PERFORMANCE CHARACTERIZATION OF AMORPHOUS SILICON DIGITAL DETECTOR ARRAYS FOR GAMMA RADIOGRAPHY

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Abstract

This paper reports the performance characteristics of a-Si detectors with Ir-192 gamma source. Imaging performance of the detector system is evaluated using contrast sensitivity over a range of material thickness of steel, signal to noise ratio, dynamic range and linearity. The radiographic sensitivity was observed over a range of thickness of steel using standard image quality indicators. Quantum efficiency of the scintillator material (CsI) for Ir-192 and Co-60 was studied using theoretical models. For Ir-192 source both theoretical models and experiments were performed to find the minimum and maximum thickness limitation for steel using the a-Si detector system. Various configurations of pipe weld with defects such as lack of fusion, penetration, tungsten inclusion and porosities were studied to evaluate the imaging performance.

1. Introduction

Amorphous Silicon (a-Si) Digital Detector Array (DDA) is used in automotive, aerospace, petrochemical and electronic industries as it offers many advantages over conventional film based radiography. The major benefits are faster image acquisition, easier archival and retrieval, image processing, analysis and automated defect recognition. Attempts have been made to use DDAs in petrochemical industries to evaluate integrity of process pipelines. However, accessibility is a major issue incase of clustered pipelines in the field with bulky x-ray radiography sources. This brings in the necessity to use gamma ray sources with a-Si DDA. The authors studied the suitability of these detectors to be used with gamma ray sources.

Over the past decade or so, Digital Radiography (DR) has emerged as a leading technology for recording an x-ray image. It has found wide-ranging applications in automotive, aerospace, petro-chemical and electronic industries, as it offers many advantages over conventional film-based radiography [1]. The most prominent among these are the increase in productivity, ease of archiving and retrieving images, use of powerful image processing tools to qualitatively improve and quantitatively study images, and the high sensitivity, implying a lower x-ray dose to inspect the object. Digital Radiography enhances productivity as it records a ready to process image in a very short time (order of few seconds) and eliminates the need for any chemical processing required as in the case of using a film. Many digital detectors can be used in a real-time format, where a continuous series of images (30 frames per second) can be obtained. This enables online inspection and powerful algorithms can be developed to perform automated defect recognition (ADR), which leads to reduction of inspection costs. Amongst the well-known Digital detector technology of today is the amorphous silicon (a-Si) flat panel detectors [2]. These detectors show good signal-to-noise performance and allow for high contrast imaging with short exposure time. X-ray Image Intensifiers (XIIs) are also used in industries for radiography to obtain digital images. It turns out that XII’s are limited in spatial resolution, dynamic range and exhibit blooming artifacts, when compared to flat panels with respect to their performance.

Amorphous Si (a-Si) flat panels are ideal for projection radiography. These detectors consist of a scintillator layer as an active medium to convert x-ray photons into optical photons, which then fall on a layer of a-Si (passivated with hydrogen) [3]. The a-Si:H semiconductor absorbs the optical photons, which leads to creation of electron-hole pairs in the electronic states of the semiconductor. The a-Si: H layer is pixilated, with each pixel configured as a thin film transistor. When these transistors are biased properly, the charges created by excitation of the semiconductor can be read out as an electric current, which then results in a signal from the pixel. This type of technique that first converts x-ray photons into optical photons and then into electrons is known as indirect conversion. Direct conversion would involve conversion of x-ray photons into electrons directly in the semiconductor. The well-known direct conversion based flat panel uses amorphous Selenium as the active medium.

Amorphous selenium is used because of its excellent x-ray detection properties and a very high spatial resolution that it gives in this class of detectors.

2. Details of flat-panel detector

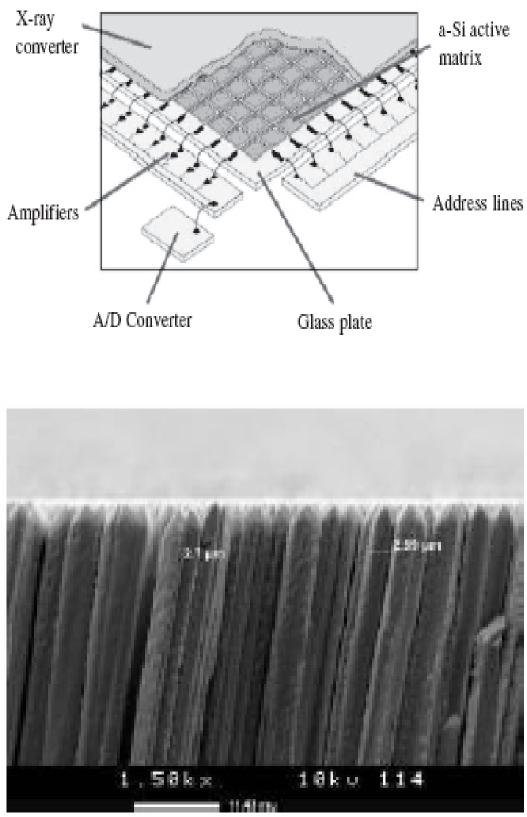

Figure 1*: a) Scintillator assembly b) CsI needle structure*

The flat panel used in the current study is used in real time mode wherein it can acquire up to 30 frames per second. This detector is an indirect conversion type one and the active medium is Cesium Iodide (CsI). The CsI crystals are grown in a needle shaped morphology over the a-Si pixilated panel [4]. The needle shaped morphology of CsI leads to better optical gain as the optical photons generated are channeled onto the pixel. In the figure above (Fig.1), we show a typical configuration for a flat panel and the structure of the scintillator layer. This detector has a pixel size of 200 microns, with 1024X1024 pixels. The response of this detector to an input x-ray signal is linear. Linearity of detector response is an important factor in producing high-quality digital radiographic images. Small amount of pixel-to-pixel variations can exist and these variations have to be compensated to get a smooth, uniform image. This correction is commonly referred to as flat field or normalization, and is typically accomplished by applying a linear transformation on a pixel-by-pixel basis to the raw image data, using offset and gain calibration data.

3. Performance Analysis of flat-panel detector using Ir-192 source

For operating the normalization procedure over a wide range of exposure conditions, the detector's basic response should be linear over the useful dynamic range. Figure 2 shows a plot of the linearity of the detector system. Relative exposure is plotted in the x-axis and the gray value counts obtained from the detector is shown along the y-axis. The detector is strictly linear with the incident dose.

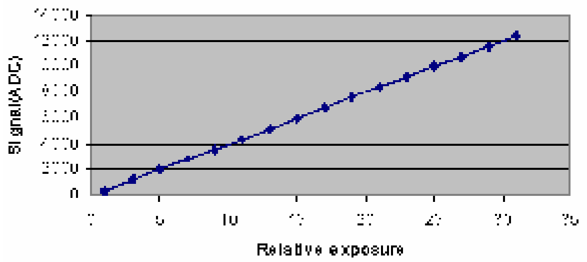

Figure 2*: Linearity of digital detectors*

The performance of this detector for conventional x-ray sources with energies up to 200 KeV is very efficient. The quantum efficiency of these detectors to high-energy photons from a Ir-192 source needs to be studied [5]. For this purpose, we have calculated the quantum interactive efficiency for the scintillator material CsI, used in this detector over a wide range of energies. The quantum interactive efficiency is given by

$$\eta = 1 - \exp(-\mu(E)t) \quad (1)$$

Where μ(E) is the linear attenuation coefficient for CsI as a function of energy and t is the thickness of the scintillator layer.

As indicated in Fig. 3, the quantum efficiency for Co-60 energies of 1.17 and 1.44 MeV are very low. However, we find that even for this low quantum efficiency, we have very good performance from this detector, as will be evident from the discussion of our results.

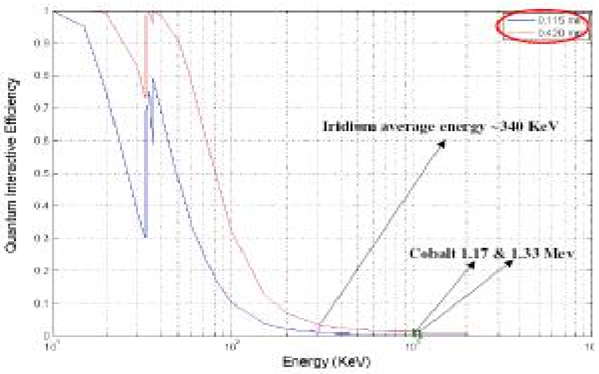

Figure 3*: Quantum Interactive efficiency plot for the digital detector*

In terms of sensitivity of these detectors as compared to x-ray films, which are traditionally used for NDT with isotope sources, we find that the incident dose required to produce an acceptable gray level for this detector is much lower compared to the dose required to produce required optical density (2D). This can be observed in the Fig. 4 below, where we see that films require at least an order of magnitude more dose than this detector to get acceptable level of optical density.

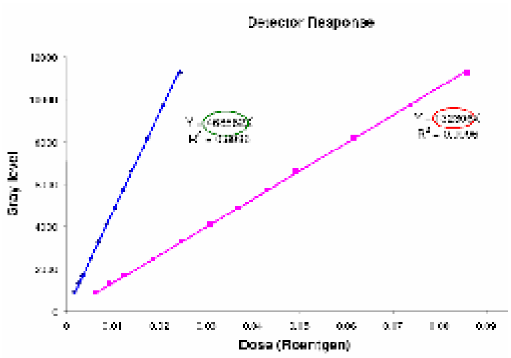

Figure 4*: Detector response for various exposure levels*

Table 1 Exposure required by various films to produce 2D optical density

Type of Film	Dose (Rontgen) for 2D density
D7	1.30
D5	1.95
D4	3.9
D2	11.7

Noise present in the radiographic images is due partly to the fluctuations in the radiation received and the noise in detector electronics. If the noise response of the detector is proportional to the square root of the mean signal level, then the noise is Poisson distributed, which is the characteristic of quantum-limited noise. Electronic noise due to detector is minimal as compared to the quantum noise.

$$Noise\ a\ (Gray\ value)^{1/2} \quad (2)$$

Nature of noise in this detector has been characterized, both with an isotope source and a conventional x-ray source, as shown in Fig. 5. We get a good fit for the data with exponent close to 0.5, and thus interpret that the noise we measure is quantum limited. We observe that the noise level for an isotope source at any gray level is in general, higher than that for an x-ray tube. We can reduce the noise level in the image by averaging over several frames in Digital Radiography.

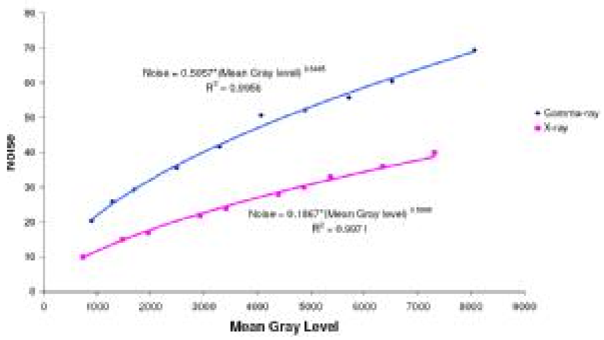

Figure 5*: Noise performance of digital detector for x-ray and isotope sources*

4. Experimental results

4.1.1. IQI Performance

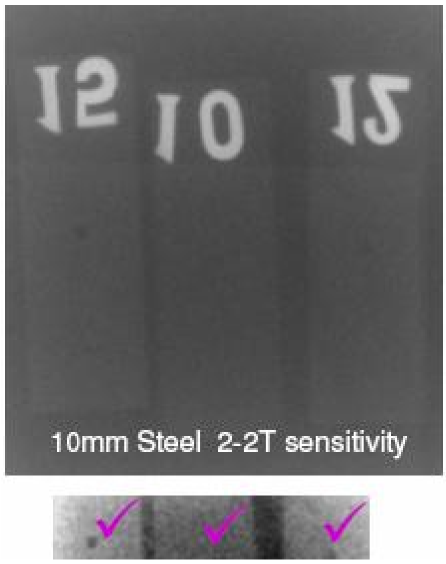

Figure 4*: IQI performance for 10mm steel*

For x-ray radiography, the performance is tested based on the IQI sensitivity that could be achieved. The standards in general recommend a 2-2T sensitivity and the images shown in figures 4 and 5 satisfies the desired sensitivity. With Ir-192 and flat panel detector, 2-2T sensitivity was achieved for 6-30mm thickness range of steel. Table-2 below shows the contrast to noise ratio of the 2-2T holes that were obtained for thickness varying from 6-30mm.

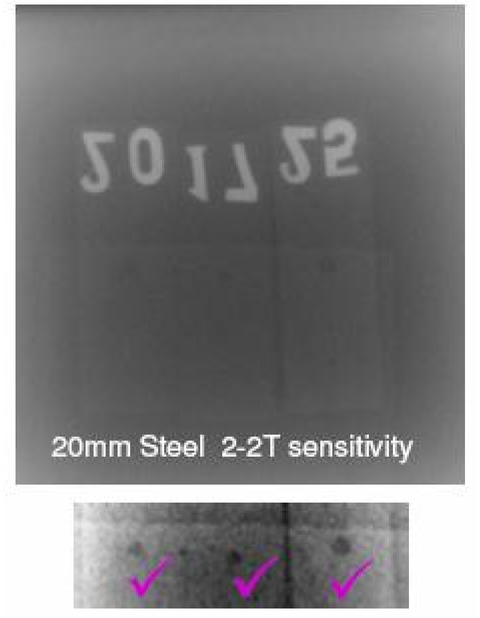

Figure 5: IQI performance for 20mm steel

Table 2 CNR achieved for various thicknesses of steel

Thickness(mm)	CNR	2-2T Sensitivity
6	7.5	Visible
10	6.0	Visible
18	8.2	Visible
20	6.36	Visible
30	5.1	Visible

4.1.2. Thickness Limitation

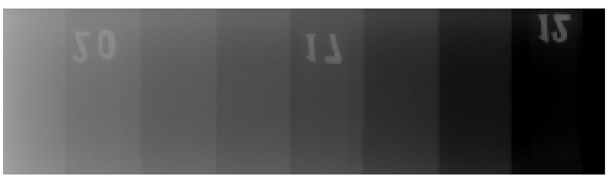

Figure 6*: DR image of a step wedge with thickness ranging from 2-20mm*

A wider dynamic range allows more usable area of the detector response range. For example, in the x-ray film case, the area of the response curve where the optical density is typically between 1.5 and 2.5 limits the dynamic range. Below an optical density of 1.5 the signal is unreliable and above 2.5 it is too intense. On the otherhand, a digital detector using a 12-bit analog to digital converter can have gray value ranging between 0 and 16383. Grayvalues greater than 1000 ensures clear visibility. Hence we get a very large usable portion of the response curve for image formation. Wider dynamic range of the detector system helps covering more variation of depth of the object material (latitude coverage) using a single exposure. Figure 5 shows the image of a step wedge whose thickness is varying from 2mm to 20mm.

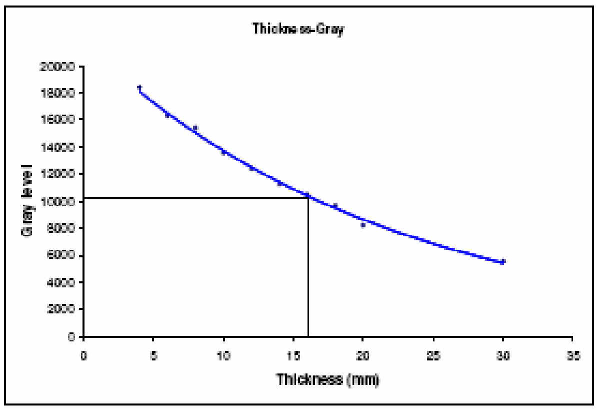

Figure 7*: DR image of a step wedge with thickness ranging from 2-20mm*

Figure 7 shows the graylevel count obtained for thickness range varying from 5mm to 30mm. This clearly shows the wide dynamic range that one can obtain from these detectors.

4.1.3. Sample Images

Sample images of castings and welds obtained using Ir-192 source and DR detector are given below:

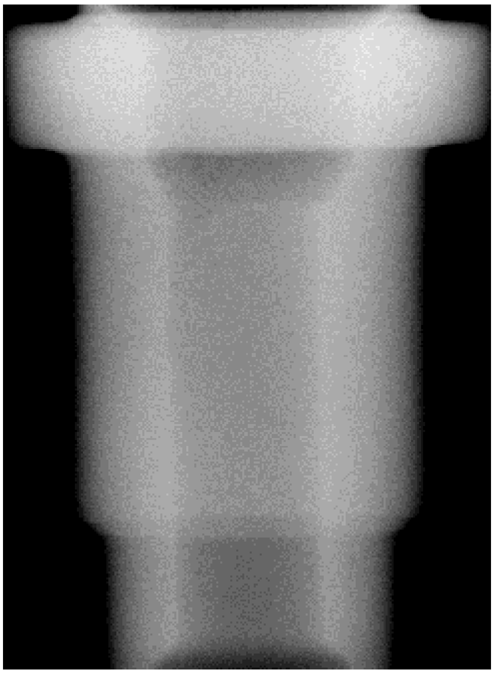

Figure 8*: DR image of a casting*

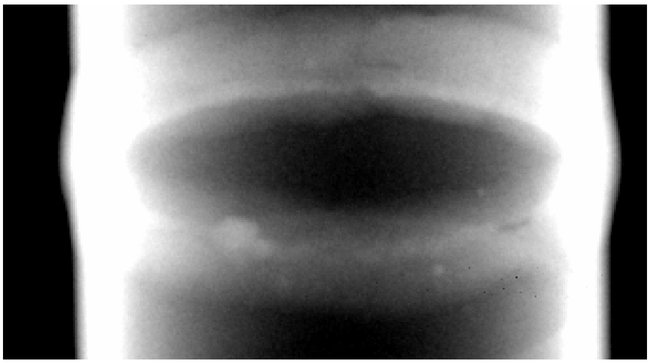

Figure 9*: DR image of a weld defect – Excess penetration and lack of fusion*

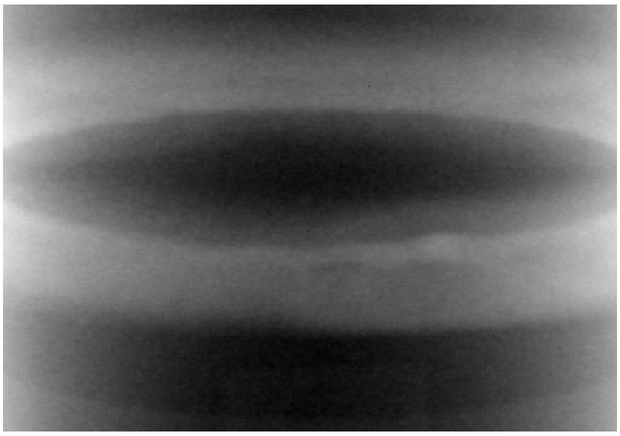

Figure 10*: DR image of a weld defect – Lack of fusion*

5. Conclusion

Gamma radiography offers a portable solution for field inspections. Minimized dose compared to film for the same application can result in increased productivity using gamma radiography. Quantum efficiency and noise behavior of gamma rays for a-Si panel was studied. Performance of Gamma radiography on IQI performance, thickness limitation have been studied

6. References

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