17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Digital radiography and Computed radiography for Enhancing the Quality and Productivity of Weldments in Boiler components

R.J. PARDIKAR
SDGM / NDT, BHEL, Tiruchirappalli,Tamilnadu-620014.
Tel:+91-431-2575237,Fax:+91-431-2520730
E-mail:rjp@bheltry.co.in

Abstract :

This paper presents a detailed performance analysis and comparison of Conventional film radiography, Real Time Radioscopy with Digital Radiography (DR) using Flat Panel and Computed Radiography (CR) using Flexible Phosphor Imaging Plates, in the case of Quality evaluation of weldments in Boiler Components. Conventional Film Radiography is a slow, expensive and hazardous method, particularly for mass production. Eventhough Real Time Radioscopy (RTR) with Image Intensifiers is an alternative to film radiography, conventional RTR systems are compared unfavorably with film radiography in two aspects viz.low contrast sensitivity and limited resolution.

The new digital detector arrays (Flat Panel Detector) have the potential to substitute the X-Ray films as they have considerably higher image quality than the conventional Image Intensifiers. They allow fast acquisition of radiography images with high dynamic range, and high signal to noise ratio.

Computed Radiography is one of the Digital Radiographic Techniques used in lieu of conventional film radiography. The Phosphor Imaging plates (IP) are used as digital detectors in place of photographic X-Ray films.

The experimental results revealed that DR can successfully replace Real Time Radioscopy with X-Rays and Image Intensifier, for Tubular Steel welds up to Single wall thickness 12mm. Using the Flat Panels with 200 microns pixel pitch, it was possible to achieve more than 3 line pairs / mm, at an MTF of over 20%. On the other hand CR has been found to be suitable for Radiography of thick wall welds (Steel thickness up to 140 mm) in Boiler components using Gamma Ray Isotopic Sources like Ir-192, Co-60 and X-Ray sources including Linear Accelerators (up to 6 MeV) with spatial resolution better than 25mico meter, meeting the 2 % Radiographic sensitivity requirements as per ASME code.

Key words: Real Time Radioscopy (RTR), Digital Radiography (DR), Computed Radiography (CR), Weldments in Boiler Components, Quality evaluation

1.Introduction:

Radiography is very well established as an NDT technique, using both film and electronic X-Ray detection systems. However there are still many inspection problems, where existing Radiographic inspection techniques are inadequate in determining the presence of critical defects in steel weldments.

How ever, Film Radiography is a slow and expensive and hazardous method, particularly for mass production where thousands of weld joints are to be inspected everyday. Real Time Radioscopy (RTR) with Image Intensifiers is an alternative to film radiography with considerable saving in running cost and processing time. However conventional RTR systems are compared unfavorably with film based systems of radiography in two aspects viz.low contrast sensitivity and limited resolution. The exponential absorption of X-rays, non-uniform conversion in the image Intensifier, vigneting in the optics will contribute to an uneven illumination. Focal spot size and limited spatial resolution in the X-ray photons will cause noisy image compared with film radiography. In order to meet the sensitivity requirements as per code it is necessary to interface the RTR system with an image processing system for suitably enhancing the images.

The new digital detector arrays (Flat Panel Detector) have the potential to substitute the X-Ray films. Digital Flat Panels are imaging plates, are claimed to provide Radiographic inspection with considerably higher image quality than the conventional Image Intensifiers. They allow fast acquisition of radiography images with high dynamic ranges. These detectors should enable new computer-based applications with new intelligent computer based methods.

However, the overall performance of radiographic systems with digital imaging plates mainly depends upon the quality of these imaging devices, which converts the radiation profile into electronic images. The parameters to the image quality like Linearity, Signal to Noise ratio, Dynamic Range, homogeneity of the images etc, can be influenced by the producer and user of the system.

2. Real Time Radioscopy (RTR) of welds in Tubular Products [1]:

Real time Radioscopy inspection systems using 320-kV X-Ray system and Image Intensifier (in lieu of Film) as the Imaging device has been installed at BHEL Trichy for online inspection of Straight Tube circumferential butt welds in boiler components. The feedback regarding the quality of the weld is given to the welder immediately, and the welding parameters are adjusted accordingly to control the process. The joints are made by MIG welding between tubes having outside diameter ranging from 38 to 76 mm and thickness ranging from 4 to 12mm . The major defects, which occur during this welding process, are Porosity, Gas Hole, Crack, Lack of fusion, Incomplete Penetration, Excess penetration, Burn through etc.

To meet the sensitivity requirements it is required that planar flaws such as crack, lack of fusion, lack of penetration in welds, etc, the criteria of satisfactory image quality should be more than a conventional IQI sensitivity value. An additional measure of image quality is required. This can be provided by the image of a duplex wire IQI, such as the type III A in BS 3971: 1985.

The major limitations of Image Intensifiers are Limited Resolution, Poor Signal –Noise Ratio,Low Contrast,Non linearity,Limited Dynamic Range, etc.However using image processing techniques ,image quality is considerably improved and brought in par with the film radiography. But due to the degradation of Image Intensifiers over a period of time the image quality ,even after image processing does not meet the sensitivity requirements as per code. Hence the image intensifiers have limited useful life and need to be replaced once in 3 to 4 years.

3. Need for Digital Radiography:

Therefore to meet the quality requirement consistently as per the code, BHEL decided to replace the Image Intensifiers with new generation Imaging devices such as Digital Flat Panel detectors .The radiographic process using digital detectors is termed as “Digital Radiography”[2]. It offers several advantages such as defect recognition software, advance analysis tools, shorter exposure times, and good response at lower energies. Since these panels are directly connected to a PC for power and control, this enables the system to be used in Real time mode.

4. Digital Radiography with Flat Panel [3]

Digital Radiography is the State of art technology based on flat panel detector (FPD) systems in which the X-ray image is displayed directly on a computer without intermediate imaging optics or mechanical scanning. The incident X-Rays are converted in to electric charge and then to digital image through a large area panel sensor. Compared to other imaging devices FPD provides high quality digital images even better than film radiography with better signal to noise ratio and dynamic range of 12 to 16 bit [4], which provides high sensitivity for radiographic application. Two distinct technologies are available for flat panel detectors: "indirect conversion" and "direct conversion ". The first design is based on a photo diode matrix, which is read out by thin film transistors (TFT). These components are manufactured of Amorphous Silicon and they are resistant against high-energy radiation. Incoming X-rays first strike a Cesium Iodide scintilator that converts the X-Rays into light. The photo diodes are charged by this light photons. The primary benefit of Cesium Iodide technology is the excellent DQE [5]. The light then passes through a photodiode matrix of amorphous silicon, which is converted into electrical signals, which are amplified and digitized. The light is directed onto the silicon without lateral diffusion, which ensures image sharpness. The digital data is then processed into images via a corresponding gray value table, and is displayed, printed or sent to computer as required. The system offers the additional advantages of image post-processing and archiving.

The second type of flat panels is based on a photo conductor like Amorphous Selenium or Cd-Te on a multi-micro electrode plate, which is read out by TFTs again. This type provides the highest sharpness and has the potential for high-resolution systems, which could compete with NDT-film. Here the photons when impact over the photo conductor like amorphous Selenium, they are directly converted to electronic signals which are amplified and digitized. As there is no scintillator (or Phosphor), lateral spread of light is absent here. This is an important difference between direct and indirect construction. A-Se has higher work function and hence less number of charge pairs are produced for a given energy; but it directly receives x-rays and hence overall conversion efficiency is better than indirect type. This compensates to an extent for lesser charge pairs [6]. In the case of Real Time radioscopy examination of welds it is essential to have a continuous series of images (30 frames per second), to enable online inspection with Automatic Defect Recognition. [7]

5. Performance Comparison of Image Intensifier with Flat Panel Experimental results

In order to make the decision with regard to the replacement of Image Intensifier with Digital Flat Panel for RTR of tubular welds, a series of experiments were carried out to assess the performance characteristics of the Digital Flat Panel and Image Intensifier and their comparison. A scrupulous account of all the tests done on both Image Intensifier and Digital Flat Panels is given in the following sections.

A variety of detailed performance characterization measurements have been performed under a set of typical Industrial Radiography conditions. These include spatial resolution (MTF), Contrast Sensitivity, Linearity, and Signal–Noise Ratio. Based on these the performance of the detectors can be compared.

5.1. Resolution

The Modulation Transfer Function (MTF) test results of Flat Panels are compared with that of Image Intensifiers. The test results reveal that the Nyquist frequency of the Image Intensifier is 3.5 lp/mm, and for imaging small features at 3.5 lp /mm, the MTF is 20%. For the Flat Panels, the Nyquist frequency is 5.0 lp /mm. The resulting MTF indicates excellent resolution for imaging of small features, with significant MTF(over 20%) at 5.0 lp /mm, which makes the spatial resolution superior to Image Intensifier.

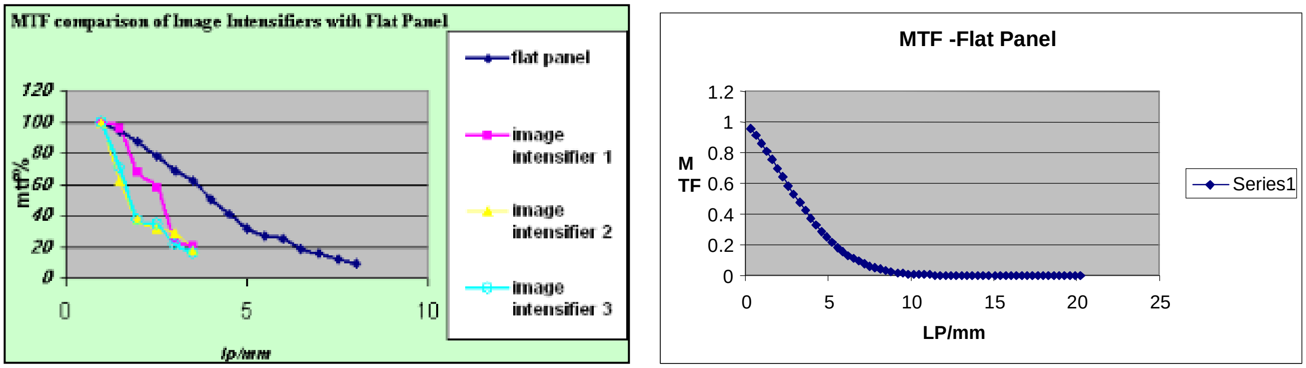

Fig. (1). MTF comparison between flat panel and Image Intensifiers

5.2.Linearity

Linearity [3] of detector response is a key factor in producing high-quality digital radiographic images. In order for the normalization procedure to work over a wide range of exposure conditions, the detector's basic response needs to be extremely linear over the detector's useful dynamic range. Linearity is characterized by illuminating the detector with an industrial X-ray source. A series of images are acquired at each dose level, and the mean signal (which is characterized by the mean Gray level of the image) is calculated over a small region in the center of the detector. The images are collected at a source-detector distance of 70 cm, using a 320kV X-Ray system. The operating voltage is maintained at 45 kV. The variation of the signal value with increasing the dosage value is plotted.

By using the results of the linearity test conducted on Individual detectors, the comparison is obtained here. The test results show that, the flat panels show linear behavior over a wide range of exposure conditions, where as Image Intensifier is nonlinear.

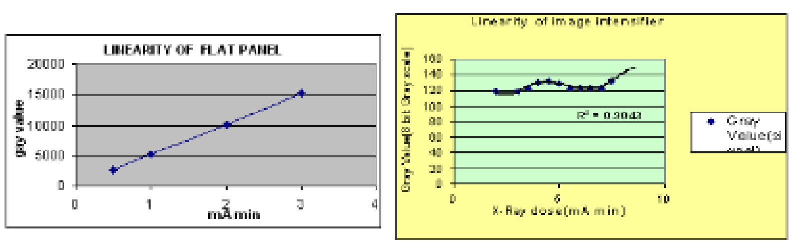

Fig.(2).Linearity Comparison between Flat Panel and Image Intensifier

5.3.Contrast Sensitivity

The measurement of contrast sensitivity (CS)of the Flat Panel and Image Intensifier is carried out by using three step wedges, which are having thickness 5mm, 10mm and 20mm respectively. In the experiment conducted, in order to have better accuracy of the test results, the CS value for each step in comparison with base thickness was taken and the mean value was taken as the Contrast Sensitivity of the particular Step wedge. The procedure is repeated for each step wedge at dosage values (mA minutes) 2,2.5,3 and 3.5 respectively. The values of contrast sensitivity obtained as a result of these calculations are given below. The given below comparison shows that in the case of Flat Panels the Contrast Sensitivity is better.

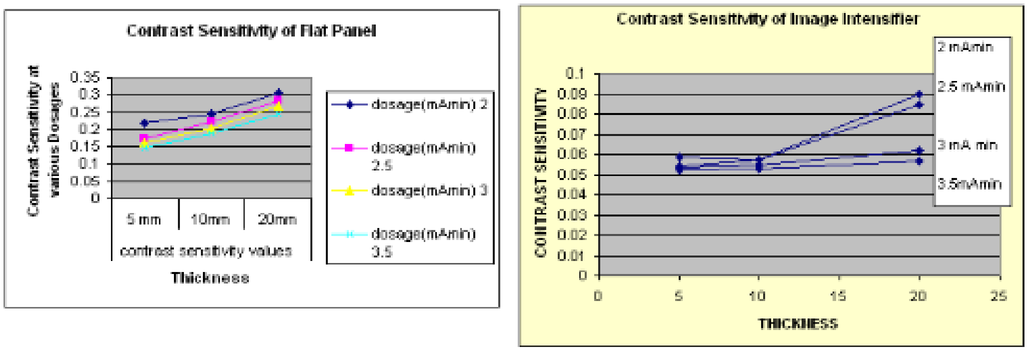

Fig. (3). Contrast Sensitivity Comparison between Image Intensifiers and Flat Panels

5.4.Signal to Noise Ratio (SNR)

The SNR experiments were conducted in the case of Flat Panel and Image Intensifier by using the contrast sensitivity gauges and exposing, at different X-Ray dosage level conditions. The images of the step wedge were captured at different mA minute values of the X-Ray equipment keeping the voltage fixed. Three step wedges (thickness 5mm, 10mm and 20 mm respectively) were used for conducting the test. Each of these was exposed to X-Ray radiation at dose values 2, 2.5,3 and 3.5 mA min conditions. The signal gray value was measured from each of these images. Also the standard deviation in these images, which is the measure of noise were noted. For comparison of detectors in terms of signal to noise variation, we use a parameter called normalized SNR or SNR_{norm} ,which is given by $\frac{SNR \times 88.6}{BSR}$ Where ,BSR is Basic Spatial Resolution of the Detector.

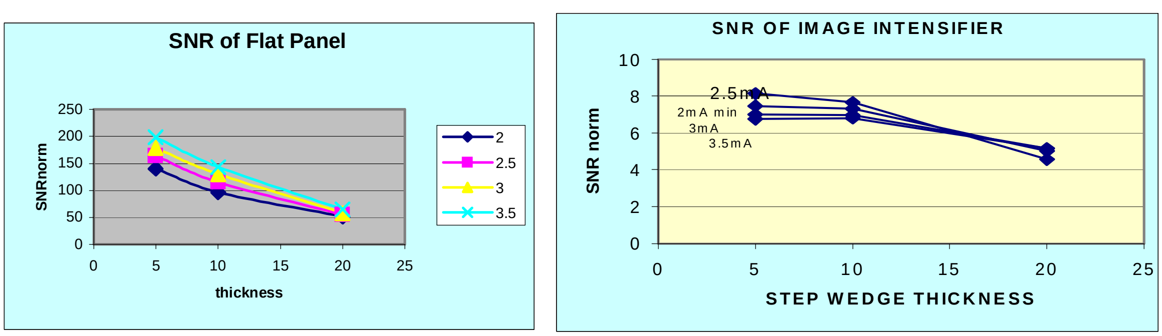

Fig. (4). SNR comparison between Digital Flat Panel and Image Intensifier.

6. Computed Radiography (CR) [8]

Computed Radiography is one of the Digital Radiographic Techniques used in lieu of conventional film radiography. The Phosphor Imaging plates (IP) are used as digital detectors in place of photographic X-Ray films. These detectors enable new computer based applications with intelligent computer based methods. They can substitute film applications with several advantages like Image Enhancement, Automated Defect Recognition, shorter exposure times (70% of film), greater Linearity and Range, sharing information, Digital Archiving and Reporting. The CR also provides considerable saving in cost of consumables (Film) and totally eliminates hazardous chemical processing of films. The High Definition Computed Radiography systems (HD-CR) can produce spatial resolution better than 25mico meter, meeting the Radiographic sensitivity requirements as per international codes.

The Imaging Plate is a Flexible Polymer support coated with sensitive layer (BaFBr doped with Eu^{2+}), used in much the same way as X-Ray film and wrapped around the job for exposure to ionizing radiation (X-Ray / Gamma Ray) during Radiographic Testing. The latent invisible image is created by Photo Stimulated Luminescence process, when the IP is exposed to ionizing radiation .The conversion of latent image to digital image is obtained by scanning of IP by LASER, during which the release of electrons emit energy in the form of blue light that is detected by a Photo multiplier tube and then converted to a digital image. The amount of blue light is linear measure of Radiographic Density at this point. The typical pixel pitch of such scanner is 50 to 150 micrometer. A LASER beam with extremely fine resolution of 12.5-micrometer spot size, together with highly efficient light bunching system can attain 20 lp/mm of resolution, revealing extremely small defects.

6.1.Computed Radiography of thick wall Boiler components

In order to meet the code of construction (ASME, section I), and the Indian Boiler regulations at present 100% radiography is carried out on butt welds of Boiler pressure parts such as Headers, Pipes, Drums etc. Since Radiography is time consuming, hazardous and expensive, BHEL has decided to go in for Computed Radiography of these welds. Initially it is proposed to use the computed radiography system for evaluation of welds of thickness ranging from 10-70 mm using X-Ray source up to 400 kV and Ir-192 source. However the feasibility study for assessing the performance of Computed Radiography has been carried out up to 140mm using the isotopic sources like Co-60 and Linear Accelerator. The experimental study was carried out to evaluate the quality of radiographs achieved with imaging plates (GE IT Imaging plates, IPC-II-High speed, and IPS-III High Contrast) and Laser processing using scanner GE IT-CR 100, and comparison was made with the performance of Agfa D7 and D4 films. Both ASTM strip hole IQI and wire type IQI were used for assessing the contrast sensitivity and duplex wire IQI as per EN 462 for the spatial resolution. The selection of IQI was done based on the thickness of the job. The thickness of the Image Intensifying screens and the exposure time to achieve the required optical density and sensitivity for the specific Phosphor imaging plates, were arrived on trial and error basis as there are no exposure charts available for Imaging plates.

6.2.Experimental results

Comparative Penetrameter sensitivity achieved with Phosphor Imaging plates and X-Ray films for weldments in Steel thickness ranging from 30mm to 160mm,using various radiation sources.

Table.1. Hole type IQI Sensitivity with Ir-192

Steel weld thickness,mm Relative exposure w.r.t Agfa D7	High speed IP (0.25)	High contrast IP	Agfa D 7	Agfa D 4
30	30-1T	30-1T	30-1T	30-1T
40	35-2T	35-1T	35-2T	35-1T
50	35-2T	35-1T	35-4T	35-2T

Table.2. Hole type IQI sensitivity with Co-60			
Steel weld thickness, mm Relative exposure w.r.t Agfa D7	High Contrast IP	Agfa D 7	Agfa D 4
40	35-1T	35-2T	35-1T
60	40-2T	-	40-2T
80	50-2T	50-2T	50-2T
90	50-2T	50-2T	50-1T
110	-	50-2T	50-1T

Table.3. Wire type IQI Sensitivity with Co-60				
Steel weld thickness,mm Relative exposure w.r.t Agfa D7	Required wire dia in mm	High contrast IP	Agfa D 7	Agfa D 4
80	1.27	-	0.63	0.6
90	1.27	0.8	1.25	0.8
110	1.6	1.25	1.25	1.25

Table.4. Hole type IQI Sensitivity with 4 MeV Linac			
Steel weld thickness,mm Relative exposure w.r.t Agfa D7	High contrast IP	Agfa D 7	Agfa D 4
80	50-2T	50-2T	50-1T
90	50-2T	50-1T	50-1T
110	50-2T	50-2T	50-1T
160	80-2T	80-1T	80-1T

Table.5. Wire type IQI Sensitivity with 4 MeV Linac				
Steel weld thickness,mm Relative exposure w.r.t Agfa D7	Required wire dia in mm	High contrast IP	Agfa D 7	Agfa D 4
80	1.27	-	0.8	0.5
90	1.27	1.25	-	0.4
110	1.6	1.25	-	1.25
160	2.5	-	2.5	1.25

Table.6 .Hole type IQI Sensitivity with X-Rays		
Steel weld thickness,mm Relative exposure w.r.t Agfa D7	High speed IP (0.25)	High contrast IP (1.0)
30	30-2T	30-1T
40	35-2T	35-1T
50	35-2T	35-1T

Table.7. Wire type IQI Sensitivity with X-Rays			
Steel weld thickness,mm Relative exposure w.r.t Agfa D7	Required wire dia in mm	High Speed IP	High Contrast IP
30	0.6	0.5	0.5
40	0.8	0.6	0.5
50	0.8	0.6	0.6

Table.8. Duplex Wire sensitivity achieved with various sources (As per EN 14784-2,Duplex wire Separation (EN 472-5))		Class A	Class B
Ir-192	Required	6	7.00
	Achieved	8	8.00
Co-60	Required	6	6.00
	Achieved	7	6.00
4 MeV Linac	Required	6	7.00
	Achieved	7	7.00

From the test results shown in the above tables, the following conclusions can be drawn.In the case of Ir-192 source, for 50mm Steel thickness, the High Speed IP gives a hole type IQI sensitivity of ASTM 35,2-2T (1.75 %) which is better than, the corresposing value (ASTM 35, 2-4T) achieved by Agfa D7 film (High Speed film). Similarly, the High contrast IP gives a sensitivity of ASTM 35,2-1T,which is superior to the corresponding value (ASTM 35,2-2T) given by a fine grain film Agfa D4.In the case of the Co-60 source even at 90 mm thickness, a High Contrast IP gives sensitivity on par with Film. Table (2) shows the performance results with Hole type IQI, which shows the sensitivity ASTM 50, 2-2T, achieved by both IP and Film, Where as the Table (3) shows the same test conducted with Wire type IQI, which clearly tells that IP has achieved a sensitivity of 1.25 % on par with Films. Table (4) and Table (5) show the Sensitivity values achieved, when 4 MeV Linac is used, with Hole type IQI and Wire IQIs respectively .The sensitivity is on par with Agfa D7 film. In the case of X-Rays upto 300kV,both the High Speed IP and High Contrast IP are able to achieve better than 2 % sensitivity. Table (8) shows that spatial resolution achieved by IPs ,with duplex wire IQI in the case of various Radiation sources are better than the required values, as per standards.

7.Conclusion

The feasibility study and the experimental results clearly revealed that the transition from Film Radiography to Digital / Computed Radiography of the welded components is practicable and can meet the National and International Radiography Code requirements. Digital Radiography can successfully replace Real Time Radioscopy with X-Rays and Image Intensifier, for Tubular Steel welds up to Single wall thickness 12mm. Using Digital Flat Panel Detectors with 200 microns pixel pitch, it was possible to achieve more than 3 line pairs / mm,at an MTF of over 20%.The implementation of DR will facilitate the Automatic Defect Recognition during online inspection of welded joints, avoiding the subjectivity in humane evaluation .On the other hand Computed Radiography using High Contrast Phosphor Imaging Plates has been found to be suitable for Radiography of thick wall welds (Steel thickness up to 160 mm) in Boiler components such as Headers, Pipes, Drums etc using Gamma Ray Isotopic Sources like Ir-192, Co-60 and X-Ray sources including Linear Accelerators (up to 4 MeV) with spatial resolution better than 25mico meter, meeting the 2 % Radiographic sensitivity requirements as per ASME code.CR will considerably reduce the exposure time and also completely eliminate the chemical hazards associated with Film processing ,thereby increasing the speed and efficiency of Radiographic Testing. Other significant advantages of CR include the electronic archiving of Radiographic images and online transmission of images for away center evaluation.

References

[1] R.J.Pardikar, 'Real Time Radioscopy and Digital Image Processing Techniques for on-line Inspection of Welds in boiler Tubes'
Journel of Non-Destructive Evaluation, Vol 20 No .3, Sept 2000 P 68-72

[2] Bruce Blakeley, 'Digital Radiography- is it for you?'
Insight Vol 46 No 7 July 2004 P 403-407

[3] G.A.Mohr and C.Beuno,GE A-Si flat panel detector in industrial digital radiography',BINDT Insight Vol 44 No 10 Oct 2002.

[4] V.R.Ravindran, 'Digital Radiography Using Flat Panel Detector for t e Non-Destructive Evaluation of Space Vehicle Components', Journal of Non-Destructive Testing & Evaluation , Vol.4, Issue 2, September 2005.

[5] Giakos, G.C.; Suryanarayanan, S.; Guntupalli, R.; Odogba, J.; Shah, N.; Vedantham, S.; Chowdhury, S.; Mehta, K.; Sumrain, S.; Patnekar, N.; Moholkar, A.; Kumar, V.; Endorf, R.E., 'Detective quantum efficiency [DQE(0)] of CZT semiconductor detectors for digital radiography', Instrumentation and Measurement, IEEE Transactions on Volume 53, Issue 6, Dec. 2004, P 1479 – 1484

[6] P.R.Vaidya, "Flat Panel Detectors in Industrial Radiography", International Workshop on Imaging NDE- 2007, April 25-28, 2007,Kalpakkam,Chennai,India.

[7] Rajashekar Venkatachalam , Manoharan V , Raghu C , Venumadhav Vedula , Debasish Mishra , 12 th A-PCNDT 2006 – Asia-Pacific Conference on NDT, 5th – 10 th Nov 2006, Auckland, New Zealand

[8] P.R.Vaidya,A.V.S.S.Narayana Rao, "Performance Evaluation of the Imaging Plates for Industrial Radiography Application", Journal of Non-Destructive Evaluation,Vol.20,No.3,September 2000,P 53-56.