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ENHANCING STEEL RADIOGRAPHY TESTING: A NEW X-RAY EXPOSURE CHART WITH PHOSPHORUS-BASED IMAGING PLATES

PENINGKATAN UJIAN RADIOGRAFI KELULI: CARTA DEDAHAN SINAR-X DENGAN PLAT PENGIMEJAN BERASAKAN FOSFOR

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ABSTRACT

An exposure chart serves as a critical tool for correlating exposure time with the strength of the radiation source and the thickness of the material being tested. It aims to ensure consistent image quality across various examinations and imaging systems. Traditionally, exposure charts were designed for X-ray machines that utilized film as the imaging medium. However, with the advent of digital imaging, imaging plates (such as those used in Computed Radiography systems) have replaced films, allowing for the creation of digital images. These digital images can be electronically stored, eliminating the need for physical film storage and streamlining image retrieval processes. While digital imaging has significantly advanced the field, comprehensive exposure charts specifically tailored for phosphor imaging plates in industrial applications are still lacking. This study addresses this gap by creating an exposure chart using a steel step wedge and a white imaging plate (equivalent to D7 film) for the Isovolt Titan E x-ray machine. To calibrate the system, we determine the minimum gray value (GVmin) and energy using a copper step wedge at a focal-detector distance of 100 cm and an energy level of 180 kV. Each step wedge is exposed to varying energy levels and constant current until the desired gray value is achieved. Subsequently, we construct an exposure chart based on steel thickness (measured in millimeters). By comparing the film and developed exposure charts, we evaluate their performance using welded plates. The results demonstrate that an exposure chart can indeed be developed for phosphor imaging plates. Furthermore, the computed radiography system significantly reduces exposure time (by approximately 80%), making it quantitatively comparable to conventional film radiography.

Keywords: exposure chart; phosphor imaging plate; steel

ABSTRAK

Carta pendedahan berfungsi sebagai alat penting untuk menghubungkan masa pendedahan dengan kekuatan sumber radiasi dan ketebalan bahan yang diuji. Ia bertujuan untuk memastikan kualiti imej yang konsisten dalam pelbagai pemeriksaan dan sistem imbasan. Secara amnya, carta pendedahan direka untuk mesin sinar-X yang menggunakan filem sebagai medium pengimejan. Namun, plat imbasan (seperti yang digunakan dalam sistem Radiografi Berkomputer) telah menggantikan filem, membolehkan penghasilan imej digital. Imej digital ini boleh disimpan secara elektronik, tiada keperluan untuk penyimpanan filem fizikal dan menyederhanakan proses pengambilan imej. Walaupun imej digital telah berkembang pesat dalam bidang ini, carta pendedahan yang komprehensif yang khusus untuk plat imbasan fosfor dalam aplikasi industri masih kurang. Kajian ini adalah untuk membangunkan carta pendedahan menggunakan baji jenjang dan plat imbasan putih (setara dengan filem D7) untuk mesin sinar-X Isovolt Titan E. Sistem ini ditentukurkan dengan menentukan nilai kelabu minimum (GV_{min}) dan tenaga menggunakan baji jenjang pada jarak fokus-pengesan 100 cm dan tenaga 180 kV. Setiap baji jenjang keluli dikenakan tahap tenaga yang berbeza dan arus yang tetap sehingga nilai kelabu yang diingini tercapai. Seterusnya, carta pendedahan dibangunkan berdasarkan ketebalan baji jenjang keluli (milimeter). Dengan membandingkan carta pendedahan filem sedia ada dan carta dedahan yang dibangunkan, kami menilai prestasi carta dedahan tersebut menggunakan plat keluli terkimpal. Hasil kajian mendapati bahawa carta pendedahan boleh dibangunkan untuk plat imbasan fosfor. Selain itu, sistem radiografi berkomputer secara ketara mengurangkan masa pendedahan (sekitar 80%), menjadikannya secara kuantitatif sebanding dengan radiografi filem konvensional.

Kata kunci: carta dedahan; plat pengimejan fosfor; keluli

INTRODUCTION

Computed Radiography (CR) has emerged as a powerful tool in Non-Destructive Testing (NDT), revolutionizing how X-ray images are captured. Unlike film-based radiography, CR employs Photostimulable Phosphor (PSP) imaging plates. These flexible plates absorb X-ray energy during exposure, temporarily storing it within their phosphor layer. After exposure, the plates are scanned using a CR reader, which releases the stored energy and converts it into a digital image. The advantages of CR include rapid image acquisition, cost-effectiveness (due to reusable plates), and the ability to adjust image quality during post-processing. Nowadays, NDT practitioners rely on CR for discontinuity detection and weld inspection, contributing to safer and more efficient Radiographic Testing (RT) processes.

A phosphor imaging plate comprises a thin layer of PSP. This phosphor material has the unique property of absorbing X-ray energy during exposure. When the imaging plate is exposed to X- rays, the phosphor grains within the plate become excited, trapping electrons within the lattice structure of the phosphor material. These trapped electrons remain latent until the second round of illumination occurs. During this second stage, the imaging plate is scanned by a laser beam, which stimulates the trapped electrons, causing them to release their stored energy. The released energy is then converted into a digital image, representing the X-ray exposure pattern captured by the imaging plate. Compared to traditional film-based radiography, CR provides immediate digital results requiring chemical development.

The exposure is determined based on the exposure chart. The chart guides the correct settings and techniques for each RT exposure. When setting up testing equipment for inspections, RT personnel refer to exposure charts to ensure repeatable testing processes. RT personnel can optimize image quality and flaw detection by following exposure guidelines specific to the type of material (such as steel), the X-ray equipment, and the source-to-film distance (SFD). Whether inspecting welds, castings, or other critical components, an exposure chart is vital in maintaining the integrity of industrial structures and equipment. Despite the numerous advantages of CR, NDT practitioners often rely on a trial-and-error approach to determine the correct exposure time during radiographic inspection.

This work aims to meet the RT requirements related to image quality or sensitivity. Therefore, our motivation lies in developing an exposure chart that utilizes phosphor imaging plates as a film replacement for inspecting steel welds in industrial applications. The comparison of exposure time based on film and imaging plates for welded plates is also studied.

METHODOLOGY

Equipment

The computed radiography system used in this study is the 16-bit ADC HD-CR 35 NDT model, along with a 650 gain HV V000121 reader. The imaging plate used is white with a 100 µm laser spot size during scanning. The X-ray machine is the Isovolt Titan E model with a voltage range of 5 to 225 kV and a focal spot size of 3.0 mm. The duplex wire used is based on ASTM E2022 (ISO 19232-5), and the copper step wedge is based on ASTM 2446.

Experimental

The Basic Spatial Resolution (SR_b) for the CR system is measured using a duplex wire Image Quality Indicator (IQI) and an X-ray machine with a focal spot-detector distance of 120 cm (Figure 1). Exposure at 90 kV without a filter in front of the X-ray beam is performed vertically and horizontally against the scanning angle until a 50-80% gray value on the duplex wire is achieved. The minimum gray value is determined based on exposure to a copper step wedge with 180 kV X-ray beam energy using a white imaging plate with a focal spot-detector distance of 1.0 meter (Figure 2). A graph of normalized SNR against gray value is plotted, and the minimum gray value for testing class A (SNR~70) is determined. This value is then used as a reference for exposing a steel step wedge with varying step thicknesses at different X-ray beam energies and currents to obtain the correct exposure values. The obtained exposure values are then plotted against the steel thickness for each voltage (beam energy) used at an SNR value of 70 using a white imaging plate. To validate the developed exposure chart, a welded plate specimen is inspected with exposure time based on the developed exposure chart. This exposure time is then compared with the exposure time required by film radiography.

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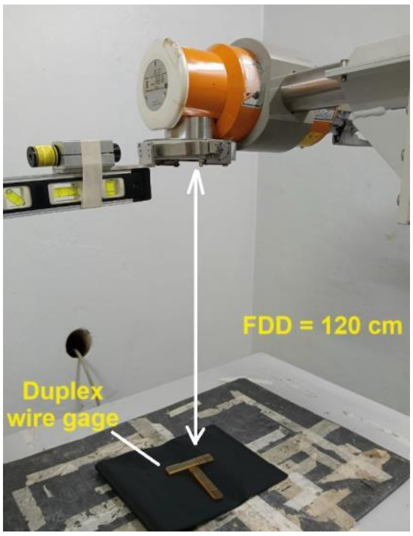

Figure 1. Basic spatial resolution, SRb measurement using phosphor imaging plate

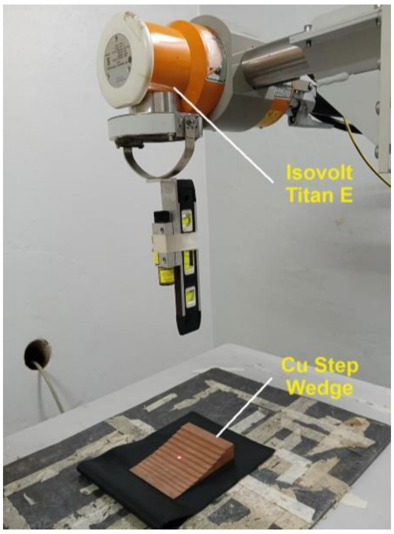

Figure 2. Experimental setup for SNR measurement using copper step wedge

RESULTS & DISCUSSION

Two horizontally and vertically images were analyzed to obtain the SR_b value using iSee! Software. The modulation transfer function (MTF) values were measured against each duplex wire thickness (Figure 3). The basic spatial resolution value at 20% was determined based on the MTF (%) graph against basic spatial resolution (µm) for both duplex wire images (Figure 4). The results showed that the SRb value for the computed radiography system with a white imaging plate was 112 µm.The gray value for each copper step wedge was determined with a region of interest (ROI) of 100 x 200, and a graph of normalized signal-to-noise ratio (SNR) against the gray value was plotted (Figure 5). The graph was found to be polynomial in nature, and the minimum gray value for testing class A (SNR = 70) was 10100 (Figure 6).)

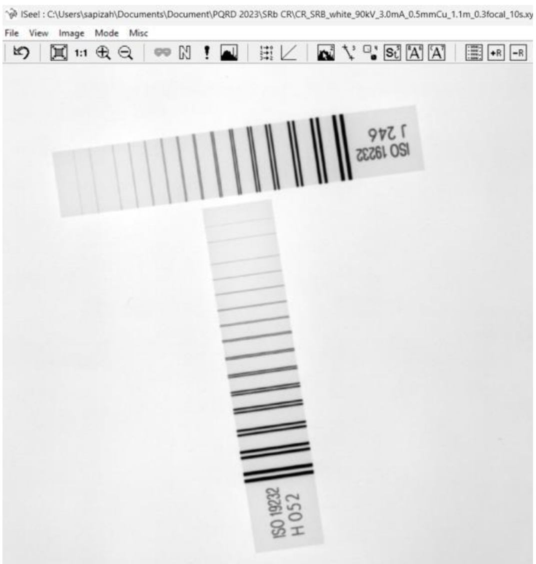

Figure 3. Duplex wire image for horizontal and vertical positions

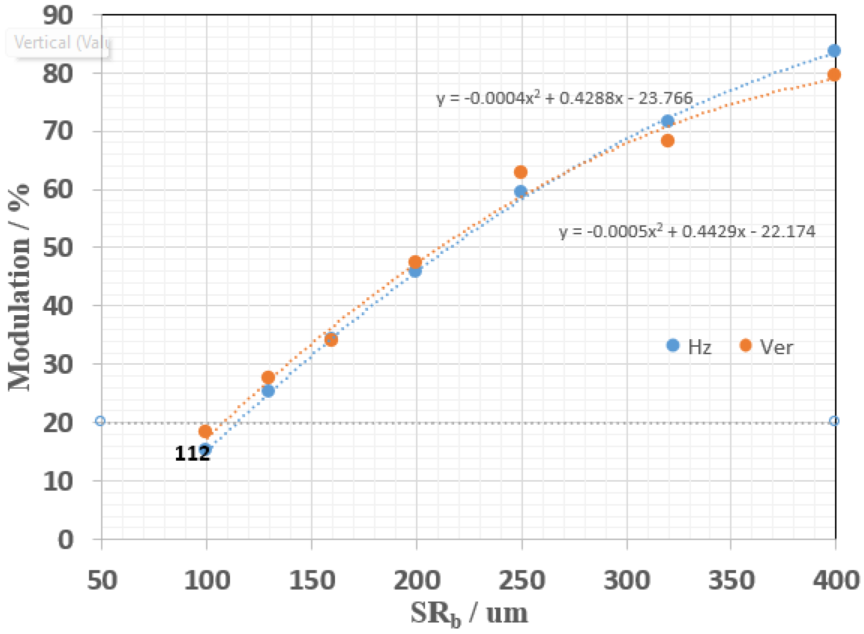

Figure 4. Determination of interpolated basic spatial resolution at 20% modulation depths of neighbored duplex wire elements

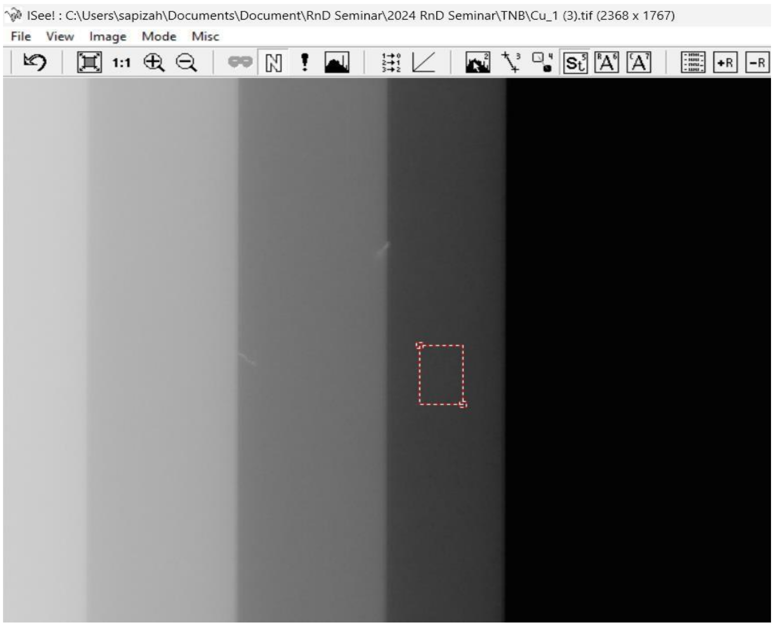

Figure 5. Gray value minimum determination using a copper step wedge.

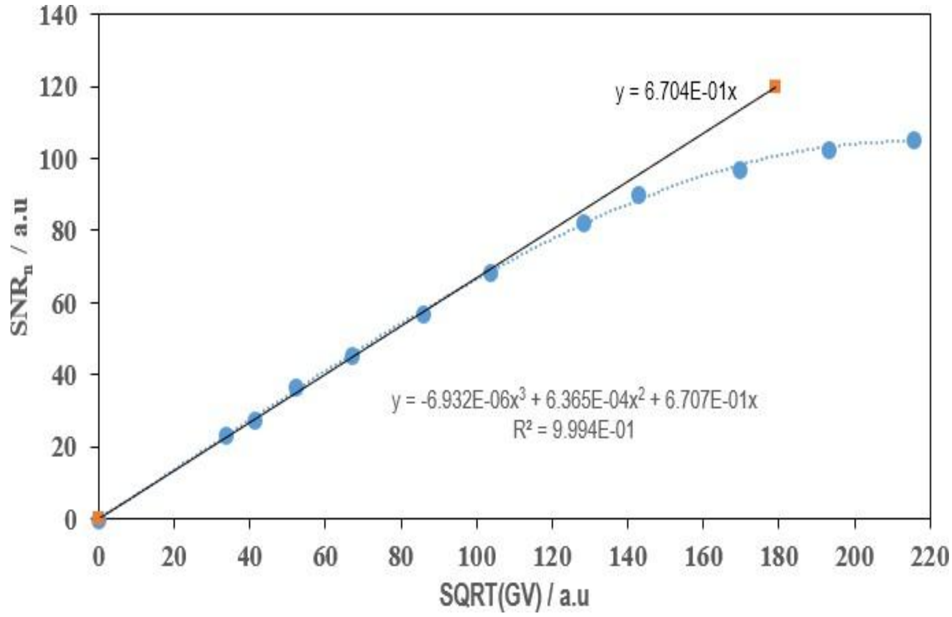

Figure 6. Graph of measured SNR versus the square root of gray value (16-bit system, SRb = 70 μm) for level I testing class determination

Therefore, this value was used as a reference to determine the exposure for each thickness and beam energy. The exposure for each thickness of steel with a specific beam energy was calculated using the following equation:

$$Exposure\ (mA.\mathrm{min}) = Current\ x\ time$$

Based on the minimum gray value obtained (~10100) and a focal spot-detector distance set at 700 mm with an SNR value of approximately 70 for testing class A, an exposure chart was developed (Figure 7a). The chart followed a similar trend to the exposure chart for film (Figure 7b), where thicker steel required higher energy to achieve the specified image sensitivity or quality. However, the exposure latitude for the phosphor imaging plate was lower, down to 0.1 mA.min, compared to film for the same thickness. This is because the imaging plate has a wide dynamic range that allows it to capture a broad spectrum of X-ray intensities, accommodating both very low and very high exposures in a single image. This reduces the risk of underexposure and overexposure, providing more consistent and reliable results. Additionally, the trend showed that at the same thickness of steel, the imaging plate required lower X-ray energy to achieve the required image quality.

a)

b)

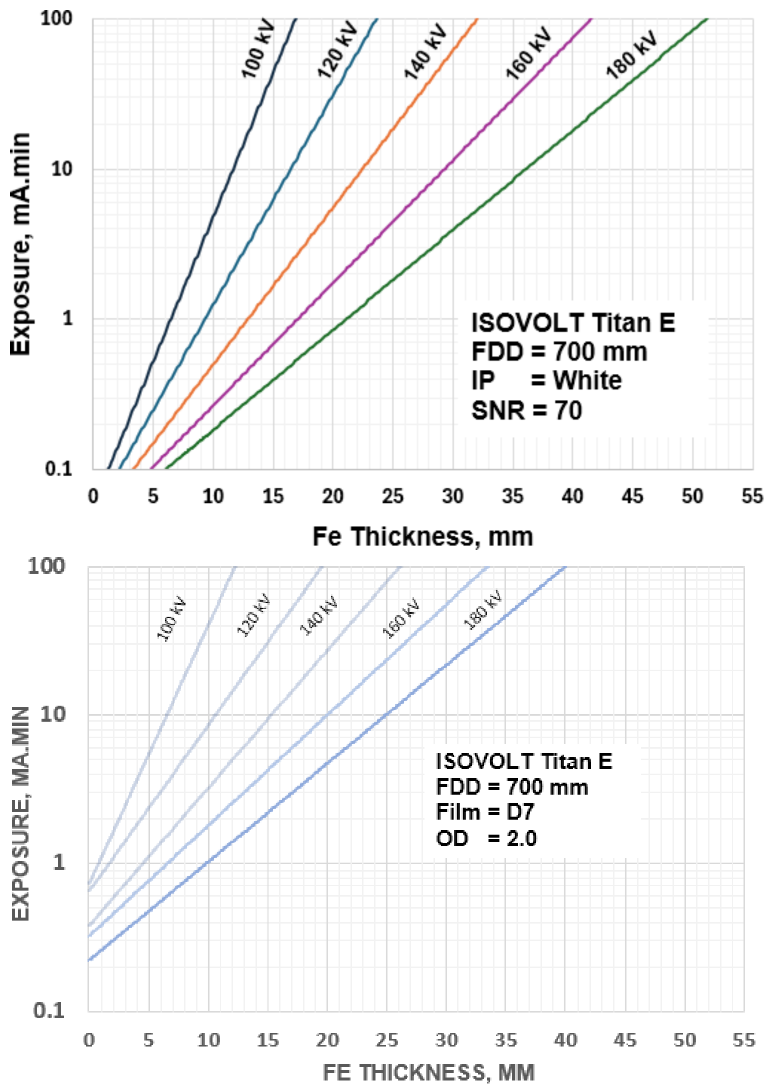

Figure 7. Exposure chart for (a) phosphor imaging plate and (b) film (replotted) for Isovolt Titan X-ray machine.

This chart has been validated by exposed a welded plate which has 10 mm nominal thickness (Figure 8). Radiographic image sensitivity for both developed exposure chart by imaging plate and film have been compared (Table 1). If both radiographic exposure have same radiographic arrangement, it is shown that using imaging plates have been reduced exposure time at about 80% from film exposure time. Furthermore, it was found that the exposure for each beam energy on the welded plate meets the required image quality, specifically SNR_n for testing class A (70) and the single wire that needs to be achieved (Table 1). This indicates that this computed radiography system only requires as low as 10100 a.u gray value to achieve the desired quality, and the developed exposure chart can be used to test structures of steel materials with different thicknesses. However, the exposure time for the imaging plate is shorter compared to film because the phosphor that reacts with X-rays is more sensitive, requiring only a low dose to form an image (Ou et al., 2021). This is because imaging plates are made of photostimulable phosphor, which is more sensitive to X-rays than industrial film and has a wider dynamic range. Therefore, less radiation is needed to produce a required image using an imaging plate, and it can capture a broader range of X-ray intensities in a single exposure. This reduces the need for longer exposure times to achieve the same image quality.

Figure 8. Radiograph image for welded plate using imaging plate for 140 kV beam energy

Table 1 : Compariosn of radigraphic image sensitivity for film and imaging plate for welded plate

10 mm Fe	Required sensitivity	Film	naging Plate
Exposure, mA.min	None	3.2	0.4
IQI (single wire : ISO)	W12	W12	W13
Duplex Wire	D8	None	D9
Signal-Noise Ratio (SNR)	70	None	101

CONCLUSION

In this study, an exposure chart was successfully developed for X-ray machine with phosphor imaging plates used in computed radiography systems. The results indicate that digital image generated from this X-ray machine and computed radiography system can achieve the required for class A testing (ISO17636-2). The developed exposure chart provides a valuable reference for NDT practitioners using computed radiography systems for inspecting steel components. The comparison with conventional film radiography demonstrates a significant reduction in exposure time, highlighting the efficiency and cost-effectiveness of computed radiography. Future work will focus on further optimizing the exposure chart for different materials and testing conditions to enhance the applicability of computed radiography in various NDT applications.

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