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The Effect of Aluminum and Stainless Steel Thickness on the Absorption of X-Ray Radiation Dose of the Betatron SEA-7 Machine

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Abstract. Radiographic contrast is the difference in brightness in a film image, due to differences in the object's absorption capacity for X-rays, which affects the quality of the radiographic image. Gray value is a substitute for the density of conventional radiographic film which is viewed and evaluated using a computer, to obtain a visual perception of image contrast and noise to measure the quantity of radiation that penetrates a certain area. Acceptance Value Minimum X-ray density refers to ASME Standards. The CRx gray value is 28800 minimum and 64000 maximum [1]. In the use of the Betatron Sea-7 machine, to obtain radiographic contrast, it is necessary to add aluminum (Al) or stainless steel (SS) as a filter layer. The method involves irradiating a steel material target with a thickness of 25 mm with 5 MeV energy with a dose of 35 R, either using or without a layer of Al or SS material, then analyzed using the Rhythm Review Application. The results obtained, for stainless steel, the density received at a thickness of 3 mm, 6 mm, and 9 mm, for aluminum a thickness of 3 mm. With this energy and dosage, stainless steel can be added as a layer in the operation of the Betatron Sea-7 machine to produce a radiographic film quality density that meets ASME standards [2].

INTRODUCTION

Non-destructive testing is a method for analysing with the aim of evaluating the properties of a material or system without damaging the object. One of the non-destructive tests used in industry is radiography[3]. This method uses radioactive materials or ionising radiation generators such as X-ray machines. One type of X-ray machine is the betatron which is capable of accelerating electrons and producing X-rays with energies up to 20 MeV. The results of radiography are images of radiation quality according to standards. The quality of radiographic images is influenced by contrast, which displays light and dark areas clearly [4]. The weakened and smaller contrast causes the radiographic film to be unreadable. To obtain high radiographic contrast, it is necessary to control the scattered radiation, which is some of the radiation that refracts or deviates from the primary radiation, where the energy decreases, but the wavelength is greater, causing the intensity of the X-rays to decrease [5]**.** This scattered radiation is not expected. To reduce it, a material is used as a filter to absorb low-energy radiation. By reducing the scattered radiation, the radiographic contrast will be higher, and the radiographic film can be read clearly.

THEORY

1.1. Radiography

Industrial radiography is a non-destructive testing method used to test a structure or material quality using radioactive materials that emit gamma rays or X-rays generated from X-ray machines. The radiographic image can be produced using chemical liquids or with the assistance of a computer. Radiographic image quality is the ability of the radiographic film to display Image Quality Indicators (IKB) or Image Quality Indicators (IQI) according to the European standard Wire IQI and Plate Hole IQI for US standards [6]. Radiographic image quality includes density, contrast, distortion and sharpness, so action is needed to overcome problems that reduce the quality of radiographic images [7]. Radiographic contrast is the difference in density or level of blackness of radiographic film in the form of differences in the appearance of light and dark film contrast [8].
The equation for radiographic contrast is as in Equation (1) :

$$Maximum\ contrast\ value = Dmax - Dmin \quad (1)$$

With D = Radiographic density value.

The degree of radiographic sharpness is influenced by geometry unsharpness (Ug), screen unsharpness, absorption unsharpness, motion unsharpness, inherent unsharpness, film grainness, and screen mottle. The quality of the radiographic image is determined by measuring the background density and visually observing samples of the test material. Factors that influence the quality of radiographic images include tube current (mA), tube voltage (kV), distance (SFD/OFD), exposition time(s), and filter [9]. The tube current affects the intensity, as in Equation (2):

$$\frac{I_1}{I_2} = \frac{mA_1}{mA_2} \quad (2)$$

with
I_1, I_2 are the X-ray intensities
$mA_1,\ mA_2$ are the X-ray tube currents

X-ray voltage (kV) affects the penetrating power and quality of radiographic images. The greater the kV, the greater the penetrating power, resulting in scatter, increased noise, and reduced radiographic contrast. The square of the x-ray kV energy is proportional to its intensity, as in Equation (3):

$$\frac{I_1}{I_2} = \left(\frac{kV_1}{kV_2}\right)^2 \quad (3)$$

with
kV_1, kV_2 are the X-ray voltage

Source to Film Distance (SFD) and Object to Film Distance (OFD) influence the intensity of X-rays onto the film according to the inverse square law, meaning that the further the distance, the lower the intensity of the rays onto the film. This is written in Equation (4):

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2 \quad (4)$$

with :
d_1, d_2 are SFD/OFD

One of the Non-Destructive Test (NDT) radiography standards is the American Society of Mechanical Engineers (ASME) Section V. This standard regulates radiography methods in the form of casting and welding tests, one of which is the radiographic density which is a support for radiographic contrast. The numerical density of pixels in a radiographic image is shown by the gray value. This value is a substitute for density in radiography using conventional film, which can be viewed and evaluated using a computer. Gray value functions to create visual perception as a function of image contrast and noise, this is used to measure the quantity of radiation that penetrates a certain area. According to the ISO 17636–2 standard, the gray value CR is equivalent to conventional radiography's optical film density value with a value range of 0–64000. Based on ASME section V article 2 standards, the minimum gray value CRx Vision X-ray density value is between 28800 to 64000.

2.2 Acceptability Standards

One of the Non-Destructive Test (NDT) radiography standards is the American Society of Mechanical Engineers (ASME) Section V. This standard regulates radiography methods in the form of casting and welding tests, one of which is the radiographic density which is a support for radiographic contrast. The numerical density of pixels in a radiographic image is shown by the gray value. This value is a substitute for density in radiography using conventional film, which can be viewed and evaluated using a computer. Gray value functions to create visual perception as a function of image contrast and noise, this is used to measure the quantity of radiation that penetrates a certain area. According to the ISO

17636–2 standard, the gray value CR is equivalent to the optical film density value in conventional radiography with a value range of 0–64000. Based on ASME section V article 2 standards, the minimum gray value CRx Vision X-ray density value is between 28800 to 64000 [10].

2. Method

In this study, computed radiography produced radiographic images of steel plates with a thickness of 25 mm. The steel plate was radiographed with X-rays emitted from the Betatron at an energy of 5 MeV and a radiation dose of 35 Roentgen [11]. In the radiation process method, the radiographic filter is placed between the Imaging Plate (IP) and the target radiation material, as in figure 1. This study uses aluminum plate AA-403 and stainless steel SS304 as filters with thicknesses of 3, 6, and 9 mm.
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Figure 1. Layer placement during irradiation

The Imaging Plate is placed in a radiography cassette in the form of black paper, so that light waves can be absorbed and are not exposed to visible light. The radiation on the target is carried out sequentially, the first without a layer, and then a layer is added [12]. After the radiation process is complete, the scanning process is carried out using CRx Vision, by first moving the IP from the radiography cassette into the CR. Analyze radiographic images digitally using Rhythm Review software, by determining both maximum and minimum density values (gray values). The difference in gray value is the radiographic contrast value. The purple color displayed shows the maximum and minimum values of the gray value. This is as in figure 2.

Figure 2. Gray value measurement in Rhythm Review software

4. Results and Discussion

The first data collection was exposure without filter material which is shown in table 1

Table 1. Exposure without filter layer

Exposure	Filter Thickness (mm)	Max density	Min density	Contrast	Average contrast	Description Density
1	No filter	50798	39278	11520	11777	
2	No filter	44439	32404	12035		accepted

The gray value is between 28800–64000 this shows that the radiographic image is acceptable according to the ISO 17636–2 standard.

The second data collection was exposure using aluminum as a filter with a thickness of 3, 6 and 9 mm which is shown in table 2. The radiographic density with layers of 6 mm and 9 mm on the 3rd and 5th exposures are rejected because they are less than 28800. The highest radiographic contrast is 3 mm thick aluminum, with an average value of radiographic contrast of 9309. The lowest contrast is a thickness of 9 mm with an average value of 9177. The percentage increase in radiographic contrast from exposure without and using a 3 mm thick aluminum filter layer is –26.5%. This shows that differences in thickness and type of filter material can affect radiographic contrast.

Table 2. Exposure using aluminum layer

Exposure	Filter Thickness (mm)	Max density	Min density	Contrast	Average contrast	Description Density
1	3	40164	31209	8955	9309	accepted
2	3	40725	31062	9663		accepted
3	6	38572	28512	10060	9211	rejected
4	6	39263	30900	8363		accepted
5	9	37788	27533	10255	9177	rejected
6	9	37952	29852	8100		accepted

The third data collection is exposure using stainless steel as a filter with a thickness of 3, 6, and 9 mm which is shown in table 3.

Table 3. Exposure using Stainless Steel filter layers

Exposure	Filter Thickness (mm)	Max density	Min density	Contrast	Average contrast	Description Density
1	3	56564	37267	19297	19461	Accepted
2	3	57993	38367	19626		Accepted
3	6	49745	31930	17815	18031	Accepted
4	6	49970	31722	18248		Accepted
5	9	48686	31942	16744	15604	Accepted
6	9	45632	31167	14465		Accepted

The radiographic image using Stainless Steel as a filter layer shows an acceptable density range according to the ISO 17636–2 standard. The highest radiographic contrast was in an image with a thickness of 3 mm with an average value of 19461. The lowest contrast was in an image with a thickness of 9 mm, an average value of contrast of 15604. The percentage increase in radiographic contrast from exposure without a layer to exposure with a 3 mm thick Stainless Steel layer was 39.5%. With the highest and lowest average contrast values of 19461 and 15604, it shows that differences in thickness and type of layer material influence radiographic contrast. The radiographic contrast graph of radiation with an energy of 5 MeV without or with aluminum and stainless steel layers can be seen in figure 3.

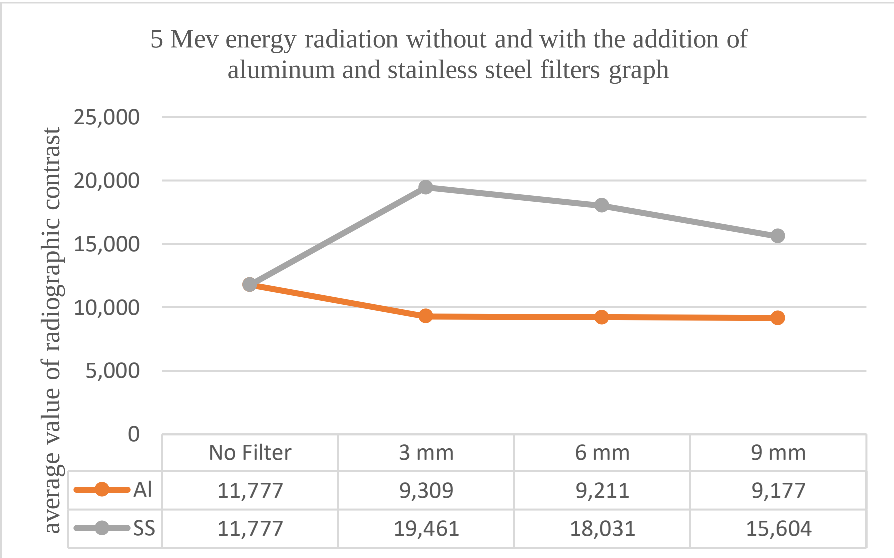

Figure 3. Graph of 5 MeV energy irradiation without and using aluminum and stainless steel filter

The graph shows that radiographic contrast decreases with increasing layer thickness. Stainless Steel has better absorption capabilities than Aluminum, so for radiation with an energy of 5 MeV, it is better to use Stainless Steel material with a thickness of 3 mm to get good radiographic contrast.

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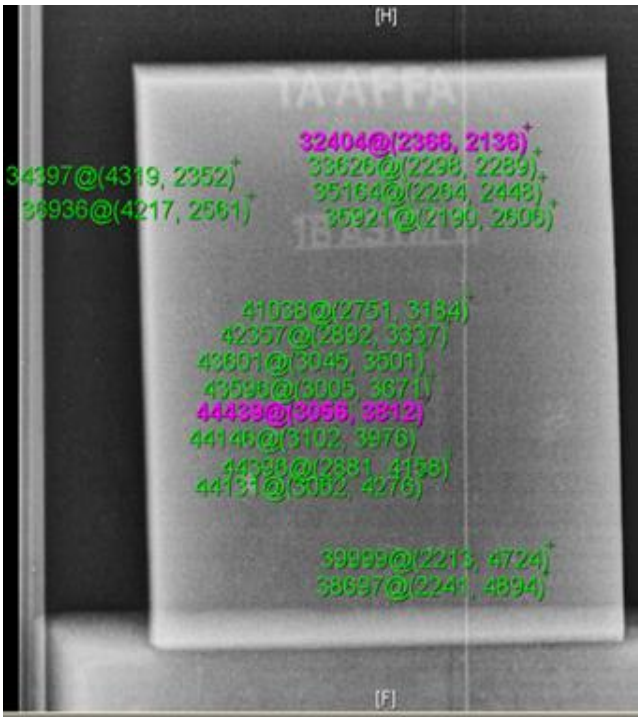

Figure 4. Radiographic image without filter layer, with energy 5 MeV

Comparison of differences in the visualization of radiographic images on 25 mm steel material with 5 MeV energy, using or without Aluminum and Stainless Steel filter layers, as in figure 4, figure 5, and figure 6.

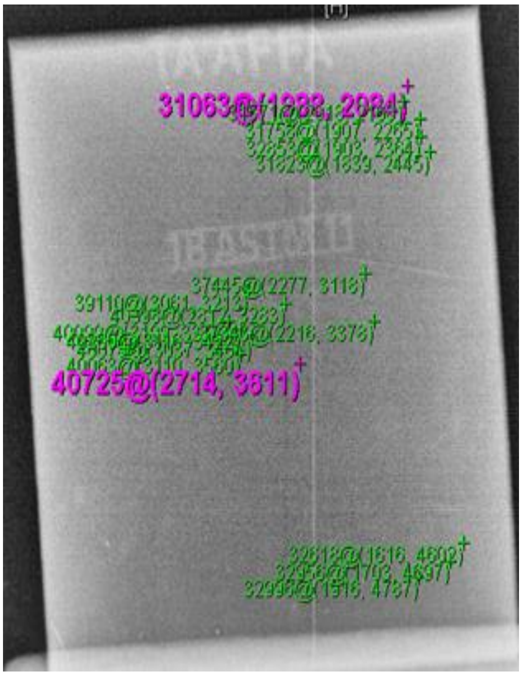

Figure 5. Radiographic image using Aluminum layer

Figure 6. Radiographic images using a Stainless Steel layer

Figure 5 shows the results of a radiographic irradiation image using a 3 mm Al layer. The results are the brightest, and the color is similar, which shows that the contrast is not good. Figure 6 shows the results of a radiographic image using a stainless steel layer, with good contrast results. So, in order to

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produce a radiographic image with an energy dose of 5 MeV 35 R, using the Betatron Sea7, a 3 mm thick layer of stainless steel can be added.

CONCLUSSION

The use of a filter layer affects the contrast of the radiographic image. The thicker the filter layer used, the lower the radiographic contrast obtained. The use of 3 mm stainless steel as a filter provides better image contrast results, with an increase of 39,5% from exposure without a filter.

DISCUSSION

Problems that affect the quality of radiographic images are thickness, type of material used as a filter, and the radiation energy value used. Stainless material with a thickness of 3 mm used as a filter is effective in producing high contrast values in irradiation of steel materials using Betatron SEA 7. For the next stage, the calculation of the radiation dose rate error value is required, to determine the effect of the density value on the radiographic image.

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