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Industrial Application Experiments on the Neutron Imaging Instrument DINGO

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Abstract

The new neutron radiography / tomography / imaging instrument DINGO is operational since October 2014 to support the area of neutron imaging research at ANSTO. The instrument is designed for a diverse community in areas like defense, industrial, cultural heritage and archaeology applications. In the field of industrial application it provides a useful tool for studying cracking and defects in concrete or other structural material. Since being operational we gathered experience with industrial applications and commercial customers demanding beam time on DINGO. The instrument is a high flux facility with is 5.3 x 10 7 [n/(cm 2 s)] (confirmed by gold foil activation) for an L/D of approximately 500 at HB-2. 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 neutron beam size can be adjusted to the sample size from 50 x 50 mm 2 to 200 x 200 mm 2 with a resulting pixel size from 27 μm to ~100 μm. The whole instrument operates in two different positions, one for high resolution and one for high speed. We would like to present our first experience with commercial customers, scientific proposals with industrial applications and how to be customer ready.

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Industrial application experiments on the neutron imaging instrument DINGO

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Abstract

The new neutron radiography / tomography / imaging instrument DINGO is operational since October 2014 to support the area of neutron imaging research at ANSTO. The instrument is designed for a diverse community in areas like defense, industrial, cultural heritage and archaeology applications. In the field of industrial application it provides a useful tool for studying cracking and defects in concrete or other structural material. Since being operational we gathered experience with industrial applications and commercial customers demanding beam time on DINGO. The instrument is a high flux facility with is 5.3×10^7 [n/(cm^{2}s)] (confirmed by gold foil activation) for an L/D of approximately 500 at HB-2. 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 neutron beam size can be adjusted to the sample size from 50×50 mm^2 to 200×200 mm^2 with a resulting pixel size from 27 µm to ~100 µm. The whole instrument operates in two different positions, one for high resolution and one for high speed. We would like to present our first experience with commercial customers, scientific proposals with industrial applications and how to be customer ready.

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Keywords: neutron tomography; non-invasive technique; archaeometallurgy

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1. Introduction

Research facilities like ANSTO providing large-scale infrastructure facing at present time a transition from pure fundamental research to a more holistic approach serving a large variety of applied science disciplines and more commercial or industrial research. Neutron radiography and tomography station at other facilities like PSI, FRM 2, HZB and NIST have shown a high impact in industrial and commercial research [E. Lehman et al. 2011, B. Schillinger et al 2004, N. Kardilov et al 2011 and D.S. Hussey et al 2004].To address this strategic change a new cutting-edge neutron imaging instrument DINGO [U. Garbe et al 2015] was built from 2011 – 2014 to support the area of neutron imaging research. A major advantage of neutron radiation over X-rays and other imaging methods like MRI is high sensitive to hydrogen inside metals or ceramics or other light elements and higher penetration depth in combination with partially higher contrast between neighboring elements in the periodic table. Neutron radiation is used world-wide in quality control of explosive devices for mining, defense and industrial applications, for example to assess oil and water flow in sedimentary rock reservoirs, assessing water damage in aircraft components and the study of hydrogen embrittlement and cracking in zirconium-alloys. A large field of applications is utilizing neutron radiation instead of X-rays or both methods in combination. The user community varies from industrial or materials research, non-destructive testing, geology, archaeology and fundamental research. The facility is capable of providing two-dimensional "shadow" images of objects (radiography) and three-dimensional neutron tomography.

To attract industrial and commercial user we created a new working group at ACNS to target the specific needs of the community. The general message is that we do measurements and not experiments. In addition neutron imaging is part of ANSTOs industrial and commercial business portfolio not an isolated method to target industrial customers. We collaborate as whole ANSTO with all capabilities we can offer. We run a commercial group with scientist from all different departments and exchanging information and contacts. Within the group we understood that industry is demanding solutions. Finally neutron imaging might not be in the focus, but overall it leads to more customers due to the larger network. By showing all capabilities like the accelerator group, nuclear analysis, synchrotron and a strong materials engineering simulation group we are targeting a broader community and increase visibility for all of us.

2. Instrument Specifications

The instrument DINGO (figure 1) is fed by a thermal neutron beam defined by in-pile collimators positioned upstream of the main shutter. Two configurations are possible, by changing the collimator diameter D and the length L. The measurements presented in this paper were carried out with the high resolution configuration defined having producing a beam divergence of about 1mrad. In this way the neutron flux was 1.1×10^7 n/(cm^{2}s) measured by gold foil activation analysis. A second configuration, not used for the case studies, is optimized for high flux, with and measured flux of 5.33×10^7 n/(cm^{2}s). A set of pin holes, mounted on a selector wheel located 2.5 m downstream of the collimators, offers different apertures to reduce beam size down to 50×50 mm^2. No beam guide is used and the neutron beam is transported in helium filled flight tubes. The main components of the neutron imaging instrument are the sample table and the detector stage. The sample stage, designed for heavy load, can be adjusted over 4 degrees of freedom (three translations and the rotary stage for tomography). The remotely controlled xyz-translation table positions the sample in the field of view. To accommodate large samples the travel length of >500mm in x- and y-direction and 400mm in the z-direction is required. The table has a loading capacity of 500kg to position large samples and /or sample environment equipment accurately. In addition, three high precision rotation stages are available for neutron tomography with a maximum resolution of 0.001°. The largest rotation stage can take up to 200kg and the high accuracy rotation stage up to 40kg.

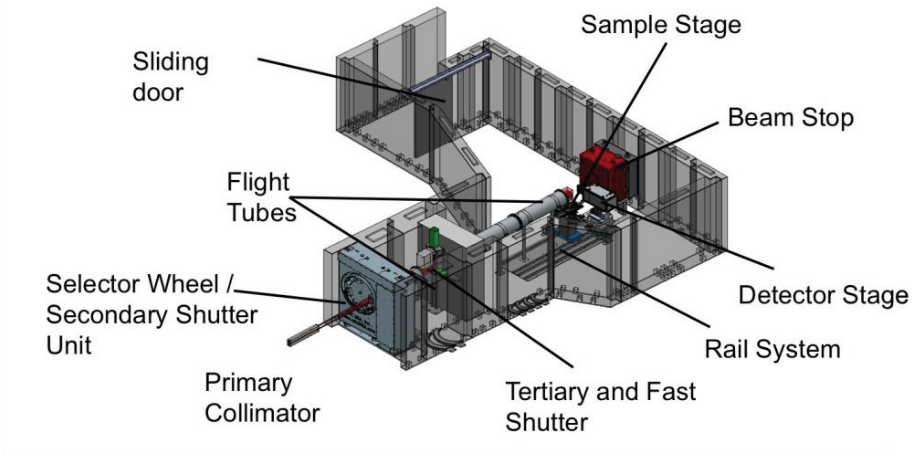

Figure 1 DINGO instrument assembly

Two detector systems are available on DINGO. A CCD camera (Andor IKON-L) for standard neutron radiography and tomography and a CMOS (Andor NEO 5.5 sCMOS) camera for fast data acquisition are running in similar detector boxes. Both cameras are mounted at 90º from the beam direction; a mirror mounted at 45º is used to reflect the emitted light from the scintillation screen to the CCD. The scintillation screens are exchangeable. An initial set of six screens (3 in 200 × 200 mm^2, 3 in 100 × 100 mm^2) with different scintillation layer thickness (50 µm-300 µm) is available. The scintillation screens are aluminum sheet with a thin layer of scintillation material ($ZnS/^6LiF$) coated. The CCD or CMOS camera is mounted on a translation stage to adjust the field of view to the experimental conditions.

The detector stage provides translation in the z-direction (up and down) to align the detector box for different neutron beam heights (high intense and high resolution). The distance between these two beams is given by the distance of the two pinholes in the primary collimator (approximately 100 mm). Depending on user requirement the position of the detector box with the scintillation screen has to be set to one of these two fixed positions.

3. Case Studies for Industry and Applied Science

3.1. Welding inspection

Energy selective neutron imaging of welds has the capability of visualizing the microstructure of the weld material [L. Josic et al 2011]. In many cases a standard tomography is sufficient if voids and gaps in the weld area are of interest only. The first example shows a slice from a 3D-model (see figure 2) through welded high strength steel tubes obtained by neutron tomography on DINGO taken for the purpose of weld inspection looking at the gap size between two joined tubes. The neutron tomography was completed by 900 projections over 13 hours in high resolution setting on DINGO (L/D = 1000). The field of view was 200 × 200 mm^2 with 100 µm pixel size. These findings can be used to refine welding condition to improve the mechanical properties and reliability or to use the obtained model to align the sample for high precision strain measurement on KOWRAI using the SSCANS system [Wensrich et al 2014]. Our welding simulation group if required by the customer can verify all measurements from imaging and strain scanning. The combination of measurement and simulation works either way and expands our capabilities as industrial group ANSTO.

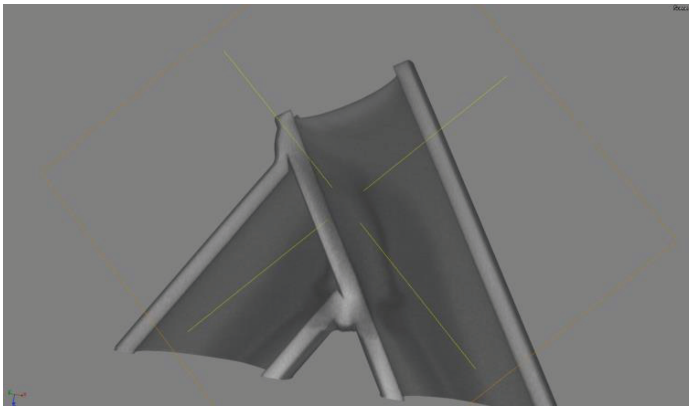

Figure 2 cut through 3D model from reconstructed neutron tomography of welded tubes

3.2. Porosity analysis and visualization of concrete

Concrete is a three phase system: aggregate, sand and cement paste, and in normal concrete the packing of the phases is optimized to infill voids and to save cost by minimizing the amounts of relatively more expensive cement component of the paste. While the computation of approximate packing fractions is detailed for spheres (see for example [Harder et al 1996]) in practice mismatches of different sized aggregates and problems with compaction can result in moderately sized voids in concrete which can act as weak points on stress loading or as channels for transport of water [EO Garcez et al 2015].

Neutron tomography has been proven to be an excellent tool to analyze concrete cores. Especially with reinforcement steel present neutron radiation is beneficial because of its high penetration depth in metals as shown in figure 3.

The sample was measured with a pixel size of 55µm and 655 projections over 180 degrees. After reconstruction with the software package Octopus [M. Dierick et al. 2004] a porosity analysis with VGStudio [Volume Graphics 2014] was calculated. The colored areas in figure 3 visualize the result with the color-coding assigned to the size of the voids (see legend figure 3). The sample shows large voids touching the reinforcement steel as shown in figure 3 which can be detector with neutron imaging.

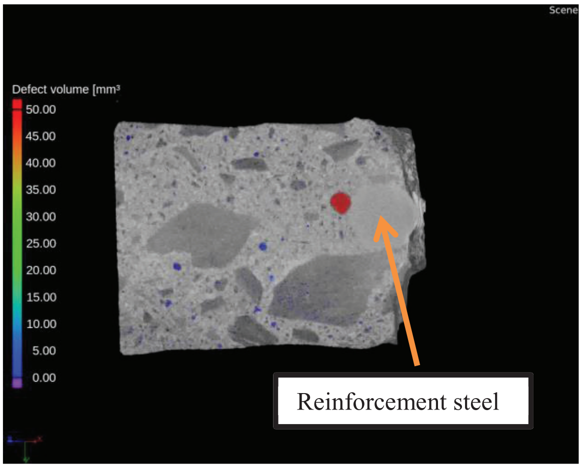

Figure 3 porosity analysis of a concrete sample with reinforcement steel

3.3. Friction stir welding of tungsten in copper

Copper is vastly employed in engineering applications because of material properties including high thermal and electrical conductivity, corrosion resistance and recyclability. Combination of copper with the high melting point, low sputtering yield and erosion resistance of tungsten (W), forms effective thermal management systems [S. Wei-ping et al 2007, A. Kurmada et al 2003], shaped charged liners [TF Wang et al 1996] and plasma spray guns[Sulzer 2012]. When used in conjunction with steel (SS), copper serves in high pulsed magnets [R. Zhou et al 1996], nuclear waste disposal canisters [L. Cederqvist 2003] and other applications requiring combination of high mechanical strength and conductivity. However, large difference in the coefficient of thermal expansion and melting point makes fabrication of Cu-W and Cu-SS composites a challenging engineering problem. High localized heat is pivotal for intimately bonding a thermally conductive material like copper. Therefore, Friction Stir Technology based thermo-mechanical bonding techniques are being developed for the fabrication of architecturally hybrid composites of copper.

Primary research shows that probeless tool aided friction stirring has been investigated for forming mechanically interlocked copper-tungsten composites [Y Ahuja et al 2014]. This fundamental research has given positive insights into the feasibility of FSF as a technique for fabricating bimetallic composites of copper (Cu) with immiscible metals such as tungsten (W) and stainless steel (SS).

FSF has been conducted to create stainless steel embedded composites of copper. As detailed in Fig.1, stainless inserts with different interfacial geometries have been investigated. In order to evaluate the effectiveness of the technique, the extent of SS-insert encapsulated by the plastically deformed copper needed to be investigated. A full 360º tomography with 0.25º steps was performed by using neutron imaging station Dingo. Each projection was taken in high resolution setting with an L/D = 1000 and a pixel size of 55 µm. ImageJ software was used for cataloguing the tomography data into sequential stacks of neutron images. Followed by this a 3D model of the sample was reconstructed using Octopus Imaging software [M. Dierick et al. 2004] and visualized with VGStudio [Volume Graphics, 2014].

As depicted by dark regions in figure 4, considerable voids and discontinuous bonding exist in the mechanically interlocked sights underneath the surface. This suggests that the Cu-SS samples fabricated using the standard FSF technique lack the effective encapsulation required for deeper and gap-free bonding.

We had a set of samples of joined tungsten with copper by friction stir welding and we were looking for the one with the smallest gap between the copper and the tungsten. That sample will be measured on KOWARI for strain scanning. We have the capability of taking our coordinate system from the imaging experiment and read it into the KOWARI system to align the instrument very accurate to the required position of the gauge volume using the SSCANS system [Wensrich et al., 2014].

Figure 4 slice through 3D model of reconstructed copper tungsten sample

4. Conclusions

The neutron imaging instrument DINGO has proven to be industrial and commercial beam time ready. The strategy of advertising DINGO through case studies of combined measurements and solution focus rather than method as part on an industry service group at ANSTO was successful. It finally led to 8 commercial measurements in the first two years of operation.

These simplified examples are very helpful to communicate the potential of neutron imaging as the real measurements are confidential and cannot be used for advertising. In addition the scientific proposal program will serve as constant source of new showcases in collaboration with the user community.

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