PARAMETERS FOR DIGITAL NEUTRON RADIOGRAPHY AT TRIGA MARK II
RESEARCH REACTOR OF MALAYSIAN NUCLEAR AGENCY

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PARAMETERS FOR DIGITAL NEUTRON RADIOGRAPHY AT TRIGA MARK II RESEARCH REACTOR OF MALAYSIAN NUCLEAR AGENCY

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I declare that thesis entitled " P^r^we^er^ For D;'g;Y%/ #eM^ro^ ^%Jz'ogr%pAy Trzg^ Mar^ 7/ ^e^e^rcA ^e^c^or O/ N^c/e^r ^ge^cy" is the result of my own research except as cited references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Neutron radiography has been widely employed in nondestructive testing technique to detect the structural nature of internal defects of optically opaque materials. For many years, conventional neutron imaging technique has been carried out using analogue technology which uses Rim as means for imaging. In making transition from analogue to digital technology, several parameters have to be optimized. Beam size and neutron flux have been identified as two principal parameters to develop digital neutron radiography. The parameters will be considered as a point to get a neutron beam to suit the scintillator size of detector and produced high quality image. Safety of the equipment was also important to protect the electronic component of the detector from damaged. In this study, a cooled charge couple device (CCD) camera system was used and a shielding is adopted to protect the CCD camera from unnecessary radiation. Therefore the thickness estimation of shielding was obtained and verified by gamma ray dose mapping. The neutron beam size has been modified by attaching a simple collimator beam plug to the neutron radiography 2 (NUR-2) beamport to accommodate 5 cm x 6 cm dimension of the scintillator screen placed in the CCD camera. With the collimator beam plug attached, the neutron beam effective diameter is reduced to 7.2 cm from 15.8 cm which effectively covers the scintillator area. The thermal neutron flux through the collimator beam plug at CCD camera location was 2.674 x 10 ^ ncm ^s*'. The neutron flux obtained is within the acceptable levels for the CCD camera requirement. Meanwhile the gamma ray dose with CCD camera shielding was less than 30 mGyh*'. The gamma ray dose mapping indicates the shielding was effective in protecting the electronic components from damaged. These experimental results consistent with the result of the analysis on the digitized the radiographic image produced using a conventional technique.

ABSTRAK

Radiografi neutron telah digunakan secara meluas sebagai teknik ujian tanpa musnah untuk mengesan sifat struktur kecacatan dalaman pada bahan legap. Buat beberapa tahun. teknik pengimejan konvensional telah dijalankan menggunakan teknologi analog seperti filem untuk tujuan pengimejan. Dalam mewujudkan peralihan teknologi analog kepada digital, beberapa parameter telah dioptimumkan. Saiz pancaran dan fluks neutron telah dikenalpasti sebagai parameter utama untuk membangunkan digital radiografi neutron. Parameter-parameter ini dianggap sebagai penentu untuk mendapatkan pancaran neutron yang sepadan dengan saiz sintilator pengesan dan menghasilkan imej berkualiti tinggi. Keselamatan pada alat juga penting untuk melindungi komponen elektronik pada pengesan daripada rosak. Dalam kajian ini, sistem kamera CCD telah digunakan dan perisai telah digunakan untuk melindungi kamera CCD daripada radiasi yang tidak diperlukan. Oleh itu, anggaran ketebalan perisai diperoleh dan disahkan dengan pemetaan dos sinar gama. Saiz pancaran neutron telah diubahsuai dengan meletakan

ringkas di alur pancaran radiografi neutron 2 (NUR-2) untuk memuatkan bukaan hujung yang menumpu dengan saiz tabir sintilasi 5 cm x 6 cm pada kamera CCD. Dengan coZ/fnm/or saiz diameter efektif pancaran neutron adalah di

sekitar 7.2 cm daripada 15.8 cm dimana ia bersesuaian untuk memenuhi luas sintilasi. Fluks neutron terma yang melalui pada kedudukan

kamera CCD adalah 2.674x 10^ nemos '. Fluks neutron yang diperoleh adalah dilingkungan tahap yang diterima oleh kamera CCD. Manakala dos sinar gama dengan perisai kamera CCD adalah kurang daripada 30 mGy per jam. Pemetaan dos sinar gama ini menunjukkan perisai adalah efektif dan dapat melindungi komponen elektronik daripada rosak. Hasil keputusan eksperimen-eksperimen ini adalah konsiten dengan hasil analisis imej radiografi secara digital yang dihasilkan menggunakan teknik konvensional.

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LIST OF SYMBOLS

n	-	number of neutron
y	-	gamma
())	-	neutron flux
())o	-	output neutron flux
Ot	-	thermal neutron flux
(j)f	-	fast neutron flux
e	-	exponential
Ed	-	macroscopic neutron cross section
pm	-	micrometer
z	-	depth
X	-	color
f	-	time
kW	-	kiloWatt
MW	-	megaWatt
L	-	length
d	-	diameter
D	-	dimension
D,,,	-	dose rate of gamma ray entering the shield
Do	-	dose rate of gamma ray at the x depth of the shield
	-	linear attenuation coefficient
x	-	thickness of the shield
^	-	build up factor
P	-	beta
keV	-	kilo electronvolt
MeV	-	mega electronvolt
-	-	almost equal

7?	-	reaction rate
A	-	decay constant
Bq	-	Becquerel
m	-	mass
id	-	detector efficiency
fe	-	gamma ray emission frequency
E	-	energy
Ca(E)	-	microscopic neutron absorption cross section
Na	.	Avogadro's number
dB	-	decibel
a	-	average
	-	standard deviation of region
mSv	-	miliSievert
mGy	-	miliGray
sd	-	standard deviation

CHAPTER 1

INTRODUCTION

Digital neutron radiography relatively new imaging technique in Malaysia exploits the penetrating abilities of neutron to study and visualize the interior properties of the object. The basic principle behind the radiography is an image can be produced by the radiation which passes through an object. For imaging purposes, neutrons are detected nowadays mainly using special area detectors, which provide digital images of high sensitivity and spatial resolutions. Previously, X-rays films were used as a conventional neutron radiography technique. Digital neutron radiography is still very much in a development stage and the main goal of this work to optimize parameters for digital neutron radiography at Triga Mark II Research Reactor of Malaysian Nuclear Agency. The optimization was carried out for the Neutron Radiography 2 (NUR-2) facility of the reactor.

1.1 Background Study

Neutrons from strong sources, mainly fission reactors, have been used for many kinds of material investigations by transmission analysis. In Triga Mark II Research Reactor of Malaysian Nuclear Agency (Nuclear Malaysia), the neutron radiography facility known as NUR-2 uses conventional techniques such as direct, transfer and track etch methods. Neutron radiography has been established as a tool in non-destructive testing (NDT) alternatively, and complementary to X- or gamma- rays radiography and other methods. There are many advantages of thermal neutron radiography compared to X-rays, such as sensitive in detection of hydrogen and the penetration of thick objects made of heavy elements such as lead, uranium, bismuth etc. In addition, neutrons are more sensitive in detection of low atomic number materials compared to gamma; it is being used as probe in radiography imaging to study internal structure of bulk materials such as the structure of turbine blade of power plant and internal mechanism of the combustion chamber of a car (Lehmann, 2004).

As neutron imaging has many significant applications in many branches of science and industry such as NDT and material science, thus development of a computerized imaging system for neutron radiography, using digital technique would enhance its performance and utilization. Currently, conventional imaging of neutron radiograph using direct, transfer and track etch techniques is slow and hampers more challenging development work. From literature, it was reported that digital imaging of neutron radiograph using Charge Coupled Device (CCD) based detectors is being carried out at neutron radiography facilities in several countries for various applications. A number of such systems have been developed for bulk material study in two and three dimensional neutron radiography, two phase flow visualization and void fraction measurement inside metallic pipes.

In this thesis, optimization of NUR-2 parameters for digital neutron radiography at Nuclear Malaysia Triga Mark II Research Reactor has been proposed. Some of the prototype systems developed using CCD camera based digital neutron imaging techniques is also described.

The advantages of digital imaging system compared to conventional system include the image produced at a faster rate, image acquisition and display, implementation of image processing, quantitative interpretation and analysis of data. Such digital imaging system will also open up possibility to carry out certain new class of experiments such as dynamic imaging which are quite difficult or impossible to carry out with the conventional neutron radiograph technology. However, this study concentrates on optimization of parameters NUR-2 facility before developing new digital imaging system and applying some of image processing method once the digital image has been obtained.

1.2 History Of Neutron Radiography

Historically, radiography came first in 1895 with the discovery by Roentgen of a radiation which called X-rays. He rapidly realized the technical implications and in the same year took an x-ray 'photograph' of a weld in a zinc plate. The significant of X-rays for the detection of unseen flaws was immediately seen by other workers and the experimental X-radiographs were soon producing in laboratories in Europe and the United States. The discovery of the neutron is credited to Chadwick in 1932, related and hypothesized on the work of Bothe, Becker and Curie and assumed that the penetrating radiation produced by bombarding beryllium with alpha particles was neither positively or negatively charged; neutron.

In 1932, neutron radiography began after discovery of the neutron. In Germany, Kallmann and Khun performed the initial experiments in neutron radiography in the late 1930's (Von der Hardt, 1981). Afterward, in 1935 to 1938, they were used Ra-Be source and a small neutron generator at the research laboratory of the I.G. Farben Aktiengesellschaft to develop methods of photographic detection of neutrons. O. Peter from the Forschungsanstalt der Deutschen Reichspost was able to produce radiographs of different objects by using the much higher intensity of an accelerator neutron source by using these methods. (Mishra, 2005)

The findings of the study by Kallmann and Khun had published several years after the work was finished and reported in several patents conclusively showing the potential of neutron radiography. In 1961, J.P Barton was working in neutron radiography in the Department of Physics at Birmingham University. Harold Watts, Dan Polanski and Harold Berger started communicating and developing this further in United Stated.

In Japan, the research on NR started and a series of domestic symposia on neutron radiography were periodically held at the Research Reactor Institute of Kyoto University since in 1970. In 1984, the Research Committee on Neutron Radiography was organized by Science and Technology Agency of the Japanese Government. In 1979, the Neutron Radiography Working Group (NRWG) was constituted under the auspices of the Commission of the European Communities. The main tasks of NRWG were the coordination of common interest activities in the field of neutron radiography and the promulgation of information and knowledge on NR (Kasoke, 1987).

The first issue of the "International Neutron Radiography Newsletter" (INRNL) appeared in Vol.26, No. 2 of the British Journal of Non-destructive Testing (BJNDT). Later in 1981, the First World Conference on Neutron Radiography was held in San

Diego, California USA. In the conference, it was decided to continue publishing the (INRNL) with J.C. Domanus as the editor (Domanos, 1987). By the year 1989 the international neutron radiography community had expanded to include many Asian countries (Fujine, 1989).

The formalization of this existing worldwide community of scientists into the International Society of Neutron Radiology (ISNR) started in 1992. Following the Fourth World Conference on Neutron Radiography in San Francisco a series of four annual editions of the International NR Newsletters provided through questionnaires for review, discussion and mailed in votes on the proposed ISNR constitution. The constitution was verified in the Fifth World Conference on NR at Berlin in 1996 (Barton, 1987)

Along with the formalization of the NR as a NDT technique, development was also being made to improve the quality of radiographs obtained by improving the detection system. Detection techniques included films with direct and transfer methods, track-etch systems and electronic techniques like scintillator-camera system, neutron image intensifiers and fast framing systems. The CCD and CMOS camera system introduction improved the real-time radiographic techniques. In recent years, photo stimulated luminescence (PSL) has been demonstrated and applied successfully in detection systems which made digital neutron radiography much more convenient.

In the mean time, neutron radiography imaging system is in progress at the organizations and also some works were on the standardization of the technique for non-destructive testing. The sensitivity of the image produced by NUR-2 using ASTM Standards Designation will be studied (ASTM, 1991). A compilation lists 104 established centers for neutron radiography around the world, about 75 of them making use of nuclear reactor sources (Berger, 2004).

1.3 Research Objectives

There are three objectives in this study:

1. To determine the cross section of neutron beam that suits the dimension of the scintillation of CCD Camera, 5 cm x 6 cm.
2. To determine the neutron flux and gamma ray dose to suit the capability of the CCD camera requirement and to protect from damage.
3. To determine the neutron beam composition and digitize radiographic film image to obtain the image configuration for digital neutron radiography system.

1.4 Rational for Research

The rationale of carrying out this research is that neutron radiography had been used as complementary technique of X-ray radiography. However with the advent of digital imaging techniques, the film based techniques have been complimented with digital CCD based imaging technique.

In Malaysia, neutron radiography facility was located at Malaysian Nuclear Agency (Nuclear Malaysia). This existing equipment is apparently conventional style because it requires long irradiation time, need film processing that effect quality of image and this does not practically suits the industrial applications.

In making transition from analogue to digital, several parameters could be optimized before developing new digital neutron radiography. The parameters for digital neutron radiography such as beam size, neutron flux distribution, gamma ray dose and image quality were determined. All these parameters were due to the ability of CCD camera as a detector will be used at same location. The new digital neutron radiography will improve the neutron radiography capabilities for various applications in fundamental research and industrial applications.

1.5 Research Hypothesis

The outlet aperture for the present neutron radiography facility (NUR-2) designed for direct method which is suit to radiographic film size. However, since digital neutron radiography proposed at same location it will require reducing almost 50% from the original size to adequate the dimension of the scintillation screen size of CCD camera. To get a good quality of image, the thermal neutron flux should be measured at several points along the beam axis. Thus, the thermal neutron flux result were confirmed either its suit with the capability of CCD camera requirement. Besides, the thickness estimation of CCD camera shielding was calculated to fabricate and design a new CCD camera shielding as a protection from unnecessary radiation. The gamma ray dose measurement was determined to verify the effectiveness of shielding.

1.6 Research Scopes.

The aims of this research to optimize a several parameters for develop digital neutron radiography in order to obtain a good quality image and protect the CCD camera. This study only covers the used of radial beam port although there were some neutron radiography facilities such as tangential beam port. Besides, the cross section of neutron beam just suits the dimension of CCD camera. There was no comparison of thermal neutron flux and gamma ray dose being done between the conventional technique and the digital neutron radiography because the result obtained with collimator beam plug installed.

1.7 Organization of Thesis

This thesis details the work, results and analysis from the study of optimization of NUR-2 parameters for digital neutron radiography. The introduction describes the neutron radiography broadly and indicates the important of parameters for digital imaging. Following the introduction chapter was literature review on imaging techniques and principle of neutron radiography which was reported in Chapter 2. Further in Chapter 3, research methodologies were discussed. Chapter 4 is presentation of results and discussion of each method. Finally, the conclusion of research and suggestions for other improvements are presented in Chapter 5.

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