Development of Neutron Imaging System for Neutron Tomography at Thai Research Reactor TRR-1/M1

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Abstract. The neutron imaging is a powerful non-destructive technique to investigate the internal structure and provides the information which is different from the conventional X-ray/Gamma radiography. By reconstruction of the obtained -2dimentional (2D) images from the taken different angle around the specimen, the tomographic image can be obtained and it can provide the information in more detail. The neutron imaging system at Thai Research Reactor TRR-/1M1 of Thailand Institute of Nuclear Technology (Public Organization) has been developed to conduct the neutron tomography since 2014. The primary goal of this work is to serve the investigation of archeological samples, however, this technique can also be applied to various fields, such as investigation of industrial specimen and others. This research paper presents the performance study of a compact neutron camera manufactured by Neutron Optics such as speed and sensitivity. Furthermore, the 3-dimentional (3D) neutron image was successfully reconstructed at the developed neutron imaging system of TRR-1/M1.

1. Introduction

Neutron Imaging (NI) is radiation transmission technique to inspect the internal structure of a specimen worldwide. Thailand Institute of Nuclear Technology (Public Organization), TINT have developed the neutron imaging system to support the neutron tomography. The conventional technology of neutron image recorder, converter screen-film, has been replaced by a digital camera coupled with a fluorescence screen to get a higher sensitivity and provide more convenience. Then, the high efficiency and high resolution neutron camera was purchased to conduct the neutron tomography. The aim of this work is to study the performance of a compact neutron camera and to reconstruct the neutron tomographic image. Firstly, the development purpose is to serve the investigation of archeological samples for which X-ray or gamma ray tomography cannot provide the hidden information such as an organic material. Moreover, the obtained information can fulfill another nondestructive technique such as the neutron activation autoradiography (NAAR) [1]. The development does not only cover the neutron imaging technique but also the shielding wall of the neutron imaging room has been renovated and a neutron shutter been renewed for physical and radiation safety purposes.

2. Methodology

The compact neutron camera manufactured by Neutron Optics [2] was purchased to conduct the development of the neutron imaging system for neutron tomography in this work. The neutron camera is composed of LiF/ZnS scintillation screen with the size of 20 cm × 20 cm and the thickness of 0.2 mm, the 45° reflected mirror and the 2048 × 2048 pixels CCD sensor camera. The incoming lights are

gathered to Nikkor lens with the focal length of 50 f/1.2 before reaching the CCD. In addition, the Peltier cooling system is equipped to the CCD sensor for noise reduction. All components are compacted in an aluminum light tight box as L-shape as shown in figure 1. The neutron imaging system has been located at the south beam tube of TRR-1/M1 TRIGA MARKIII research reactor at Chatuchak site of TINT. The nominal operating power of 1.2 MW thermal provides the thermal neutron flux at the radiographic position at the distance of about 100 cm from the reactor wall, of 10^6 n/cm²·s. The L/D ratio of this facility is about 50. Before taking radiographic images, the camera temperature was set to -20 °c to cool the CCD sensor for reducing noises during the long operation. However, the lowest camera temperature could be down to approximately -5 °c which depends on the environmental temperature in the reactor hall.

To investigate the compact neutron camera performance, the test strip B standard specimen manufactured by Argonne National Laboratory, USA was used as a reference sample. The test strip B is an opaque aluminum bar which is composed of plastic wires and cadmium wires with the difference in diameters and also a cadmium plate with the thickness of 0.5 mm. The cadmium plate is drilled to make the different hole diameters. The specific information of the test strip B is shown in figure. 2. The performances in terms of speed and sensitivity of the camera were studied by varying the exposure times from 5, 10, 30, 60, 120 and 240 seconds at the radiographic position. Moreover, the study was extended to 120 cm-distance away from the beam port to study the trend of gray value. The gray values of the obtained neutron images were then evaluated by the ImageJ software.
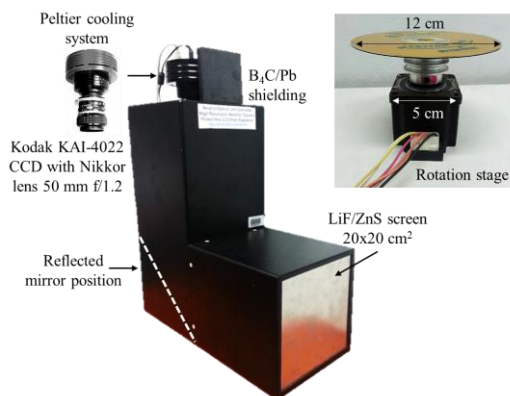
Figure 1. Neutron camera from Neutron Optics and in-house developed rotation stage.
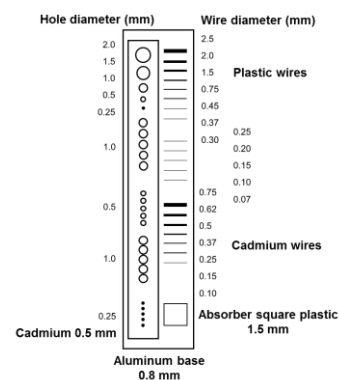

Figure 2. Schematic of test strip B.

In addition, the neutron tomography was performed with an in-house developed rotation stage as shown in figure 1. A specimen was then tested with the evaluated condition. At the beginning of the neutron tomography, a rotation step was 1.8 degree and the total projections were 101. Two different types of samples, an ancient doll and a rose sample were preliminary used to conduct neutron tomography. The exposure time for a projection was 30 s. The 2D neutron images were reconstructed to tomographic image and 3D neutron image by using Octopus Imaging software. To renovate the neutron imaging room, we used interlock Ledite to enhance the strength of the wall and shield the inner wall with 2-inches of 5% borated polyethylene. The larger neutron shutter with an automatic system was replaced the manual shutter.

3. Results and discussion

The characterization of a compact neutron camera was carried out by determination of the gray value from the background area of the obtained images at various exposure times. The relationship of neutron fluence and gray value was then plotted. The result shows that the speed of a compact neutron camera exhibits linearity as shown in figure 3. From the result, the gray value of background is saturated at the

exposure time of 103 s or neutron fluence of 1×10^8 n/cm^2. At the 120 cm-position, the gray value was decreased to 87% compared with 100 cm-position.
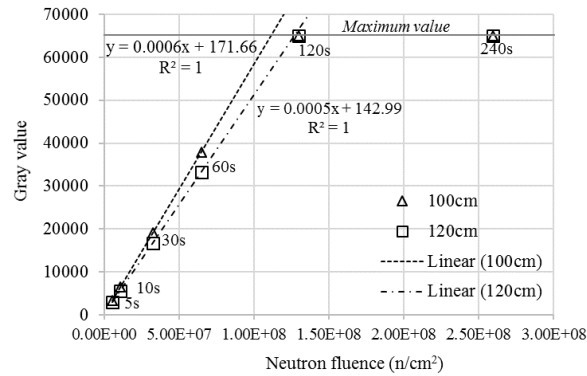

Figure 3. The exposure chart of neutron imaging using the compact neutron camera at TRR-1/M1.

The obtained images of a test strip B at 100 cm-distance and various exposure times were also evaluated to determine the sensitivity and contrast. The images of a test strip B were shown in figure 4. The gray value profiles of the cadmium and plastic wires images were studied to determine the sensitivity of the camera. The profiles are shown in figure 5. The results show that the smallest plastic wire which can be observed in this experiment is a plastic wire with a diameter of 0.37 mm at 120 second-exposure time. Also, the smallest cadmium wire diameter is 0.1 mm which can be observed at all exposure time conditions. The image contrast was determined by calculating the difference of gray value between the cadmium plate and the plastic plate area. The result shows that 30-120 s exposure time could provide the best image contrast at 85% in this experiment. This information is useful for evaluation of neutron tomographic condition.
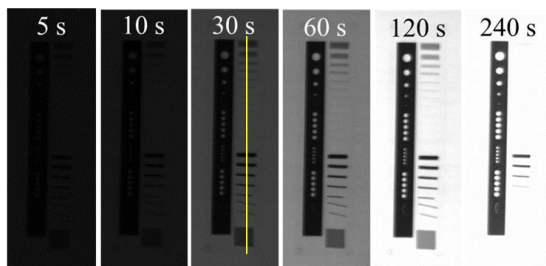

**Figure 4**. Neutron imaging of test strip B.
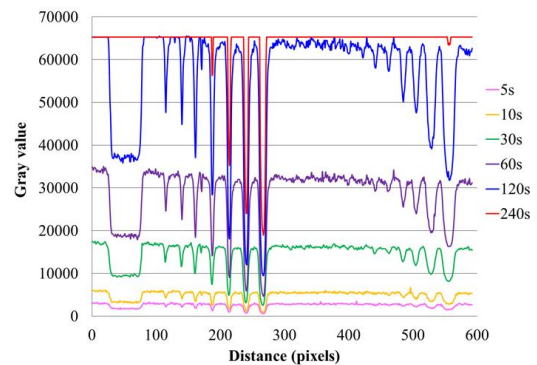
Figure 5. Gray value profiles of the cadmium and plastic wires.

The neutron tomography was performed with an in-house developed rotation stage. The exposure conditions for neutron tomography were 1.8 degree-rotation step, 30 s-exposure time and 101 projections. After that, the obtained 2D neutron images were reconstructed to a tomographic image and a 3D image by using Octopus Reconstruction software version 8.8.6 with parallel beam geometry. The 3D images were presented with Octopus Visualization software version 2.0.1.0. To conduct the neutron tomography at TINT with our compact neutron imaging system, the tomographic image and 3D image were successfully reconstructed as shown in figure 6 and 7, respectively. The preliminary images were not fully complete, due to the limitation of the neutron imaging facility of TRR-1/M1, coarse exposure condition and sample positioning. However, it was satisfying for the early stage of the development.

The 2D projection of an ancient doll reveals a crack at the neck position and a crack can be observed in the 3D image. And also the complex structure of rose petals could be observed in 3D visualization. At present, the size of the sample was limited by the load capacity of the rotation stage and the size of the fluorescence screen. The sample weight should not exceed 3 kg and the size should not be larger than 20×20 cm^2. Nevertheless, the neutron imaging system should be continually developed to improve the reconstruction image quality and the standard specimen for neutron tomography should be tested to determine the specific information of the neutron tomography system.
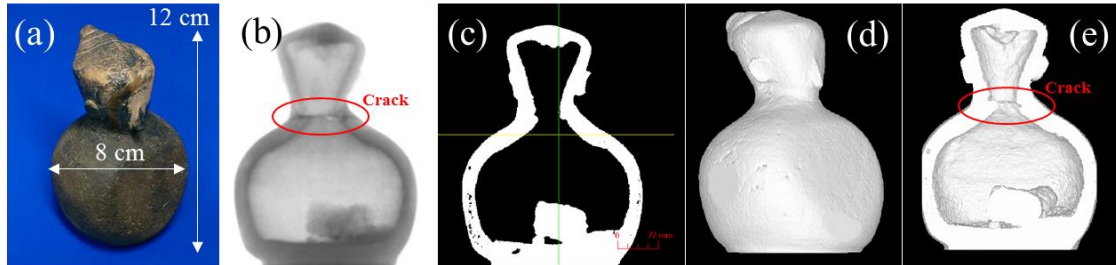
Figure 6. (a) Ancient doll, (b) 2D projection, (c) tomographic image, (d) 3D volume rendering image and (e) cutting of 3D image.
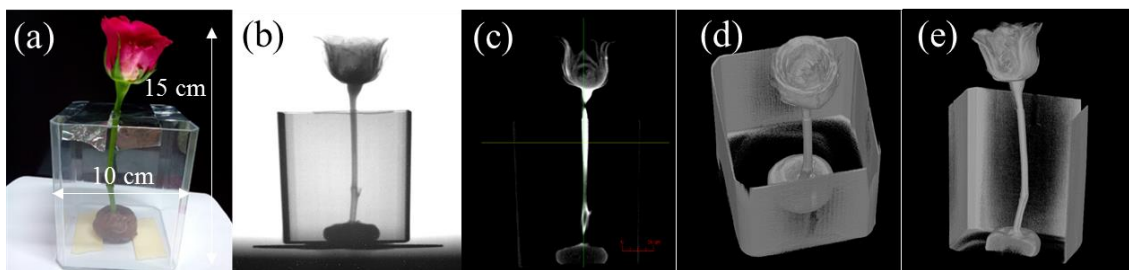
Figure 7. (a) Rose sample, (b) 2D projection, (c) tomographic image, (d) 3D volume rendering image and (e) cutting of 3D image.

4. Conclusion

The neutron tomography system at TINT is currently improved to support nondestructive investigation in Thailand. By using a compact neutron camera combined with the medium neutron flux reactor, the neutron imaging can present a good image quality with high speed and high sensitivity. By using the reconstruction image software, the neutron tomographic images were successfully produced. However, the neutron imaging system and the tomographic image quality should be continuously improved. In the future, the out-core neutron collimator is planned to be installed behind the neutron shutter to get better neutron beam quality.

5. Acknowledgement

References

[1] Khaweerat S, Ratanatongchai W and Channuie J 2015 A significant contribution of INAA in autoradiography for elemental profile construction *Physics Procedia* **69** 382–7
[2] Hewata A W 2015 Inexpensive Neutron Imaging Cameras using CCDs for Astronomy, *Physics Procedia* **69** 185–8