THE STUDY OF COLLIMATION EFFECT OF LOW ENERGY X-RAY FOR RADIOGRAPHIC IMAGING

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time. Last but not least, my heartfelt thanks to other family members and friends for continuous encouragements and support.

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ABSTRACT

Radiographic imaging is the preferred method in the medical and industrial field because it does not permanently alter the diagnosed or inspected object's structure, nonintrusive, nor cause permanent damage. The present work aims to provide guidelines to improve radiographic image quality by optimizing X-ray filtration parameters, which do not involve detector replacement or modification to the existing system. The image quality was quantified using the calibrated contrast noise ratio (CNR) of the sample images obtained using a low energy X-ray source of 40 kV at the Malaysian Nuclear Agency. A sample comprising of low and high Z materials was used to represent contrabands in a baggage carrier. CNR of the images is observed by varying X-ray applied current (1 mA - 2 mA) and exposure time (1 s - 100 s). Five collimator slits with different openings (5 mm - 15 mm) were prepared and tested at different speeds (0.40 mm/s - 5.71 mm/s). From observations, X-ray filtration improves image quality at specific optimal settings of 40 kV anode voltage, 0.40 mm/s scanning speed, and 15 mm slit width opening. This finding is specifically for this system. Different system may have different response in terms of slit size, scanning speed, and other radiation parameters. This work serves as a reference for improving radiographic image quality from low to high Xray energies in medical and industrial applications.

ABSTRAK

Pengimejan radiografi adalah kaedah yang digemari dalam bidang perubatan dan perindustrian kerana ia tidak mengubah struktur objek yang didiagnos atau diperiksa secara kekal, tidak bersifat merejah, serta tidak menyebabkan kerosakan kekal. Kajian ini dijalankan untuk memberikan panduan bagi meningkatkan kualiti imej radiografi dengan mengoptimumkan parameter penapisan sinar-X, yang tidak melibatkan penggantian pengesan atau pengubahsuaian pada sistem sedia ada. Kualiti imej yang telah dikuantifikasi menggunakan nisbah kebisingan kontras (CNR) tertentukur sampel imej yang diperolehi menggunakan sumber sinar-X tenaga rendah 40 kV di Agensi Nuklear Malaysia. Sampel yang terdiri daripada bahan Z rendah dan tinggi digunakan untuk mewakili barangan kontraban dalam bagasi penumpang. CNR imej dicerap dengan mengubah arus sinar-X (1 mA - 2 mA) dan masa dedahan (1 s - 100 s). Lima kolimator celah dengan bukaan yang berbeza (5 mm - 15 mm) telah disedia dan diuji pada kelajuan yang berbeza (0.40 mm/s – 5.71 mm/s). Daripada pencerapan, penapisan sinar-X meningkatkan kualiti imej pada tetapan optimum spesifik dengan voltan anod 40 kV, kelajuan pengimbasan 0.40 mm/s, dan bukaan lebar celah 15 mm. Dapatan kajian ini adalah khusus untuk sistem yang digunakan. Sistem yang berbeza akan mempunyai tindak balas yang berbeza dari segi saiz celah, kelajuan imbasan dan parameter radiasi yang lain. Kajian ini berfungsi sebagai rujukan untuk meningkatkan kualiti imej radiografi dari tenaga sinar-X rendah hingga tinggi dalam aplikasi perubatan dan perindustrian.

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LIST OF ABBREVIATIONS

X-ray	-	X-radiation
SNM	-	Special Nuclear Material
MRI	-	Magnetic Resonance Imaging
PET	-	Positron Emission Tomography
SNR	-	Signal Noise Ratio
CNR	-	Contrast Noise Ratio
CT	-	Computed Tomography
MRI	-	Magnetic Resonance Imaging
FOV	-	Field of View
RT	-	Radiographic Testing
LINAC	-	Linear Accelerator
DC	-	Direct Current
DAQ	-	Data Acquisition
PP	-	Pair Production
2D	-	2 Dimensional
3D	-	3 Dimensional
NDT	-	Non-Destructive Testing
NDE	-	Non-Destructive Examination
OD	-	Optical Density
CR	-	Computed Radiography
ROI	-	Region of Interest
FWHM	-	Full Width Half Maximum
RPM	-	Revolution Per Minute
Ave	-	Average
Std	-	Standard Deviation
Cov	-	Coefficient of Variation

ZBV	-	Z-backscatter Van
AS&E	-	American Science and Engineering

LIST OF SYMBOLS

μ	-	Mean
σ	-	Standard deviation
Z	-	Atomic number of an element
S	-	Number of electrons in innermost shell
W	-	Percentage/atomic composition
Z_{eff}	-	Effective nuclear charge

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CHAPTER 1

INTRODUCTION

In this chapter, a brief explanation of the study's background is provided. In addition, the statement of the problem, research objectives, research scope and significance of the study are also discussed.

1.1 Background of Study

Radiography is an imaging technique that uses ionizing and non-ionizing radiation to probe the internal structure of an object. It is one of the most used non-intrusive technique and has vast advantages in many fields especially for medical and industry purposes [1–4]. The rapid technological advanced in medical radiography has improved the diagnosis and treatment of patients where one can access the seriousness of a patient's condition and decide the need for corrective surgery, especially for patients with critical health conditions. This technique is less risky for patients and uses short period of time to diagnose the illness. It is also used to improve cancer detections during preliminary screening that helps to reduce mortality rate.

The radiological procedures using radiography differs according to the patients needs. Photon energy range that are usually used for mammography is around 25 kV [5] whereas general chest X-ray is about 60 - 120 kV and medical CT is around 80 - 140 kV [6, 7]. Computed Tomography (CT) by gamma ray is the most complicated yet advanced imaging technique to visualise the inner parts of the human body from any direction. General X-rays have also been used as a diagnostic tool for a long time ago since they are painless, fast and non-invasive. It is frequently used to diagnose bone and joint-related conditions such as fractures and dislocation at most parts of the body. Another technique that helps in medical diagnosis is nuclear medicine which reveals the internal problems of the body by detecting radioactive materials that were injected into the body. Positron emission tomography (PET) also uses the same technique as nuclear medicine but specifically for detection of cancer cells.

Other techniques are also used in the medical field, which does not involve ionizing radiation but is still considered radiography, such as magnetic resonance imaging (MRI) and ultrasound. MRI produces three dimensional (3D) imaging of soft tissues that are hardly seen when using X-rays. MRI technology uses powerful magnets and radio waves to create pictures of the body. Ultrasound is another technique that is also considered the safest technique to monitor babies during pregnancy [8].

Radiographic imaging in industry uses short X-rays and gamma rays to penetrate various materials. Radiographic testing (RT) in industry consists of a variety of non-invasive inspection techniques to evaluate materials properties, components, or entire process units. A technique that is used to detect, characterize, or measure the presence of corrosion or cracks is often referred as non-destructive technique (NDT) or non-destructive examination (NDE). Petrochemical industries frequently rely on this technique to inspect internal structures of bulk pipes and surfaces that are impossible to detect using the naked eye. RT has many advantages over other NDE techniques because it is highly reproducible and can be used on almost any materials. The collected data can be processed later and stored future for references. The systems are mostly designed to be portable with little surface preparation which allows for in-situ measurements, even at elevated positions [9].

Other industries also utilize radiographic imaging such as security screening at borders and ports all around the world. The growing number of cargo that crosses the borders every single day means that radiographic imaging is crucial to detect smuggling of weapons, drugs, explosives and other contrabands [10, 11]. Smuggling of counterfeited or pirated goods can cause harm to a nation's well-being due to missed taxes that could otherwise be put to service for society [12]. Weapons and drugs smuggling would also raise crime rates in the affected countries. For most systems, the contraband is detected in two ways either by integral absorption of certain materials or by atomic numbers concerned [10]. There are also several new techniques that have been developed and installed in ports to meet the needs of material inspections like transmission mode and back-scattered mode. These modes are considered in security check at ports because the inspection's object usually are bigger compare to in petrochemical inspection industries.

The transmission mode directly injected the beam from a manufactured source in front of a tested object and projected it onto a detector array behind it [13]. In contrast, the back-scattered mode is located at both sources and detectors at one side of the tested object position [14]. Thus the back-scattered detector only detects scattered beams produced by secondary interaction during scanning. NDT or NDE in this study area required an inspection in short time interval without manual opening [15]. Some radiation sources have been considered in industrial imaging to widen the utilization of NDT and NDE techniques.

Several types of radiation sources have been used for industrial imaging nowadays. These include single and dual-energy X-rays, neutron source and photon energy produced by gamma source. Cargo scanning system that uses X-ray energy ranging from 1 - 10 MeV to form shadow radiographic images is widely used over gamma and neutron [3, 10]. Security inspection system are divided into a primary and secondary system. The primary system is firstly used to detect suspicious objects. Then, if any suspicious threats are found, an alarm is given 31 for the inspected cargo to undergo a secondary imaging system for further checks. The secondary system is usually placed after the primary system or integrated into primary system which is operated in a different mode for imaging larger and heavier cargo. The secondary system is usually separated from the primary system to enhance the detection efficiency for both inspection procedure [3]. A new technology for cargo imaging have been recently developed which uses muon energy from the surrounding. This on-going research focuses on detecting special nuclear material (SNM) inside truck cargos [3]. As such, muon imaging is suitable as a secondary inspection system since it can specifically detect the location of SNM in fully loaded cargos. There are also many inventions and studies performed to meet the needs of ports inspection system in order to give reliable and promising material discrimination results for later analysis by custom officer.

For all of the radiographic imaging techniques described, one crucial and common figure of merit is image quality. Image quality is crucial to allow one to obtain as much information as possible from the image. A system that can rapidly produce high-quality images with the minimum procedure during inspection activities is important in this non-destructive testing field. A system that can easily discern between subtle differences in shape, density and material is the most demanded in all ports. Research starting from the late '90s until now is still searching for the ultimate detection in cargo imaging for various aspects including optimizing the source used, system configuration and suitable detectors system [3]. The minimum modification which can help to improve image quality is by using collimators. Collimation system includes pre-collimator (located between source and inspected object) and post collimator (located between inspected object and detectors). A fan beam collimator is widely used at ports for transmission X-ray cargo scanning system [3,10]. This system produces high quality radiographic images but if the X-ray energy is too high, shadows will form and result in blurry and lower quality image. A study by Bendahan shows that better radiographic images can be obtained when a post collimator is added into the transmission cargo scanning system [3]. This work aims to study the effect of various filtration parameters in order to optimize the image quality of and X-ray radiographic imaging. This lab scale study will be performed using a transmission X-ray located at Medical Physics Laboratory, Malaysian Nuclear Agency.

1.2 Problem Statement

Conventional radiographic imaging using X-ray film has been around for more than 100 years. The X-ray film quality has undergone huge development from manual to digital radiography and its optimization was focused specifically for medical and industrial purposes. Improving the hardware of imaging system usually involves huge amount of costs since it requires replacing the detectors. Medical X-ray film system are customized to excellently discriminate image contrast using low and medium dose for patient safety. But in industry for example NDT, the film can only give maximum image quality with 10 to 100 times higher dose needed for optimum exposure.

This research proposed a comprehensive study on how radiographic imaging can be improved using collimators for transmission X-ray radiographic imaging. This research aims to provide guidelines to optimize radiation parameters for radiographic imaging. Additional collimation may minimize scattering and reduce radiation interactions with the detectors component and the scanned object before the detection procedure [16].

The testing sample for lab-scale 40 kV system must include all relevant materials covering in medical and industrial inspection. For the case of medical imaging, the common energy used in diagnosis is within 10 kV to 400 kV depending on the scanned area [17]. To probe human tissue and cancers with common effective nuclear charge, (Z_{eff}) is 5-15, low x-ray energy is enough [18]. This can reduce the internal exposure effect and risk to patient. For the case of industry, the common energy used for inspection is from 160 kV to 6.5 MeV including baggage scanner, cargo inspection and non-destructive testing [10]. Furthermore, in industry the inspection does not involved human at scanning site thus higher energy can be used. Common inspected object in the case of smuggling and airport scanner have material with Z_{eff} about $3 < Z_{eff} < 50$ [10] (i.e: pistol $Z_{eff}=26$). Testing sample consist of four different materials such as paracetamol, fertilizer, razor and coin are fabricated for present work. These materials are chosen based on the effective nuclear charge of about $3.0 < Z_{eff} < 26.8$ that are suitable for low energy x-ray and covers both medical and industrial purpose.

Focal spot is important to reduce the scattering effect when the X-ray interact with the testing sample. Focal spot reduces the geometric un-sharpness that will results in poor signal contrast onto object [19]. For medical purpose, common focal spot use for imaging bone is between 0.8 mm to 1.8 mm [19], while for cargo imaging the focal spot must be < 2.0 mm [10]. Source aperture selection is to make sure full image can be recorded while acting as additional source collimation. Source aperture and focal spot selection is based on the desired irradiation region and minimization of the accumulated radiation dose deposited onto object [19]. Combination of beam source aperture and focal spot lead to certain diffraction limit serves as waveguiding geometry for all x-ray devices. In present Philips X-ray system at Malaysian Nuclear Agency, only two setting of X-ray focal spot are available which are 1.0 mm and 5.5 mm. For the 155 mm x 150 mm sample testing, two suitable source aperture size, which is 4 cm and 7 cm, is a complimentary setup for the available focal spot. The source aperture of 7 cm results in an irradiation region of 21 cm diameter at 100 cm distance, while 4 cm source aperture will result in 16 cm diameter at 100 cm distance. Small focal spots and smaller source aperture are required to irradiate a particular test object of (150 mm x 155 mm) to reduce geometric unsharpness that will result in poor signal contrast onto the object [19]. Both correct combinations of the focal spot and source aperture would also minimize radiation accumulated dose deposited onto objects that are both very significant for medical and industry [19].

Suitable collimator slit width and scanning speed must be determined to irradiate the test object. Suitable collimator slit width need to be choose to reduce the scattering effect when the X-ray interact with the test object. Suitable scanning speed need to be determined to make sure enough irradiation time to record the image of test object. Stationery or moving slit collimator are both convenient to use for scanning of moving or stationery object. Moving slit collimators is proposed in this study to optimized the detectability of signals of stationery object. This type of collimator produces fan beam type X-ray geometry which possessed uniform angular interval during data taking procedure. The slit collimator helps to distinguish an item under a complex background by filtering out the unwanted rays that may build up overlapping noises during signals detection. While scanning speed is to make sure the irradiation time is enough to record the image of test object. Wider collimator slit width will result in slower scanning speed and can confirm the uniform angular interval when data are taken [20]. For present work, five collimator slit width are studied with the size of 5 mm, 8 mm, 10 mm, 12 mm and 15 mm. Five scanning speed are associated with each slit width.

Source collimation effect recently have been studied in many medical and industrial radiography techniques because it can contribute to increase in imaging quality thus, they can apply even lower radiation dose to patient [21, 22].

1.3 Objectives of Study

The objectives of this research are :

- To quantify the test sample image quality obtained from low energy X-ray source using calibrated Contrast Noise Ratio (CNR)
- To determine the effect of source aperture and focal spot for radiographic imaging.
- To determine the effect of a moving collimator slit and scanning speed for radiographic imaging.

1.4 Scope of Study

The present work aims to provide a guidelines to improve the radiographic image quality of X-rays. This work includes the study of CNR analysis using lab-scale 40 kV transmission X-ray system on a sample consist of $2 \leq Z_{eff} \leq 23.6$ by several filtration criterias. At first, a test sample was prepared from combination of organic materials (flour, paracetamol, fertilizer, razor and coin) for the material discrimination purposes. The X-ray system consists of two focal spot settings (1.0 mm and 5.5 mm) undergone installation of external source collimator and moving slit collimator for the optimization of radiographic imaging of the sample. Five collimators with the slit size of 5 mm, 8 mm, 10 mm, 12 mm and 15 mm was prepared for the experiment. The x-ray experiment was done using 40 kV X-ray voltage source with vary anode current of 1.00 mA - 2.00 mA and exposure time from 1 s - 100 s. Quantitative testing is studied to obtain which CNR and SNR method indicates the best image quality contrast as figure of merit for evaluation of radiographic image quality. The outcome of present work will help X-ray imaging system to improve the image quality without need to change to a more sensitive detector.

1.5 Significance of Study

This work may provides guideline for research and development in studying the radiographic imaging as it applies all filtration parameters to improve the imaging quality. Even though the used of 40 kV with 1 mA to 2 mA current range is the limitation of this work due to the presently available system for lab scale study, these settings are commonly used for medical imaging purpose. The pattern observed at 40 kV and combined current pattern can be implemented for higher X-ray energy with more penetration depth. Further discussions using high X-ray energy also included in future remarks.

1.6 Thesis Outline

This thesis is arranged into five chapters. Chapter 1 introduces the background of the work and the statement of the problem. Chapter 2 highlights conventional X-ray radiographic imaging techniques used around the world for specific imaging purposes in medical and industrial field. Quantitative image analysis details also been discussed. In chapter 3, the methodology of the work is discussed in brief which includes experimental setup, material and apparatus used to meet the objectives. Detailed result in chapter 4 consists of several parts of the results achieved. It is also discussed the contrast optimization comparison of samples from several different experimental setup. The detailed result is concluded in chapter 5.

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