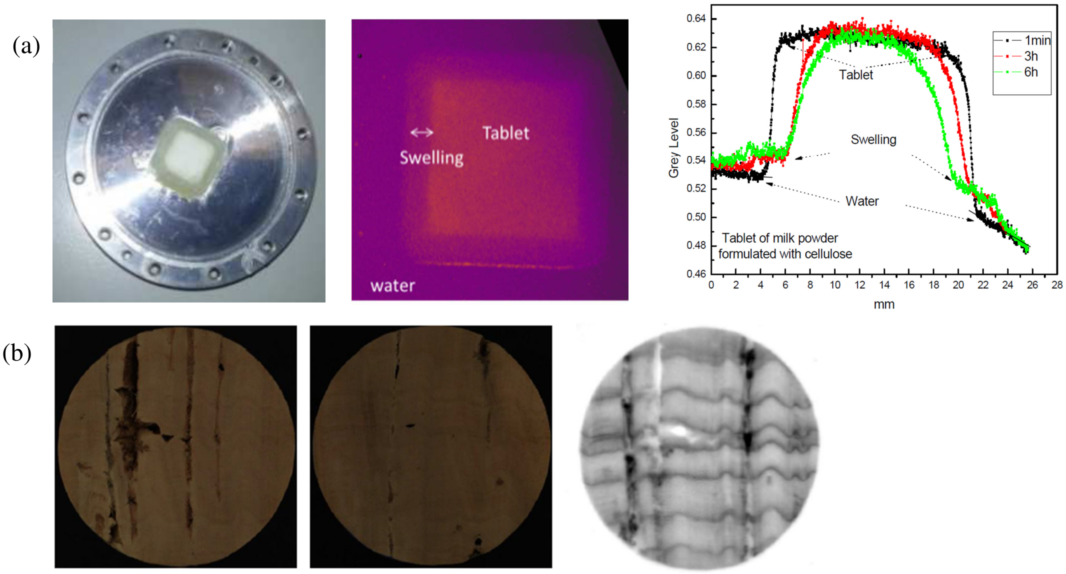

Figure 3: (a) Following the dissolution in water of a milk powder tablet formulated with an excipient (cellulose), which delays its dissolution (Assifaoui A. & Loupiac C., 2014). (b) Characterization of the defects of cork stoppers for wine bottles (Lagorce, 2014). The neutron radiograph (right) provides far more accurate information on the defects and density fluctuations of a cork disk than the optical pictures (left).

Acknowledgements

This research project has been supported by the European Commission under the 7th Framework Program through the 'Research Infrastructures' action of the 'Capacities' Program, NMI3-II Grant number 283883 on Neutron Imaging.

References

ANDOR: http://www.andor.com/
Assifaoui A. & Loupiac C., 2014, unpublished
FIJI: http://fiji.sc/Fiji
ImageJ: http://imagej.nih.gov/ij/
Lagorce-Tachon, A., Karbowiak, T., Loupiac, C., Gaudry, A., Ott, F., Alba-Simionesco, C., Gougeon, R., Alcantara, V., Mannes, D., Kaestner, A., Lehmann, E., Bellat, J.-P. 2014. The cork viewed from the inside. Accepted in Journal of Food Engineering.
Messaouidi, C., Boudier, T., Sanchez-Sorzano, CO., Marco, S. 2007. TOMOJ: tomography software for three-dimensional reconstruction transmission electron microscopy. Bioinformatics 8, 288.
Octopus Imaging: http://www.octopusimaging.eu
Photonics Science: http://www.photonic-science.com/products/SCMOS-camera.html
RC Tritec Ltd.: http://www.rctritec.com/
TomoJ: http://u759.curie.fr/fr/download/softwares/TomoJ
Whatman: http://www.gelifesciences.com