EVOLUTION OF NEUTRON IMAGING AT TRIGA PUSPATI REACTOR: A PROMISING DIGITAL REAL-TIME IMAGING FOR ENGINEERING RESEARCH

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ABSTRACT

Neutron radiography is a powerful tool for non-destructive testing of materials and finds numerous applications in industry and in material research as well. The basic principle is similar to that of X-ray radiography. A beam of neutrons falls on the sample and after passing through the sample, leaves the sample image on a photographic plate or on a detector. The neutrons interact with the nuclei of the atoms that compose the sample and the absorption and scattering properties of the contained elements make it possible to produce images of components containing light elements, like hydrogen beneath a matrix of metallic elements, (lead or bismuth), which cannot be easily done with conventional X ray radiography. Exploiting this property, neutron radiography has been used in applications requiring the identification of (light) materials inside solid samples. This article gives an overview of utilization of the CCD camera system in neutron imaging system for real time radiography/tomography investigations.

ABSTRAK

Radiografi Neutron adalah alat yang berkuasa untuk bahan ujian yang tidak merosakkan dan mendapati banyak aplikasi dalam industri dan penyelidikan bahan juga. Prinsip asas adalah serupa dengan radiografi X-ray. Rasuk neutron jatuh pada sampel dan selepas melepasi sampel, meninggalkan imej sampel pada plat fotografi atau pada pengesan. Neutrons berinteraksi dengan nukleus atom yang menyusun sampel dan sifat penyerapan dan hamburan unsur-unsur yang terkandung di dalamnya membolehkan menghasilkan imej komponen yang mengandungi elemen cahaya, seperti hidrogen di bawah matriks unsur logam, (plumbum atau bismut), Yang tidak boleh dilakukan secara mudah dengan radiografi X ray konvensional. Memanfaatkan harta ini, radiografi neutron telah digunakan dalam aplikasi yang memerlukan pengenalan bahan (cahaya) dalam sampel pepejal. Artikel ini memberi gambaran keseluruhan penggunaan sistem kamera CCD dalam sistem pengimejan neutron untuk penyiasatan radiografi / tomografi masa nyata.

Keywords: neutron radiography, neutron tomography, digital imaging

INTRODUCTION

Neutron imaging is the process of making an image with neutrons. Neutron radiography (NR) produce 2D transmission images of objects revealing their inner structure. Neutron Radiography is an imaging technique which provides images similar to X-ray radiography. The difference between neutron and X-ray interaction mechanisms produce significantly different and often complementary information. While X-ray attenuation is directly dependent on atomic number, neutrons are efficiently attenuated by only a few specific elements. X-rays are attenuated based on a material's density. Denser materials will stop more X-rays. With neutrons, a material's likelihood of attenuation of neutrons is not related to its density. Some light materials such as boron will absorb neutrons while hydrogen will generally scatter neutrons, and many commonly used metals allow most neutrons to pass through them. For example, organic materials or water are clearly visible in neutron radiographs because of their high hydrogen content, while many structural materials such as aluminium or steel are nearly transparent.

Neutron imaging has shown to be a valuable complementary method to other techniques like X-ray, useful for several aspects in non-destructive method. Neutron imaging is based on the mapping of the attenuation function for a sample in a neutron beam. Therefore it provides straightforward non-destructive information about the inner structure of the sample. This is the reason to consider neutron imaging as the most powerful and flexibly applicable method when neutrons are used for non-destructive testing studies including characterization of materials. The examples of industrial use (e. g. electric fuel cells, car industry, aircraft, geosciences, etc.) underlay the high demand for neutron imaging capability now and in the future.

A major step in the improvement of the neutron radiography activity at PUSPATI TRIGA REACTOR is the implementation of digital neutron detector. A neutron detector is an imaging system based on a digital camera. The neutron detector based on a scintillator, a front coated mirror, lenses and CCD camera is a guarantee of more reliable and accessible images and a progress for neutron radiography imaging.

The introduction of digital imaging methods enabled a much more efficient and advanced neutron use compared to traditional film techniques. The advantages of the digital systems compared to the previously dominating film methods are the following:

i. high sensitivity and efficiency
ii. fast read-out, high frame rate
iii. high linearity (CCD based)
iv. comparable spatial resolution to film, variable FOV and spatial resolution
v. digital information suitable for quantitative evaluation
vi. image post-processing possible
vii. easy archiving and data transfer
viii. neutron tomography becomes possible.

Preliminary testing after the implementation of digital neutron radiography based on CCD neutron camera has been done using SANS beam port. Rawi et al. [1] and [2] have reported the design and set up of the experiment. It was done in such that safe the CCD neutron camera from fast neutron and gamma ray. However, the CCD camera has a limitation of the scintillator size of dimension 6.7 cm ×5.0 cm (Figure 1).

Figure 1. CCD Camera FDI CoolView

Recently, we received a new inexpensive advance neutron camera with high resolution and bigger field of view. With this new advance neutron detector, it is expected that neutron imaging system at TRIGA MARK II PUSPATI could provide a rather good productivity and the achievable results in terms of the quality of non-destructive inspection.

This paper gives an overview about the implementation of new advanced neutron detector for radiography and real time investigation performed at SANS beam port in TRIGA PUSPATI reactor.

ADVANCED DETECTOR BASED ON COOLED CCD CAMERA

The new advanced neutron detector is appropriate for medium flux reactor. The main features are low noise, high resolution and fast imaging. This neutron detector 200x200mm scintillator screen size and front-surfaced super mirrors with Nikkor f/1.2 50mm optics lenses.

The components of the advance detector system are place in L-shaped light-tight camera box in two parts. Figure 2 shows the L-shaped camera complete with the CCD and its B4C/Pb protection on top, with the imaging box containing the scintillator in front of the interior mirror at the bottom.

The 200x200mm imaging detector uses a 2048x2048 pixel CCD to provide 100 µM resolution. This large CCD also makes the camera more efficient, since big pixels collect more light. A large Nikkor f/1.2 50mm lens is used to maximise the scintillator light at the CCD, which is read out to 16-bit resolution to provide a high dynamic range. And the CCD is cooled to allow long exposures

This type of this neutron detector consists of a neutron sensitive scintillator screen which has the task of converting the neutrons in photons and a camera which is the recording device for the light emitted by the scintillator. The first step of the detection mechanism for these scintillator materials is an (n, α)-reaction:

$$^{6}_{3}\mathrm{Li} + \mathrm{n} \rightarrow ^{3}_{1}\mathrm{H} + ^{4}_{2}\mathrm{He} + 4{,}78\ \mathrm{MeV}$$

Then these emitted -particles cause a secondary converter emission in the form of visible light which is recorded by the camera.

The main advantage of this imaging camera, the aluminium neutron scintillator plate shown can also be replaced by a thin carbon fibre plate with an X-ray scintillator. So the same imaging camera can be used for both X-rays and neutrons. Figure 3 shows both scintillator for neutron and X-ray.

Figure 2. New advanced neutron detector based on Peltier-cooled CCD camera

Figure 3. LiF-ZnS scintillator for neutrons, green light emitter (left) and X-ray scintillator each with 200mm×200mm dimensions.

EXPERIMENTAL APPARATUS FOR NEUTRON RADIOGRAPHY

Since the new NR facility is still not ready for Neutron Radiography, the NR group has decided to try this new advanced neutron detector at SANS beam port TRIGA reactor. However this new neutron detector should be protected from gamma radiation and fast neutron. The basic experimental layout of NR consists of a neutron source, of a collimator functioning as a beam formatting assembly, of a detector and of the object of study, which is placed between the exit of the collimator and the detector. Figure 4 shows neutron radiography experimental setup at SANS beam port.

Figure 4. Experimental setup for neutron radiography at SANS beam port TRIGA reactor

The visible light emitted from the ^{6}LiF-ZnS (Ag) scintillator exposed to the neutron beam was imaged with an optical lens onto a Peltier-cooled CCD camera through a 45º mirror. The converter was fixed onto a 2-mm-thick aluminum plate to avoid penetration of surrounding light inside the detection box. Additional shielding is needed to protect the CCD camera from gamma.

The neutron beam intensity at SANS beam port is estimated to be ~ 10^3 n/cm2/s. with the TRIGA reactor operating at 750kW.

EXPERIMENTAL APPARATUS FOR X-RAY IMAGING

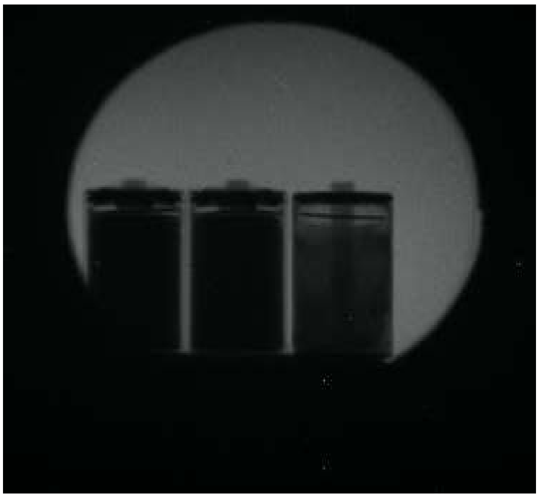
The basic experimental layout of X-ray radiography consists of a detector and of the object of study, which is placed between the exit of the X-ray and the detector. The X-ray source used in this experiment is a medical X-ray source from Kumpulan Fizik Perubatan, NM. Figure 5 shows experimental setup using medical X-ray at Block 32 Tambahan.

Figure 5. Experimental X-ray Setup for X-ray Radiography using advance neutron camera with X-ray scintillator.

NEUTRON IMAGING RESULT

First images with the new detector for neutron imaging were acquired for a lithium battery. Integration times on the sensor of the CCD to obtain good images, 60s.

(a)



(b)

Figure 6. Test object: (a) 3 Lithium batteries (2 new and 1 old) ,(b) Neutron radiography of test objet

A common source of noise in neutron radiography raw data are ‘‘white spots’’ generated by direct hits of gamma rays on the CCD chip.

X-RAY RADIOGRAPHY

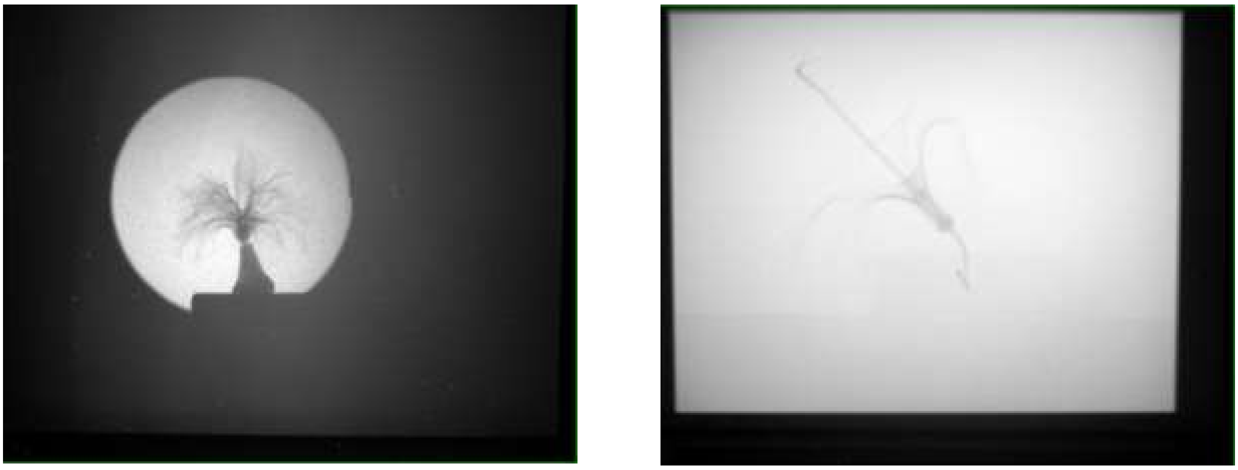
The X-rays are absorbed by the material they pass through in differing amounts depending on the density and composition of the material. Figure 7 and 8 show high quality X-ray radiography of internal structure of watch and battery. Most metal components produce high contrast compare to plastic components.

Figure 7. X-ray radiography of internal structure of watch using new advance detector with X-ray scintilator

Figure 8. X-ray radiography of internal structure of Lithium battery using new advance detector with X-ray scintillator

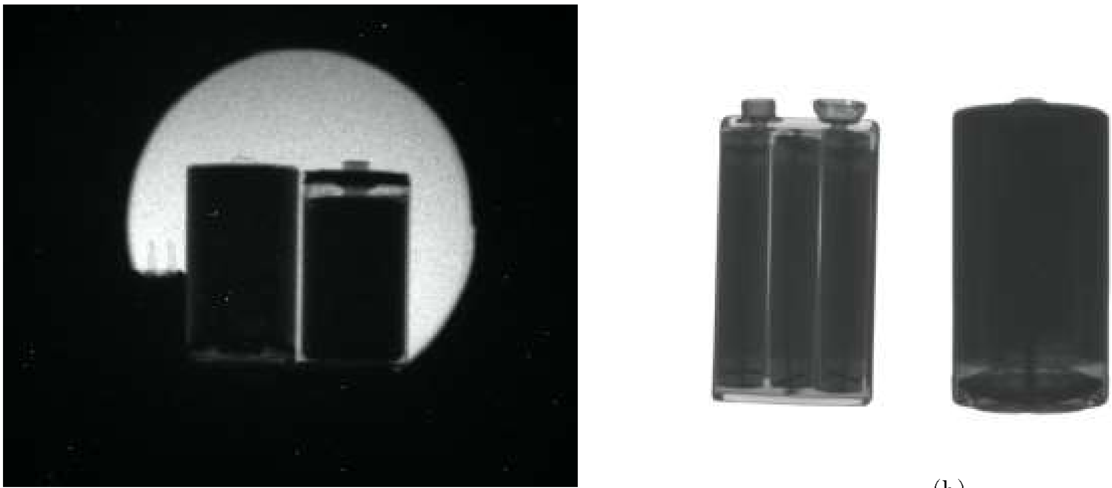
COMPARISON OF X-RAY AND NEUTRON RADIOGRAPHY

Figure 9a and Figure 10 demonstrated impressively that NR can yield different information then obtainable with X-rays, because these two methods are able to visualize other materials. These two images express the complimentary result obtainable with these two methods very clearly.



(a) (b)

Figure 9. (a) neutron radiography of bunga raya (b) x-ray radiography of bunga raya using new advanced detector



(b)

(a)

Figure 10. (a) neutron radiography of lithium battery (b) x-ray radiography of lithium battery using new advanced detector

REAL TIME DYNAMIC NEUTRON RADIOGRAPHY

Real-time imaging allows to see movement within object. This technique allows to follow a dynamic process in real-time. The objective is to make observations which are not possible in steady state. Typical time resolution for dynamic imaging: 1 – 60 s. As a first step, basic experiment for real time dynamic neutron radiography was commissioned using the new neutron detector. In real-time imaging the aim of the investigation is to follow a dynamic process in real time. Figure 11 demonstrated the first real-time dynamic images produced using advance neutron camera at TRIGA reactor. However, the images are low resolution due to limitation of intensity neutron flux. The exposure times of 1second per image.

Figure 11. Demonstration real time dynamic neutron radiography

CONCLUSIONS

As a first step, the neutron imaging system for static image acquisition with the advance detector was successfully commissioned. Real time neutron radiography has been experimental set-up to and is capable of producing static and dynamic images.

The operational ability of the new advance neutron camera has been experimentally proven. The results here presented have demonstrated that the new neutron camera show high potential to inspect low-thickness samples with a high resolution. Even though the intensity of the neutron flux produces at the beam-port is relatively low, this paper demonstrates that a good combination of efficient digital neutron area detector system and suitable neutron intensity shows a promising result. More work will be explored on real time neutron radiography using new advance neutron camera.

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