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A new Neutron Radiography / Tomography / Imaging Station DINGO at OPAL

U. Garbe*,a, T. Randalla, C. Hughesa, G. Davidsona, S. Pangelisa and S.J. Kennedya

a Australian Nuclear Science and Technology Organisation, Lucas Heights NSW 2234, Australia

Abstract

A new neutron radiography / tomography / imaging instrument DINGO was built to support the area of neutron imaging research (neutron radiography/tomography) at ANSTO. The instrument is designed for an international user community and for routine quality control for defense, industrial, cultural heritage and archaeology applications. In the industrial field it provides a useful tool for studying cracking and defects in steel or other metals. The instrument construction was completed at the end of June 2013 and it is currently in the hot commissioning stage. The usable neutron flux is mainly determined by the neutron source, but it depends on the instrument position and the resolution. The instrument position for DINGO is the thermal neutron beam port HB-2 in the reactor hall. The measured flux (using gold foil) for an L/D of approximately 500 at HB-2 is $5.3 \times 10^7$ [n/cm$^2$/s], which is in a similar range to other facilities. A special feature of DINGO is the in-pile collimator position in front of the main shutter at HB-2. The collimator offers two pinholes with a possible L/D of 500 and 1000. A secondary collimator separates the two beams by blocking one and positions another aperture for the other beam. The whole instrument operates in two different positions, one for high resolution and one for high speed. In the current configuration DINGO measured first radiography and tomography data sets on friendly user test samples.

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* Corresponding author. Tel.: +61 2 9717 7217; fax: +612 9717 3606.
E-mail address: ulf.garbe@ansto.gov.au
1. Introduction

A new state-of-the-art instrument has been built to support the area of neutron imaging research (neutron radiography/tomography). The new facility will provide standard neutron radiography and neutron tomography (Schillinger et al., 2000), (Hillenbach et al., 2005) setups. For neutron tomography a set of 2D radiography images are taken under different angles or projections. From these data sets, a 3D representation through the object may be constructed. In a workshop in late 2000, the Bragg Institute identified a number of Australian industries (various non-destructive testing and oil/gas exploration companies, agricultural industry, recycling, various CRCs, and DSTO) that could benefit from access to domestic neutron radiography. In addition there will likely be academic interest for the study of historic artifacts including ancient Egyptian and Chinese pottery, or in rare fossils for instance from Antarctica.

It should be noted that some of the methods can be better realized using a thermal neutron beam spectrum while others work better in conjunction with a cold spectrum. However world leading instruments utilize different sources, for example a direct cold source position such as ANTARES at FRM II (Schillinger et al., 2004), a hot beam tube position like NEKTAR at FRM II (Bücherl et al., 2009), a cold neutron guide position like CONRAD at HMI (Kardjilov et al., 2011) or spallation source thermal instrument NEUTRA at PSI (Vontobel et al., 2006). The main performance indicators are neutron flux, resolution, beam size and flexibility.

One of the special features of neutron imaging compared with x-rays or synchrotron imaging is the feasibility of scanning large samples such as running engines or archaeological sculptures. Therefore a desirable beam size for a neutron imaging instrument should be approximately from 5x5 mm$^2$ to 200x200 mm$^2$, depending on the instrument position and length. The flexibility needed is mainly driven by the user community. Variation in speed and resolution needs a set of different apertures, scintillation screens and possibly detector systems.

To investigate different imaging methods, such as phase contrast (Strobl et al., 2009), (Jacobson et al., 2004), (Kardjilov et al., 2003 and 2004) or magnetic imaging (Kardjilov et al., 2008), special equipment is needed, which can be seen as an optional feature. These features will be added on user demand at a later stage of the instrument if feasible with the existing thermal neutron beam spectrum. DINGO in its recent state finished one year of hot commissioning and is now fully operational for commercial and academic user access.

2. Instrument Layout

To optimally accommodate a large variety of samples which differ in size, scattering powers and attenuation coefficients, the neutron imaging instrument will individually be operated at two different beams, a high resolution beam and a high intensity beam. The general assembly of the instrument DINGO is as shown in Fig. 1.
A selector wheel is used to separate these two beam generated by the primary collimator. One beam will be blocked whilst the other passes through the aperture to be used for the experiment. A Helium filled flight tube is used between the selector wheel and the sample shutter unit. The sample shutter unit consists of two shutters, a fast shutter and the tertiary shutter. The main sample shutter (tertiary) is connected to the safety interlock system and regulates access to the sample area. The second one (the fast shutter) is directly connected to the detector system. It opens only when the detector is collecting neutron radiation data. For the rest of the time the fast shutter is closed, even with an open sample shutter, to protect the detector and to reduce background radiation. This will enhance the resulting image quality. Both shutter work independently.

After the neutron beam passes through the tertiary shutter, it enters a second flight tube. This flight tube is operated under the same conditions as the first one, Helium-filled at ambient pressure. No shielding is required for both flight tubes, as the beam is highly collimated and the flight tubes are oversized. The Helium filling is to suppress air scattering, which would reduce the neutron flux at the sample position by approximately 50%.

The sample stage consists of a xyz-translation table and a rotation stage. The xyz-translation table is needed for sample positioning in front of the detector. For this procedure a range of >500mm in x- and y-direction and 400mm in the z-direction is essential. The table is required for radiography and tomography as well. It has a loading capacity up to 500kg. In addition two high precision rotation stages are supplied with a maximum resolution of 0.001° that is needed for neutron tomography. The large rotation stage has a loading capacity of up to 200kg and the small high accuracy rotation stage can take up to 40kg.

All materials used are non-magnetic metal, where practical. The position of the sample stage is flexible in beam direction to adapt to the best possible beam size and/or L/D ratio (Fig. 1 and 2 a/b). Sample and detector stage are mounted on a rail system and can move independently. This is a required feature in order to carry out phase contrast imaging.

The detector stage provides support for the detector box to align the scintillation screen of the detector box to the neutron beam. Translation in the z-direction (up and down) is required, because the two setups (high intense and high resolution) for the instrument work on different beam heights. The distance between these two beams is approximately 100mm. Depending on the configuration in use, the detector box with the scintillation screen has to translate between these two fixed positions.
The detector system consists of a CCD camera counting events on a scintillation screen, which converts neutron radiation into visible light. The detector box is especially design for neutron imaging purpose and is based on existing concept at PSI, FRM II and NIST. The major design feature of these kinds of detectors is the CCD camera mounted out of the beam, at an angle of 90 degrees to the scintillation screen with a mirror mounted at 45 degrees to reflect the emitted light from the scintillation screen (see fig. 3). The scintillation screens are interchangeable. An initial set of six screens (3 of area 200 x 200 mm$^2$, 3 of area 100 x 100 mm$^2$) with different scintillation layer thickness (50µm-200µm). The scintillation screens are Aluminium sheet on which a thin layer of scintillation material (ZnS/6LiF) is coated. To accommodate the two screen sizes an interchangeable front section (including mirror) has been manufactured.

The CCD (Andor IKON-L) camera is mounted on a translation stage to adjust the field of view to the experimental conditions. To expand the range of the field of view, two different lenses with 50mm and 100mm fixed focal length are available. After setting the experimental conditions, the camera box needs to be closed and light-sealed. All further functions (exposure time, pixel binning, CCD-chip cooling) of the CCD camera are controlled remotely from the instrument computer.

Behind the detector and at the end of the instrument is a permanent beam stop designed as a layered structure to provide maximum shielding capacity. The beam stop is designed to cover both neutron beams delivered from the in-pile collimator. The opening of the beam stop shown in figure 4 is designed to prevent the scintillation screen and the detector itself from backscattered neutrons. The first layer being hit by the neutron beam through the oversize opening of the beam stop is a 5mm B4C sheet followed by 200mm borated polyethylene to shield and absorb neutron radiation. B4C generates much fewer backscattered neutron than shielding material with hydrogen content like Borated Polyethylene or Boroflex. The second part of the beam stop is 200mm thick steel box filled with a shielding mix for combined neutron and gamma radiation attenuation as determined by the shielding layout calculation.

The DINGO instrument heavy concrete shielding concept is optimized to make it easy to assemble and dismantle. In addition 5% Borated Polyethylene (PE) shielding, totaling a thickness of 100mm (2 x 50mm thick panels) is added to the internal faces of the walls and roof in the outer-pile section of the instrument.

3. First Results

During hot commissioning we analyzed the beam spectrum and intensity of the HB2 beam by installing a time-of-flight set up and gold foil activation analysis. The gold foils were fixed on to the aluminum support plate of the scintillation screen to measure the neutron flux at the sample position. The same procedure was used for high intensity and high resolution configuration. The flux calculated by a McStas (Willendrup et al., 2004) software simulation is consistent with the measured flux as shown in table 1.
The spectrum measured on HB2 is a thermal spectrum with a maximum intensity at 1.08Å as shown in figure 5. After running radiation surveys to guarantee the safe operation of DINGO and to characterize the neutron beam the instrument was ready to run a first test sample to take a first radiography. As a first sample we have chosen a mechanical alarm clock. The results of the first radiography and the following tomographic reconstruction on DINGO are shown in figure 6 a,b and c.

The radiograph in figure 6 b) was corrected with open beam images to take into account the inhomogeneous beam intensity distribution at the sample position. In addition a white spot filter was applied. All corrections have been carried out with the software ImageJ (Schneider et al., 2012). The tomographic reconstruction was calculated with the software package Octopus (Dierick et al., 2004) and rendered with VGStudio Max (Volume Graphics, 2014).

| Resolution (L/D) | Dingo - peak foil [n/s*cm²] | Dingo - foil average [n/s*cm²] |
|------------------|------------------------------|-------------------------------|
| 500              | $5.59 \times 10^7$          | $5.30 \times 10^7$           |
| 1000             | $1.06 \times 10^7$          | $9.00 \times 10^6$           |
4. Summary

The radiography/tomography instrument significantly enhances the research capabilities of the Australian neutron science facilities at ANSTO. It provides university, government and industry-based users of the new ANSTO research reactor OPAL a new world-class powerful tool for non-destructive real space testing and evaluation, with properties complementary to x-rays and synchrotron methods. First results acquired by friendly user experiments during hot commissioning have revealed that DINGO delivers high quality radiographs and tomography result which have finally led to the first scientific paper published from DINGO on a combined strain scanning and tomography experiment (Wensrich et al., 2014). The instrument can be effectively utilized by a large area of scientific research from medical applications, biology and environmental science, geology and engineering science as well as industrial application which are key areas for future technology and industrial developments in Australia.

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