IMPACT OF FOCAL SPOT SIZE ON FILM IMAGE QUALITY BY USING YXLON Y.XMB 225 X-RAY SYSTEM: A COMPARATIVE STUDY

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ABSTRACT

Non-destructive testing (NDT) is a technique used to detect flaws in structures, with X-ray machines being a key component. An experiment was conducted to investigate the impact of different focal spot sizes on film quality and contribute to more efficient NDT methods. Results showed that smaller focal spot sizes produced sharper, more detailed images, while larger ones produced slightly softer and less detailed images. The study emphasizes the importance of aligning the choice of focal spot size with specific imaging requirements and material properties.

ABSTRAK

Ujian tanpa musnah (NDT) ialah teknik yang digunakan untuk mengesan kecacatan dalam struktur, dengan mesin sinar-X menjadi komponen utama. Satu eksperimen telah dijalankan untuk menyiasat kesan saiz titik fokus yang berbeza terhadap kualiti filem dan menyumbang kepada kaedah NDT yang lebih cekap. Keputusan menunjukkan bahawa saiz titik fokus yang lebih kecil menghasilkan imej yang lebih tajam, lebih terperinci, manakala yang lebih besar menghasilkan imej yang lebih lembut dan kurang terperinci. Kajian ini menekankan kepentingan menyelaraskan pilihan saiz titik fokus dengan keperluan pengimejan khusus dan sifat bahan.

Keywords: *non-destructive testing, film quality, x-ray imaging*

INTRODUCTION

Non-destructive testing (NDT) is a technique that enables the detection of both internal and exterior (surface) flaws in a structure. They provide information on the functional qualities of the tested object by enabling one to ascertain the state of micro- and macro-structures without tampering with the object's structure [1]. The most widely used nondestructive testing (NDT) methods include radiography testing (RT), thermal/infrared testing (IR), dye penetrant testing (PT), magnetic particle testing (MT), electromagnetic testing (ET), acoustic emission testing (AE), and ultrasonic testing (UT) [2]. Among the various NDT methods, radiographic testing (RT) stands out for its ability to reveal internal structures and detect hidden flaws. Two types of rays, X-rays and gamma rays are often used in RT to produce radiograph that shows the internal flaws or defects, such as cracks, inclusion, porosity and etc. that appeared in the sample to be examined [3]. RT is widely used in the oil and gas, automotive, transport, aerospace, military, manufacturing, offshore, petrochemical, marine and power generation industries due to its high dependability [3,4].

X-ray machines are at the heart of X-ray RT, which typically consist of a control system, high voltage power supply and an X-ray tube [5]. The two electrodes that make up the X-ray tube are sealed inside an evacuated chamber. After being turned on, the tungsten filament cathode can generate energic electrons by means of a thermionic effect when the electric current heats it to 2200°C. X-rays are created when fast-moving electrons collide and interact with the anode material in a vacuum when an accelerating voltage is supplied. Usually, the X-ray tube emits 80% bremsstrahlung X-ray photons [5,6]. The materials needed to be inspected will be penetrated by the X-rays that are released from the tube. Positive film will record the imaging results, creating detailed images of their internal features.

YXLON, a leading manufacturer in the field, has developed a range of advanced X- ray systems renowned for their precision and reliability. The Y.XMB mobile X-ray system by YXLON Copenhagen is engineered to excel in demanding inspection environments such as power plants, aircraft structures, and the petrochemical industry. Its standout feature is mobility; the system is designed for ease of handling and operation in narrow and hard-to- reach areas, thanks to a compact metal ceramic X-ray tube mounted on a flexible high voltage cable supporting lengths up to 20 meters. This flexibility allows it to navigate and perform effectively in challenging conditions. The Y.XMB system is highly versatile, capable of accommodating a broad range of high-quality X-ray tubes, including both directional and panoramic variants with different focal spot sizes. Its modular design facilitates swift adaptation to various inspection tasks simply by switching the X-ray tube, and it seamlessly supports both film and digital imaging. This adaptability ensures that the system can handle a wide spectrum of inspection jobs without disrupting workflow. In terms of performance, the Y.XMB offers impressive technical capabilities, available in 100, 160, and 225 kV variants and operable from 7.5 kV to a maximum of 225 kV. It boasts a high X-ray power of up to 2.25 kW and a broad mA range from 0 to 20 mA, depending on the specific system and tube configuration. These features contribute to reduced exposure times and create a more efficient workflow, giving users a competitive edge in high-performance inspections [7]. Overall, the Y.XMB mobile X-ray system is a robust and adaptable tool designed to deliver exceptional performance in a variety of rigorous applications.

A key factor influencing the quality of radiographic images is the focal spot, the area of the X-ray tube where the electron beam hits the target to produce X-rays. There are two types of X-ray source focal spot, which is actual focal spot and effective focal spot. The area where the high-speed electron beam strikes the metal target is known as the actual focal spot, whereas the area where the actual focal spot of the X-ray tube is projected in a direction perpendicular to the tube axis is known as the effective focal spot [8]. The size of the focal spot is crucial in determining the resolution of the images; a smaller focal spot typically yields sharper images, which is essential for detecting fine details and defects whereas larger focal spot leads to more geometric unsharpness and penumbra in the image. Typically, the effective focal spot of the X-ray tube is calibrated by the manufacturer in accordance with the standards specified by IEC60336, EN12543, or ASTME1165 [8]. In this experiment, the focal spot size calibrated by the manufacturer for YXLON Y.XMB 225 X-ray machine is 0.4 mm and 1.0 mm respectively.

Despite the advancements in X-ray technology and the proven capabilities of YXLON machines, challenges remain in optimizing RT for various applications. The primary objective of this experiment is to investigate how the film quality is affected by the imaging parameters set on the YXLON Y.XMB 225 X-ray machine, particularly focusing on the implications of different focal spot sizes, 0.4 mm and 1.0 mm. By systematically analyzing the radiographic images produced under different conditions, we aim to understand the capabilities and limitations of this specific configuration in detecting various types of defects. By addressing these aspects, we hope to contribute to the ongoing development of more effective and efficient NDT methods.

MATERIALS AND METHOD

Sample preparation

The experiment was held at the bunker of Blok 59, Malaysian Nuclear Agency. Different steel plates with thickness of 14 and 15 mm are prepared. For radiographic identification, we utilized lead letters to mark each sample distinctly, allowing for clear differentiation during analysis. To ensure the accuracy and consistency of the imaging process, we employed an Image Quality Indicator (IQI) according to ASTM standards. For instance, for the steel plate with a thickness of 14 mm, we used a hole-type IQI number 20. This setup allowed us to assess the radiographic quality and ensure that our imaging met the required standards for each thickness.

Film preparation

The film preparation process for X-ray imaging was conducted in a meticulously controlled dark room to prevent exposure to white light, which could fog the film. We began by thoroughly inspecting the cassettes to ensure they were free of any holes or damage that could allow white light to enter and compromise the film's integrity. Next, we examined the lead screens to ensure they were clean and devoid of dust or debris that could scratch or damage the film. Once these checks were complete, we carefully transitioned from white light to red light in the dark room, creating the necessary conditions to handle the film safely. During the loading process, we handled the film only by its edges to avoid introducing any artifacts or fingerprints onto its surface. The film was then placed securely between the lead screens and inserted into the cassette. After positioning the film correctly, we sealed the cassette with masking tape to prevent any light leaks and labeled it clearly for identification. This careful and methodical approach ensured that the film was prepared without any imperfections that could affect the quality of the X-ray images.

Shooting preparation

To set up the X-ray equipment for precise imaging of the welded structure, we began by ensuring the X-ray focal spot was directed downward towards the imaging area. Using a measuring tape, we accurately set the focal-to-film distance (FFD) to 700 mm, as required for this experiment, which is crucial for achieving consistent image quality. We then installed a laser pointer at the focal spot to serve as a visual guide for accurate alignment. Next, we carefully moved the laser pointer to the center position and placed the steel sample beneath it. This step was crucial to ensure that the welded structure of the sample was precisely aligned with the middle part of the focal spot, guaranteeing that the X-ray beam would be accurately targeted during exposure. Once the sample was correctly positioned, we returned the laser pointer to its original position to avoid any interference during the X-ray exposure. This meticulous alignment process was essential to ensure that the welded structure was centered in the focal spot, optimizing the quality and accuracy of the radiographic images.

YXLON Y.XMB 225 X-Ray System

To capture the radiographic image of the steel plate, we first documented the specific exposure parameters, including the voltage (kV), current (mA), and exposure time (sec), tailored to the requirements of this experiment as shown in Table 1.

Table 1 System parameters for image quality deterimination

Thickness	Voltage (kV)	Current (mA)	Exposure time (sec)
14 mm	180	4.4	27
15 mm			34

These settings are crucial as they determine the energy and intensity of the X-ray beam, directly affecting the quality and clarity of the resulting image. With the exposure details set, we then positioned the prepared X-ray film directly below the steel plate, ensuring it was aligned precisely under the X-ray focal spot. The accurate placement of the film is critical to capture the radiographic details of the welded structure within the steel plate. After confirming that all elements were correctly aligned, we activated the X-ray machine. The X-ray beam penetrated the steel plate, transferring varying degrees of radiation to the film based on the material's density and thickness. This differential exposure created a latent image on the film, which represents the internal structure of the steel plate and its weld.

Film analysis

After exposing the X-ray film and capturing the radiographic image, we proceeded to the film processing stage, which took place in a controlled dark room environment to prevent any light exposure that could damage the film. The first step involved washing the film. We dipped the film in a series of chemical baths, starting with a developer solution that brought out the latent image created by the X-ray exposure. This was followed by a stop bath to halt the development process, and then a fixer solution that solidified the image and made it permanent. Finally, the film was thoroughly rinsed in water to remove any residual chemicals. Once the film was fully washed, we carefully dried it to prevent any damage or distortion. The film was hung in a dryer, allowing it to dry completely. Proper drying is essential to avoid streaks or artifacts that could affect the image quality. After the film was dry, we proceeded with a detailed analysis using a densitometer. This device measures the optical density of the film at various points, providing precise data on the film's exposure levels. By comparing these measurements against the required conditions and standards, we could determine if the film met the desired quality criteria. This analysis ensured that the radiographic image captured on the film accurately represented the internal structure of the steel plate and that the exposure parameters were appropriately set. Any deviations from the expected density readings would indicate areas for potential adjustment in the exposure process.

RESULTS AND DISCUSSION

Density

At focal spot of 0.4 mm, the densitometer readings for the 14 mm thick samples were consistent and within the acceptable range of 2 to 4, with densities for Plate A - 7 recorded at 2.10, 2.21, and 2.28, and for Plate A - 8 at 2.05, 2.14, and 2.14. This indicated that both films provided good quality images and accurately represented the internal structure of the steel plates. Similarly, for the 15 mm thick samples, the density readings were slightly higher, reflecting the greater material thickness. Ex2 - 3 recorded densities of 2.79, 2.29, and 2.34, while Ex2 - 4 showed densities of 2.59, 2.39, and 2.34. The results can be seen from Table 2. These readings confirmed that the films effectively captured the details of the thicker steel plates. The analysis revealed that the X-ray films used were capable of producing high-quality images for both the 14 mm and 15 mm steel samples. The films met the required optical density standards, demonstrating that our chosen exposure settings were appropriate for the material properties and desired imaging outcomes. The experiment also highlighted the importance of precise film handling and processing to avoid artifacts and ensure uniform development. Overall, the films performed well, providing clear and detailed radiographic images suitable for industrial applications.

At focal spot of 1.0 mm, the densitometer readings for the 14 mm thick samples, Plate A- F1 were recorded at 1.90, 2.21, and 2.19. Plate A - 2 F1, exposed under similar conditions, yielded density values of 2.14, 2.25, and 2.28. These consistent density readings indicate that both films effectively captured the internal details of the 14 mm thick steel plates, meeting the required standards and confirming their suitability for detailed radiographic analysis. The slight variations in density among the readings can be attributed to minor differences in the exposure or film processing conditions. For 15 mm thick steel plate, Ex2 - 1 F1 produced density readings of 2.22, 2.53, and 2.30, while Ex2 - 2 F1 showed densities of 2.31, 2.34, and 2.30. These higher density values, compared to the 14 mm samples, reflect the greater absorption of X-rays by the thicker steel plates. Despite the increased material thickness, the films successfully captured the necessary details, indicating that the exposure settings were appropriately calibrated for these conditions. The results can be seen from Table 3.

Table 2 Density for sample with different thickness at focal spot = 0.4 mm

Sample	Voltage (kV)	Current (mA)	Time (sec)	density			Thickness (mm)	conclusion
Plate A - 7	180	4.4	27	2.10	2.21	2.28	14	Film accepted
Plate A - 8	180	4.4	27	2.05	2.14	2.14	14	Film accepted
Ex2 - 3	180	4.4	34	2.79	2.29	2.34	15	Film accepted
Ex2 - 4	180	4.4	34	2.59	2.39	2.34	15	Film accepted

Table 3 Density for sample with different thickness at focal spot = 1.0 mm

Sample	Voltage (kV)	Current (mA)	Time (sec)	Density			Thickness (mm)	conclusion
Plate A - 1 F1	180	4.4	27	1.90	2.21	2.19	14	Film accepted
Plate A - 2 F1	180	4.4	27	2.14	2.25	2.28	14	Film accepted
Ex2 - 1 F1	180	4.4	34	2.22	2.53	2.30	15	Film accepted
Ex2 - 2 F1	180	4.4	34	2.31	2.34	2.30	15	Film accepted

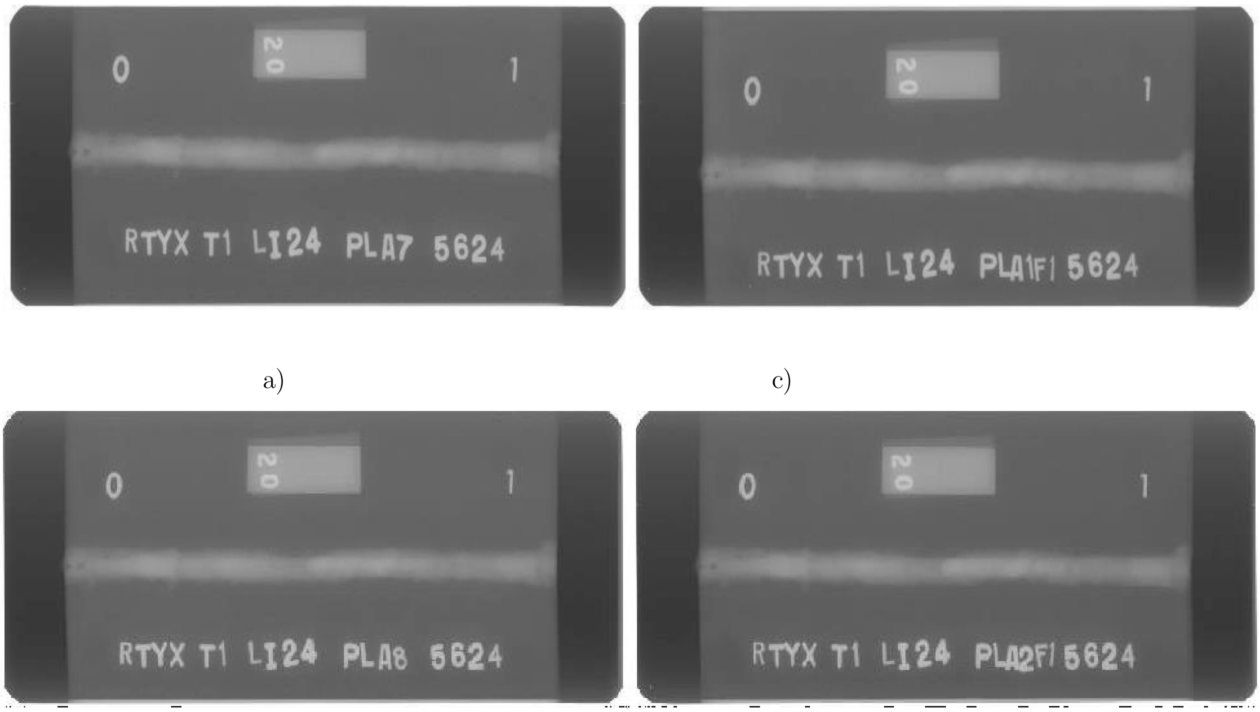
In the first experiment utilizing a focal spot size of 0.4 mm, we observed consistent and acceptable optical densities across both 14 mm and 15 mm steel samples. The films exhibited densities that correlated well with the expected material thickness, indicating effective penetration and imaging capability. Specifically, for the 14 mm samples, the films showed densities ranging from 2.05 to 2.28, while the 15 mm samples displayed slightly higher densities between 2.59 and 2.79. These results suggest that the smaller focal spot size facilitated sufficient X-ray penetration through both thicknesses, capturing detailed internal structures with clarity and precision. Conversely, in the second experiment employing a larger focal spot size of 1.0 mm, we aimed to achieve comparable results in terms of image quality and density variation across similar steel thicknesses. The films exposed under these conditions demonstrated densities ranging from 1.90 to 2.28 for the 14 mm samples, and from 2.22 to 2.53 for the 15 mm samples. Despite the larger focal spot size potentially resulting in less precise spatial resolution, the films still effectively captured the necessary details within the steel plates. The higher densities recorded for the 15 mm samples with the larger focal spot size indicate enhanced X-ray absorption due to increased beam spread, compensating adequately for the greater material thickness. In conclusion, the smaller focal spot size of 0.4 mm provided slightly more uniform density readings and potentially sharper images, particularly beneficial for discerning fine details in thinner materials. Conversely, the larger 1.0 mm focal spot size demonstrated sufficient capability to penetrate and image thicker steel samples, albeit with slightly higher density values reflecting broader beam coverage.

Film quality

For the 14 mm thick steel samples, the optical density readings from the 0.4 mm focal spot size consistently fell within the acceptable range, suggesting that this smaller focal spot size provided sharp, high-resolution images that captured intricate internal details of the steel as shown in Figure 1. The consistent densities observed across both the 14 mm and 15 mm samples further affirmed the films' ability to maintain image clarity and detail even as material thickness increased.

In contrast, the use of a 1.0 mm focal spot size, while still yielding acceptable optical densities, exhibited slight reductions in image sharpness and detail resolution as shown in Figure 2. The larger spot size, though effective in penetrating thicker materials like the 15 mm samples, tended to produce images with softer edges and potentially less precise representation of the steel's internal structures. Despite these differences, the films from both focal spot sizes met the required optical density standards and effectively rendered the steel samples' details, underscoring the versatility of X-ray radiography in adapting to different material properties and thicknesses.

The experiment highlights the delicate balance between achieving sufficient X-ray penetration and maintaining high image resolution. The smaller focal spot size (0.4 mm) demonstrated superior capability in producing detailed, high-quality images, crucial for applications requiring fine structural analysis. Meanwhile, the 1.0 mm focal spot size, although slightly less sharp, still provided robust imaging suitable for thicker materials. These findings emphasize the importance of optimizing focal spot size and exposure parameters to enhance the quality of X-ray images, ensuring that they meet specific industrial requirements for precision and clarity.



a) c)

b) d)

FIGURE 1 Film quality at 0.4 mm focal spot size of a) Plate – A 7 (14 mm thickness), b) Plate – A 8 (14 mm thickness) and at focal spot size 1.0 mm of c) Plate – A1 F1 (14 mm thickness), d) Plate – A2 F2 (14 mm thickness)

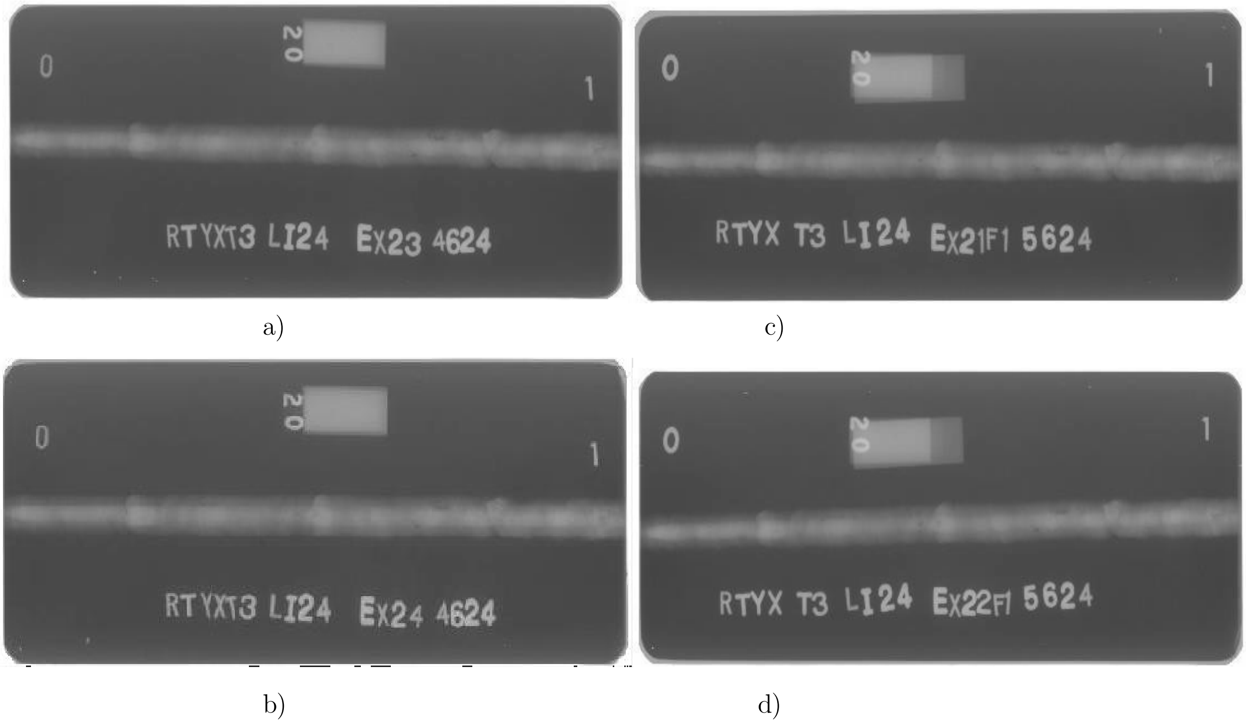


FIGURE 2 Film quality at 0.4 mm focal spot size of a) Plate – EX23 (15 mm thickness), b) Plate – EX24 (15 mm thickness), and at 1.0 mm focal spot size of c) Plate – EX21 F1 (15 mm thickness), d) Plate – EX22 F1 (15 mm thickness)

CONCLUSION

The experiment comparing X-ray imaging quality for steel plates with varying focal spot sizes provided clear insights into the effects of focal spot size on radiographic image detail and clarity. Utilizing a 0.4 mm focal spot size consistently yielded sharper and more detailed images for both 14 mm and 15 mm thick steel samples. This smaller focal spot size significantly enhanced the film's ability to capture fine internal structures, making it highly suitable for applications demanding high-resolution imaging and precise structural analysis. In contrast, the 1.0 mm focal spot size, although effective, produced slightly softer and less detailed images. This larger focal spot size was advantageous for ensuring sufficient X-ray penetration through thicker materials but at the cost of reduced edge sharpness and detail resolution. Both focal spot sizes maintained optical density readings within acceptable standards, indicating that the selected exposure parameters were appropriate for imaging steel samples of these thicknesses. The consistency in density values, particularly for the 0.4 mm focal spot size, highlighted its capability to produce uniform and high-quality images. However, the 1.0 mm focal spot size, while still providing acceptable image quality, showed minor variations in density readings, reflecting its broader spot's influence on the imaging process. The findings suggest that the 0.4 mm focal spot size is particularly advantageous for applications where high detail resolution is crucial, such as in quality control or detailed structural inspections in industrial settings. Conversely, the 1.0 mm focal spot size, with its stronger penetration capability, is better suited for general industrial imaging tasks where extremely fine detail is less critical, but overall clarity and coverage are important. This study underscores the importance of aligning the choice of focal spot size with specific imaging requirements and material properties. For tasks requiring high precision and fine detail, a smaller focal spot size like 0.4 mm is recommended, while for scenarios prioritizing material thickness and penetration depth, a larger focal spot size such as 1.0 mm offers a viable solution. Future research could extend this exploration to include varying focal spot sizes and exposure parameters across a broader range of material thicknesses, aiming to further refine the X-ray imaging process and optimize it for diverse industrial applications. In summary, the focal spot size is a critical factor in X-ray radiography, significantly impacting the clarity and resolution of the resulting images and thus must be carefully selected to achieve desired imaging outcomes.

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