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Computed Radiography with Isotopes- Suitability for Weld Inspection

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Abstract

Computed Radiography (CR) is gaining importance in industries for inspection of welds and castings using x-rays. CR is preferred because of lesser exposure time, no chemical processing, lesser cost of consumables and advantage of a digital image output. It also allows archiving of digital images over many years, which is mandatory as per standards. Hence, Heavy engineering industries, manufactures of high-pressure boilers, Oil & Gas and Energy industries are interested to use Computed Radiography (CR) for testing weld integrity and corrosion monitoring of process pipes. These applications require radiography to be carried out using radioactive isotopes such as Se-75, Ir-192 and Co-60. However, industries do not have enough experience of using CR with isotopes. They require information on choosing the right isotope for different range of thicknesses of a material, in order to meet the ASME Section–V standards. It will also be helpful if there exists data on comparative performance of CR with respect to films on image quality. The authors have done extensive study at various engineering industries and characterized the performance of CR with isotopes. The image quality performances were studied using weld specimens with defects like lack of fusion; penetration, cracks, concavity, and porosities. This paper presents the quantitative metrics used for evaluation of CR specific to standards and comparative study of CR with various film systems.

Keywords: Computed Radiography, Isotopes, Weld inspection

1. Introduction

Currently, film radiography is one of the most versatile NDT method used to check the integrity of welds in Heavy Engineering Industries that manufacture components & structures for Energy and Oil & Gas Industries. For example, in a typical steam generating system, thousands of weld joints of thicknesses ranging from 5 to 200 mm are made using automatic and semi automatic welding systems and inspected by radiography. Since Film Radiography is slow, expensive and hazardous, the industry is looking for other alternative technologies such as computed radiography and digital radiography. As these technologies are new to many of the industries, they are looking for experimental data to find its suitability for shop floor applications. They have questions such as

1.1 Can we use CR with Ir-192, Se-75, Co-60 and MeV range x-rays?
1.2 Can we meet image quality requirements specified by standards such as ASME, API and EN?
1.3 What range of object thickness can be covered?
1.4 How do we set optimum exposure and scan conditions?

2. Computed Radiography

Computed radiography (CR) systems using storage phosphors have continued to evolve in parallel with instant readout digital radiography systems. CR refers to x-ray imaging using imaging plates containing storage phosphors as detection medium. The latent image formed in the imaging plate after radiation exposure is scanned using a laser beam to get digital radiographic image of object exposed. CR is getting popular in non-destructive evaluation of materials due to its large dynamic range, portability and faster digital imaging capability as compared to conventional film based radiography.

3. Benefits of CR over films

Imaging plates are available in multiple sizes in the market to cover wide range of applications. Large-area plates are conveniently produced, and because of this format, images can be acquired quickly. The plates are reusable, have linear response over a wide range of x-ray intensities, and are erased simply by exposure to a uniform stimulating light source to release any residual traps. It can be flexibly wrapped around any object shape and gives sharp images. Imaging plates are portable which enables field radiography. It is cost effective and needs lesser exposure time as compared to film radiography.

Computed radiography has the potential to replace conventional film based radiography for many applications in shop floor and in field radiography. Imaging plates require lesser exposure time as compared to film and also do not involve any chemical processing to acquire images. Formation of digital images offers other advantages of post processing and archival of images. Imaging plates are continuously under development to match image quality of different types of high contrast and high-speed industrial x-ray films. Isotope sources with CR imaging plates can be used for field applications in field and inaccessible areas.

4. Image quality in Computed Radiography

The Radiographic image quality is described by Image unsharpness and Contrast to Noise ratio. The image unsharpness is due to geometrical unsharpness (focal spot blurring) and detector unsharpness. The detector unsharpness is quantified by a metric called Basic Spatial Resolution. This can be measured by duplex wire gauge as per standard: EN-14784-1. The basic spatial resolution is one half of total unsharpness measured by duplex wire. The contrast to noise ratio, which is essential for perceptions of flaws, is given by $CNR/\Delta w = SNR.\ \mu_{eff}$ where Δw is the small thickness change, SNR is signal to noise ratio and μ_{eff} is the effective attenuation coefficient which depends on quality of radiation, materials, thickness of the object, filters, metallic screens and scattered radiation. Hence, the imaging plate is characterized by Normalized signal to noise ratio as a function of incident dose. The Normalized signal to noise ratio is calculated using equation (1) where SR_b is the basic spatial resolution

$$SNR_{normalized} = SNR_{measured} * 88.6 / SR_b \qquad (1)$$

The quality of radiographs is judged by using Image Quality Indicators. There are various types of image quality indicators such as wire, hole and duplex as suggested by ASTM, ASME, EN and other standards.

5. Design of experiments for CR performance evaluation

This paper presents the performance of imaging plates developed by GE Inspection Technologies for industrial inspection. Plate type-I (referred to as IPS) has excellent homogeneity of phosphor and gives higher SNR. Plate-Type-II (referred to as IPC) has higher absorptions efficiency and gives sufficient SNR with a shorter exposure time. Two commercially available CR scanners - namely CR-50P and CR-100 were used for the study. The first phase of experiments were conducted to characterize imaging plate using Normalized SNR and basic spatial resolution. The second phase of experiments was designed to study suitability of Type-I and Type-II Imaging plates for weld inspection of Steel whose thickness range from 10mm to 180 mm using Ir-192, Co-60 and 4 MeV x-rays. The image quality indicators were used as per ASME – Section –V article-2 as most of boiler inspections are carried out as per the ASME standards. The experimental trials were carried out at Bharat Heavy Electricals Limited, Trichy, GB Engineering Limited, Mumbai and GE Inspection Technologies, Berchem. Table 1 shows the various kinds of sources, specimen thicknesses, imaging plates and scanners that were used for the study.

Radiation Quality	Specimen thickness (in mm)	Imaging Plates	Scanners
Ir-192 Co-60 4 MeV x-rays	10,20,30,40 50,60,80,90 100,160 of steel weld specimens	IPS IPC	CR-100 CR-150

Table 1. Design of Experiments

Fig. 1. Experimental setup for computed radiography with Ir-192.

6. Experimental Results

The normalized SNR of Type-1 plate was measured as per EN 14784-1 for Ir-192 spectrum. Duplex wire gauge was used for measuring the basic spatial resolution.
Figure 2 shows the plot of Normalized SNR for IPS plate with Ir-192 as source. SNR increases as the dose increases up to a certain point and becomes almost constant from then on. This is attributed to the structural noise of imaging plates.

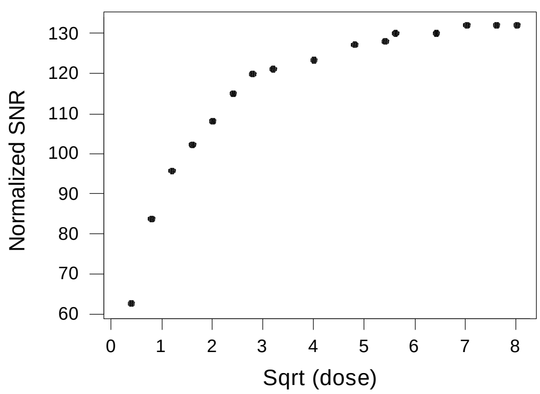

Fig.2. Normalized SNR – IP Type-I – IPS with Ir-192.

The profile of a duplex wire image is as shown in Figure.3. The basic spatial resolution achieved was 130 microns.

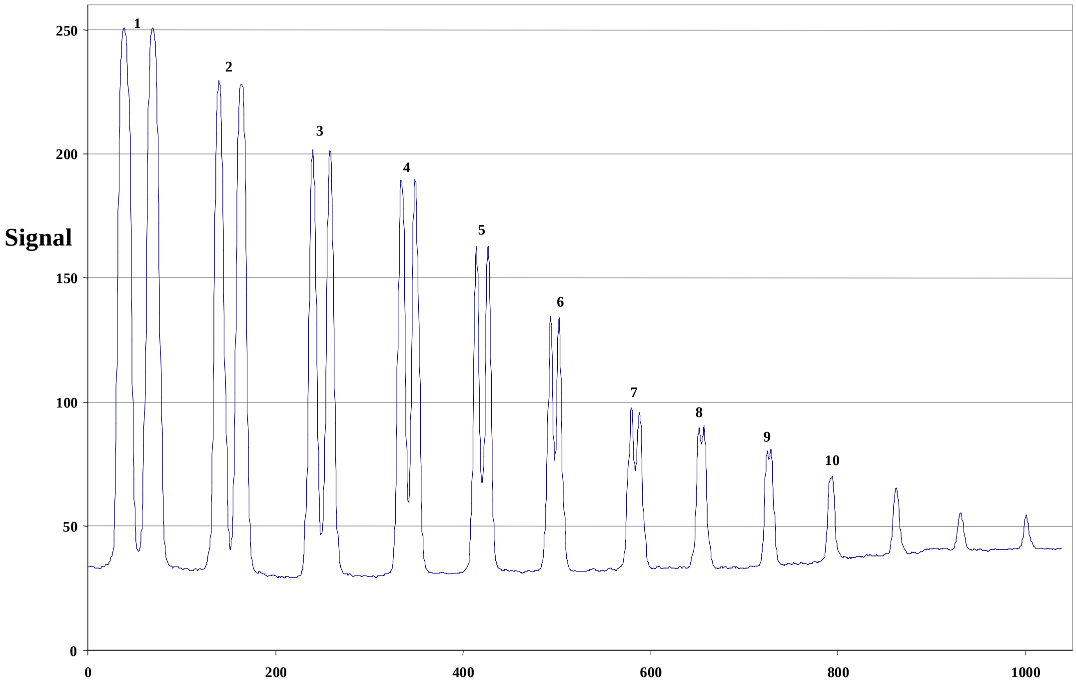

Fig.3. Signal profile across Radiograph of Duplex wire IQI - IPS with Ir-192.

The Image quality indicator sensitivity achieved with IPS plate is tabulated in Table 2.

Fe thickness – mm	Source of Radiation	Wire type IQI Diameter in mm Achieved (required)	Hole type IQI sensitivity achieved
10	Ir-192	0.41 (0.41)	2-4T
20	Ir-192	0.2 (0.41)	2-2T
30	Ir-192	0.25 (0.64)	2-1T
40	Ir-192	NA (0.81)	2-1T
50	Ir-192	NA (0,81)	2-2T
60	Co-60	NA (0.81)	2-2T
80	Co-60	NA (1.27)	2-2T
90	Co-60	1.25 (1.27)	2-2T
110	4 MeV x-ray	1.25 (1.6)	2-2T
160	4 MeV x-ray	1.6 (2.5)	2-2T

Table 2. ASME Section-V IQI sensitivity achieved using IPS with Ir-192.

The image quality indicator sensitivity achieved with IPC plate using Ir-192 is shown in Table 3.

Object thickness	Source of Radiation	Wire type IQI sensitivity-mm Required (Achieved)	Hole type IQI sensitivity
15	Ir-192	0.32 (0.41)	No holes seen
20	Ir-192	0.4(0.51)	2-4T
25	Ir-192	0.4(0.51)	2-2T
30	Ir-192	0.4(0.64)	2-2T

Table 3. ASME Section-V IQI sensitivity achieved using IPC with Ir-192

Experiments were carried out on actual weld specimens with natural defects such as slag, Crack and porosities. Some sample images are shown in Figures 4, 5, and 6.

Fig.4. Slag inclusion in 80 mm thick weld (IPS with Co-60)

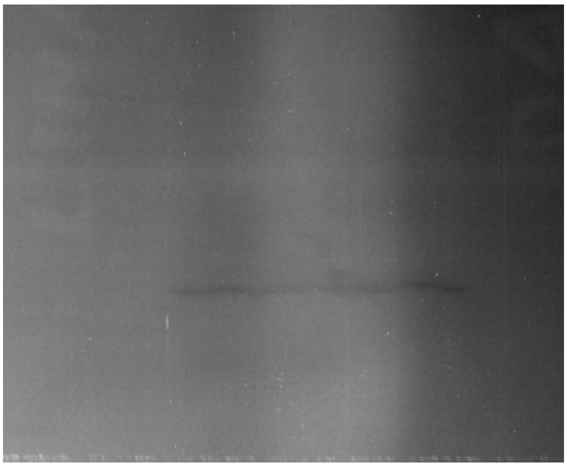

Fig.5. Crack in 160 mm thick weld (IPS with 4 MeV x-rays)

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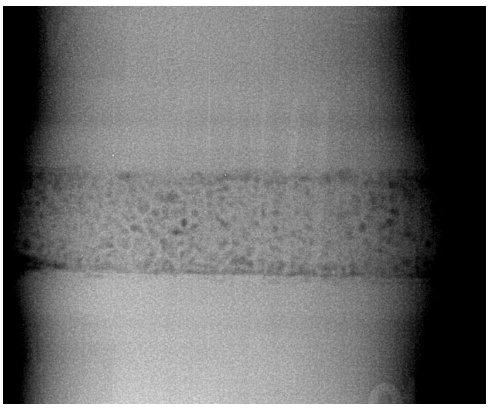

Fig.6. Porosities in 110 mm thick weld (IPS – 4 MeV)

7.Conclusion

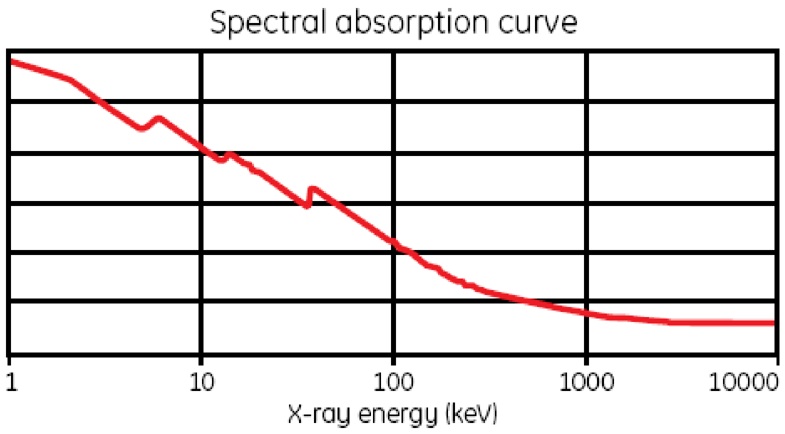

Fig. 7. Spectral absorption plot for phosphor used in IPS plate

The x-ray spectral absorption plot for phosphor used in IPS plate is shown in Figure 7. The absorption of energy is very less for Ir-192 energy as compared to low energy x-rays. However, the normalized SNR saturates at 130 at an exposure of ~ 3R. This limiting SNR corresponds (Limited by structural noise) to IP system class IP-1 as per 14784-1 and IP special as per ASTM E2446-05. It would be interesting to see similar plot for Co-60 and MeV Range of X-rays. We conclude from the IQI sensitivity measurements on actual weld specimens that one could meet ASME Section-V requirements for thickness range of 20 to 160 mm using IPS imaging plate and a suitable source of radiation such as Ir-192, Co-60 and 4 MeV x-rays. However, below 20 mm the reliability of achieving IQI sensitivity with Ir-192 is questionable with the techniques used in this study, suggesting that other x-ray sources such as Se-75 or conventional x-ray tubes might be more appropriate for inspection of thinner objects.

8.References

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