FILM REPLACEMENT BY DIGITAL TECHNIQUES APPLIED TO WELD INSPECTION

Carla Alves MARINHO[1], João Marcos Alcoforado REBELLO, Ricardo Tadeu LOPES
[1]Petrobras Research Center Leopoldo A. Miguez de Melo, CENPES – PETROBRAS, Av. Horácio Macedo, 950, Cidade Universitária, 21941-915 Rio de Janeiro, RJ, Brazil

ABSTRACT

Nowadays, industrial segments, related to equipment inspection, make an intense effort to replace the radiographic technique using conventional films with the so-called digital techniques, in which the use of phosphor plates or Digital Detector Arrays (DDAs) provide all the advantages of working with digitized images shown in a computer screen. However, due to the insufficient resolution of these new detectors and to the unfilled knowledge and practical experience gaps, this replacement is carried out in a cautious way and always after validation in comparison to conventional films. This work discusses the commitment between image quality, detectability and fulfillment of regulative requirements based on the practical experience of Petrobras in its research and field works, within the Double Wall Double Image (DWDI) technique application range, evidencing that the substitution by digital techniques is possible, but the fulfillment of the specific requirements of detectability and quality for these techniques must be taken into account. In present days, conventional radiography still presents higher quality than that of Computed Radiography, although it is surpassed by Direct Radiography.

Key words: Film Replacement, Computed Radiography, DDAs, Quality Requirements, Detectability, Weld Inspection

1. INTRODUCTION

This work aims to present the experience acquired by Petrobras in the use of Computed Radiography applied to weld inspection in the Double Wall Double Image (DWDI) technique application range. A brief description of DDAs and some results obtained with its use are also presented. Petrobras has been developing an intense work studying and assessing the replacement of conventional radiography in weld inspection, seeking future and constant application of digital techniques in the company's works.

2. BIBLIOGRAPHIC REVIEW

The Computed Radiography Technique

The Computed Radiography technique (CR), despite keeping the same physical principles of the conventional technique, presents peculiar characteristics that must be considered upon its application.

Leaving the use of X-ray films aside, CR uses photostimulable X-ray storage phosphors plates, or imaging plates, which, by absorption of ionizing radiation, form a dose proportional latent image.

During the radiation incidence, electrons and holes are generated and captured locally in storage centers: F-centers or “traps”. The stored information is read out by scanning with a focused red laser. This leads to a local excitation of the trapped electrons which subsequently recombine with the trapped holes causing the emission of light. This emission is known as photostimulated luminescence (PSL). The information is then recorded by means of a photomultiplier tube (PMT), digitized by an A/D converter and displayed with the aid of a computer [1,2]. The remaining information in the imaging plate will then be erased by a strong white light, so the plate can be reused.

In order to assess the quality of the image obtained, it is necessary to determine the radiographic sensitivity through the use of contrast IQIs (Image Quality Indicators). However, two additional parameters appear: Basic Spatial Resolution (SR_b) and Normalized Signal to Noise Ratio (SNR_N). The basic spatial resolution of a Digital Radiography system corresponds to the effective pixel size of the image, whereas the signal to noise ratio (SNR) may be described as the linear proportion between the average value of the signal intensity and the signal noise standard deviation in this intensity [3].

As far as regulation is concerned, two European (EN14784- parts 1 and 2 -Non-Destructive Testing – Industrial Computed Radiography With Storage Phosphor Imaging Plates) and North American (basically ASTM-2446 - Standard Practice for Classification of Computed Radiology Systems, besides the ASME V mandatory Appendix) standards stand out, guiding the use of Computed Radiography for weld inspection. In the European concept, the radiographic trial is usually split in two test classes (A and B), and the quality requirements vary according to these classes. Basically, there are requirements in respect to sensitivity to contrast, normalized signal to noise ratio and basic spatial resolution, the latter being also defined based on the radiation energy and the density of the material to be inspected (table 4 of EN14784-2) [4]. The minimum SNR_N values required for a digital radiography have been indirectly obtained based on the international standards, which traditionally describe the industrial radiography practice [3]. The ASTM standard is similar to the European standards, while the ASME V mandatory appendix has requirements in respect to the sensitivity control with the use of IQIs only. Generally speaking, the requirements of sensitivity to contrast are the same as those used for the conventional technique.

In Brazil, the technique is not yet regulated, but Petrobras has developed its own standard regarding the use of CR in weld inspection: N-2821 Non-Destructive Trial – Computed Radiography of Welded Junctions. This standard was heavily based on the European work and on the Company’s own lab and field experience.

The great hamper for CR has been the fulfillment of the minimum acceptable SR_b requirements. These limits have been determined experimental or empirically, since they were not required for conventional films. The established resolution values for class B of table 4 (EN14784-2) have proven to be too rigorous, according to Petrobras’ experience, and for this reason the Company adopted those from class A only, which were more easily achieved. Still, it is known that the configuration need to meet the required resolution in all diameter and thickness ranges is that in which the laser spot size of the scanner is equal or inferior to 12.5µm [3]. For larger optical reader sizes, there are restrictions for meeting the resolution requirements, imposing limitations to the inspectionable diameter and thickness ranges. This relationship between equipment specification and limitations in the radiographic inspection is still not well-defined in the literature and lab and field experience.

Digital Detector Arrays – DDAs

Among the digital radiography techniques, that in which the image of the inspected object is formed and presented in real-time on a computer screen is called Direct Radiography (DR). The detectors used are DDAs (digital detector arrays), including flat panels and linear detectors.

There are basically three kinds of DDA structure technology: one of them resorts to the use of amorphous silicon sensors, the other is based on amorphous selenium and the third uses CMOS (Complimentary Metal Oxide Silicon) technology [5].

Detectors made of amorphous silicon (a-Si) have, in their structure, a scintillator coupled with silicon transistors matrix, which is fixed on a base of flat glass. The function of the scintillator is to convert the radiation into light photons. These photons are converted into electrons that can be read, amplified, digitized and stored as an image. In these detectors, a pixel is the area involving a transistor and a photodiode. [6].

In amorphous selenium detectors (a-Se), the selenium photoconductive material converts the radiation directly into electric charges, with no generation of light. One obvious advantage in this case is that the image-forming charges can be more efficiently directed to the electrode structure than in the process involving light formation [6]. The sharpness of the image and the speed of conversion are higher. One disadvantage of this type of detector is that the selenium layer must be considerably thicker in order to obtain good sensitivity, which means that the radiation energy will be deposited in a region that is thicker than those in configurations with luminescent activator. The disadvantage is that the spreading of the radiation and divergence of the beam might impair the spatial resolution of the image [5,6].

Detectors based on the CMOS technology also generate digital images by means of the indirect radiation-light-electric signal conversion, thus also making necessary the presence of scintillators in the equipment constitution. The differential of this technology is that each pixel is set up with its own amplifier, which represents a huge gain, because the electronic control is located directly on each pixel, instead of using a parallel circuit for performing this function. These peculiarities bring advantages such as: more sturdiness for the detector, better SR_b (one can reach up to 80μm against the usual 125-160μm range), higher photon-detecting capacity and lower bad pixel occurrence probability [5].

Characteristics that are common to all DDAs are the rigidity and the fragility, which make field applications hard, as well as on curve surfaces (in the Double Wall Single Image – DWSI technique). Furthermore, most of the detectors used for DR suffer degradation during their life cycle, particularly the bad pixels problem, which harms their technical application [7].

The DDAs allow a fast and efficient inspection. Most of them are used in X-ray booths, and need storage that protects them from the environment. The DR technique is especially advantageous for real-time application in small, light and preferably flat pieces, although it is also used in longitudinal welds on large diameter tubes [3,7].

Another interesting point is the calibration. Before carrying out any inspection job, the detector needs to be calibrated, since, in any DDA, every pixel has different gain and offset, while some of them are completely different from the others; these latter as the so-called bad pixels. So, to calibrate would be to standardize the active pixels' response and to correct bad pixels in the generated image [7].

The calibration process is based on the fact that the pixels' responses are practically linear. So, if images the contents of which are known (for instance, the image created by a direct exposition over the detector) were provided to the system, the response from the pixels can be calibrated through linear adjusts. If these images were taken at different dose values (keeping the voltage constant), it would mean a multi-gain calibration. Figure 1 schematizes the process before and after calibration [7].

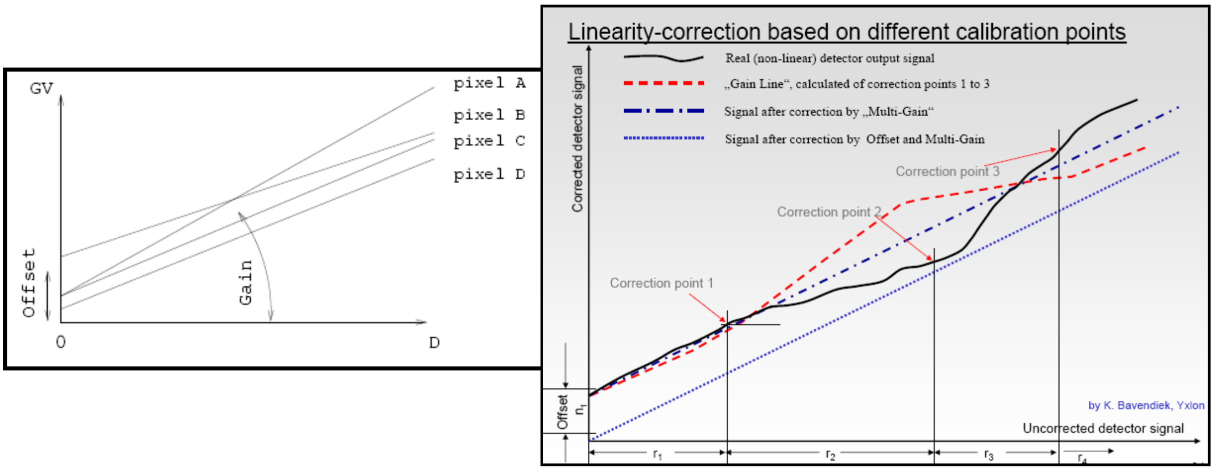

Figure 1– Multi-gain calibration process in DDAs: the different detector pixel offsets and gains before the calibration and the linear adjust of the responses based on images the contents of which are known, obtained with different doses (mA) (courtesy BAM, YXlon).

Despite the limited SR_b, the new multi-gain calibration procedures that have been developed allow the attainment of ultra-high values of SNR_N (in the order of magnitude of 1500) for the images and sensitivity to contrast capable of distinguishing changes of up to 1/1000 in penetrated thickness of material. So, the quality of the image obtained exceeds by 10 times (or more) the performance of conventional films. It can also be inferred that computed radiography might be surpassed in an even higher degree [7].

The radiographic practice with DDAs is not described by any standard yet, but there are proposals for their discussion. The first standard for the qualification of these detectors, ASTM E 2597 (Standard Practice for Manufacturing Characterization of Digital Detector Arrays), was recently published [7].

3. ASSESSMENT OF REGULATIVE REQUIREMENTS AND FAULT DETECTION IN CR SYSTEMS – LABORATORY TESTS

Materials and Methodology

Laboratory tests have been made with samples, containing faults that were inserted during the welding process, in the dimensions shown in Table I.

As radiation sources, two X-ray tubes, with 3.5mm (tube 1) and 1mm (tube 2) of spot size are used. The samples have also been inspected with the conventional radiography technique, so that the comparison between the images obtained with Computed Radiography could be made. The films used were of the D4 and D7 Agfa Structurix Pb VACUPAC type. The radiographic films were digitized using the Array 2905HD scanner, with a 50µm pixel size and 12-bit resolution.

In order to carry out the assessment according to the most strict quality criteria, the source-detector distance values have been taken based on Class B of the ISO 17636 (Non-Destructive Testing of Welds - Radiographic Testing of Fusionwelded Joints) standard.

Table I– Inspected sample dimensions

Sample	Diameter (inches)	Thickness (mm)
S1	1.5	5.08
S2	2	5.54
S3	2	11.07
S4	3	5.49
S5	3	7.62

The CR systems used will be reported as system 1 and 2. The system 1 is composed by a scanner (laser spot size=12.5µm and pixel size=20µm) and new blue plates by the same manufacturer, and the system 2 by another scanner (laser spot and pixel size=50µm) and high resolution IPs. With the 1mm spot size tube, both CR systems were used; for the system 2, the cassette containing a frontal leaden screen, with a thickness of 0.25mm, was also used in the S1 inspection. With the 3.5mm spot size tube, only the system 1 was used.

Quality Requirements

Table II shows the quality requirements for the samples based on standards EN14784-2 (SR_b), Petrobras N-2821 (SNR_N), ASME V and ISO17636 (contrast).

For the measuring of the images' SR_b, the duplex-wire IQI (EN-462-5) was used, always on the source side. Wire IQIs (EN426-1) were used to assess contrast, also always on the source side. The executable ISee! analysis software was used.

Table II – Radiographic quality requirements for the images

Sample	Contrast – Essential Wire (DIN)			SR_b		SNR_N
	ASME V	ISO17636				
		Classe A	Classe B	Classe A	Classe B	
S1	W12	W13	W14	12D	>13D	>70
S2	W12	W13	W14	12D	>13D	
S3	W10	W11	W13	11D	13D	>60
S4	W12	W13	W14	12D	>13D	>70
S5	W11	W12	W13	11D	13D	>60

Results

Table III shows the resolution values attained by the systems that were used. They correspond to the mounted setup resolution.

Table III –Basic Spatial Resolution of the setups

System	Source detector distance - SDD (mm)	SR_b
Film Class I + tube 1	all tested	>13D
Film Class II + tube 1		
Film Class I + tube 2		
Film Class II + tube 2		
System 1 + tube 1	750 (S1 and 2)	12D
	900 (S3)	13D
	1400 (S4 and 5)	>13D
System 1 + tube 2	1000	>13D
System 2 + tube 2	900 (S1)	11D
	1000 (S2 and 3)	
	1200 (S4 and 5)	

Table IV shows the resolution values found during the inspection of samples with the duplex-wire IQI positioned on the source side.

Table IV- Basic Spatial Resolution of the radiographies

Sample	System				
	Film Class I or II+ tube 1	System 1+ tube 1	Film Class I or II+ tube 2	System 1+tube 2	System 2+tube 2
S1	12D	11D	13D	12D	11D –10D*
S2	11D	10D	13D	12D	10D
S3	11D	11D	11D	12D	11D –10D
S4	12D	11D	12D	12D-11D	10D
S5	11D	11D	11D	11D	10D

* attained resolution with the use of cassette with Pb screen

Table V show the sensitivity to contrast values obtained with the use of conventional radiography, for the tubes 1 and 2. It also shows a comparison to the sensitivity attained by the CR systems. For the system 1, with use of the tube 1, the minimum kV and exposition values in which the best sensitivity was attained were indicated. The average optic density, measured in the welding cord, for every film was 2.4HD.

Validation of results related to the comparison between the images obtained by CR and conventional radiography as to fault detectability. The digital image was considered approved only when it showed all the faults acknowledged in the films. The comparison was made between the images obtained with both the X-ray tubes and CR systems, keeping the same setup.

Figure 2(a) shows S1 and the result of the inspection with film, tube 1, 150kV and 24mA.min, sdd = 750mm (W14 D=2.1HD). 2(b) and (c) are images obtained with the system 1 under two different kV/exposition conditions (tube 1 and same sdd); in (c) detectability equivalence was attained - 150kV and 20mA.min – W14 SNR_N=353. The image in 2(d) corresponds to the system 2, for 130kV and 15mA.min, tube 2, sdd=900mm (W14 SNR_N=175), and use of cassette with leaden screen. To make visualization easier, a high-pass filter was applied to all the radiographies. The observation is valid for all subsequent figures in this item.

Table V– Conventional and computed radiography – sensitivity comparison

Sample	Sensitivity to contrast				
	Film + Tube 1	CR – system 1+ Tube 1	Film + Tube 2	CR – system 1+ Tube 2	CR – system 2+ Tube 2
S1	W14	W14 120kV-10mA.min	W14	W14	W14
S2	W14	W14 120kV-10mA.min	W14	W14	W14
S3	W12	W11 180kV-15mA.min	W12	W12	W11
S4	W14	W14 130kV-20mA.min	W15	W15	W15
S5	W14	W13 140kV-15mA.min	W14	W14	W14

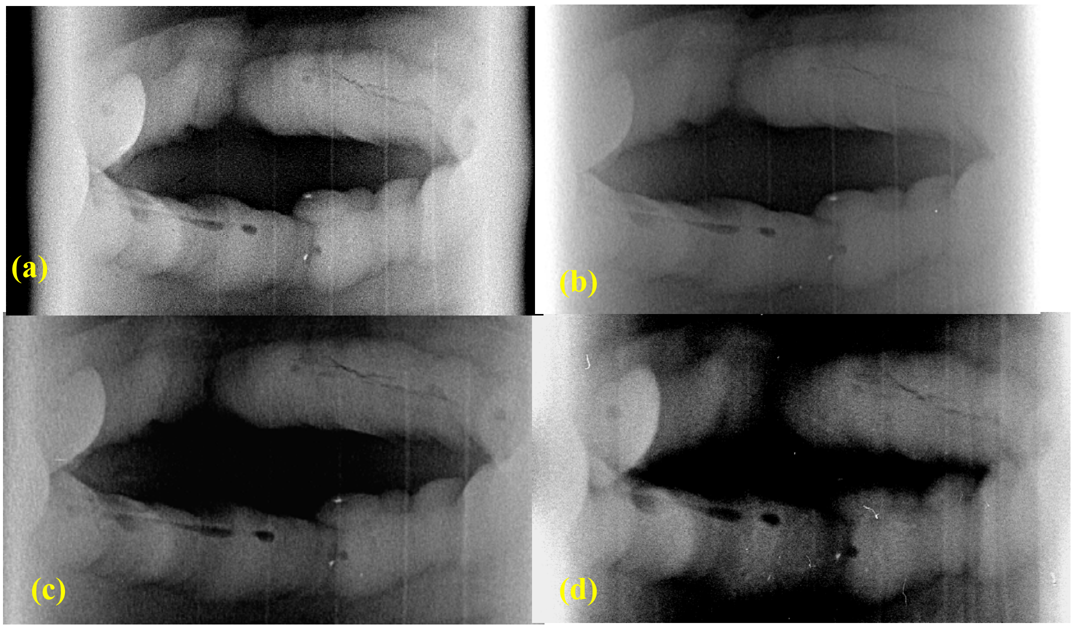

Figure 2– S1: (a)Class I film - contrast W14 D=2.1HD; (b)system 1, tube1, 130kV and 15mA.min – W14 SNR_N=236; (c)system 1, tube 1, 150kV and 20mA.min – W14 SNR_N=353; (d)system 2 +cassette with intensification 130kV 15min – W14 SNR_N=175.

Table VI presents the evolution in detectability, in terms of SNR_N and contrast, of the system 1 with an increase in exposition/kV for the tube 1. Marked in blue are conditions from which the digital images became equivalent to the film.

Figure 3 shows the results for S3. 3(a) is the image of the film, tube 2, 175kV and 48mA.min, sdd=1000mm (W12 D=2.2HD). In 3(b) and (c) are observed the best results obtained with systems 1 and 2, and the respective parameters in which those where attained; tube and sdd are the same.

The arrows indicate artifacts in the images obtained with the system 2, probably due to the specific scanning process of the scanner used.

Table VI – Evolution in detectability of the system 1 with the increase of exposition/ kV for the tube 1 – sample S1.

kV	Exposition (mA.min)							
	5	10	15	20	25	35	40	80
120	144-W13	156-W13	214-W14	----	244-W14	----	314-W13	348-W14
130	158-W14	201-W14	236-W14	252-W14	309-W14	----	346-W14	----
140	----	242-W14	----	339-W14	349-W14	358-W14	----	----
150	228-W14	300-W14	346-W14	353-W14	366-W14	449-W14	----	----
160	242-W14	329-W14	358-W14	419-W14	420-W14	----	----	----

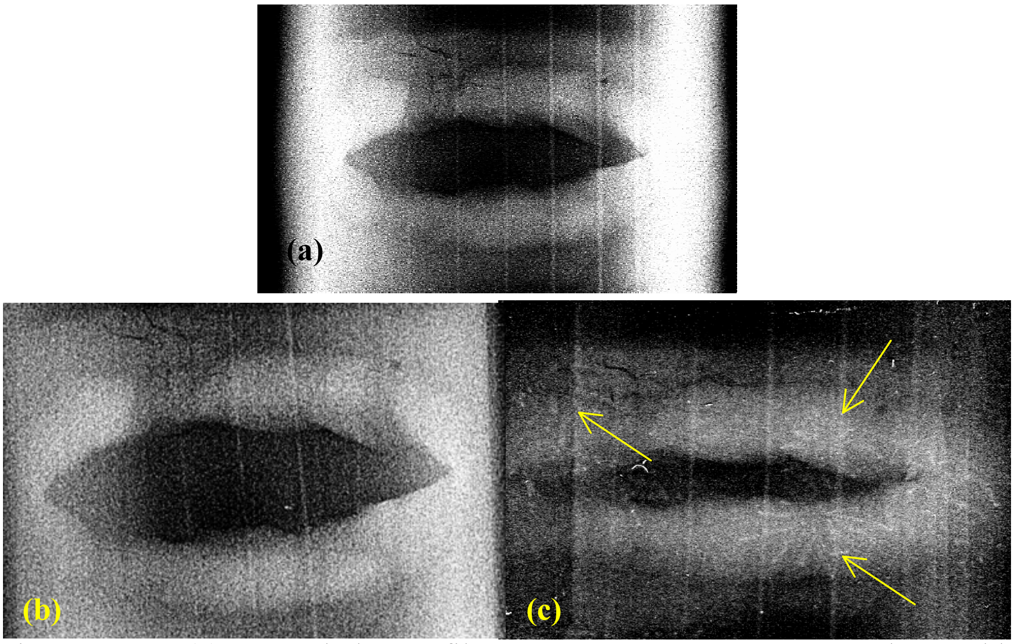

Figure 3– S3: (a)Scanned class II film - contrast W12 D=2.2HD. Tube 2, sdd-1000mm: (b)system 1, 210kV and 30mA.min – W12 SNR_N=327; (c)system 2, 160kV and 25mA.min– W12 SNR_N=213. Arrows show the artifacts in the images.

Figure 4(a) shows the image of the film, tube 2, 150kV and 48mA.min, sdd=1000mm (W15 D=2.1HD) for S4. In 4(b) and (c), the results that presented equivalence obtained with the systems 1 and 2, both for 140kV and 25mA.min, are shown. In this case, the sdd are different: 1000mm for system 1 and 1200mm for system 2, which explains the differences in SNR_N (308 and 204, respectively).

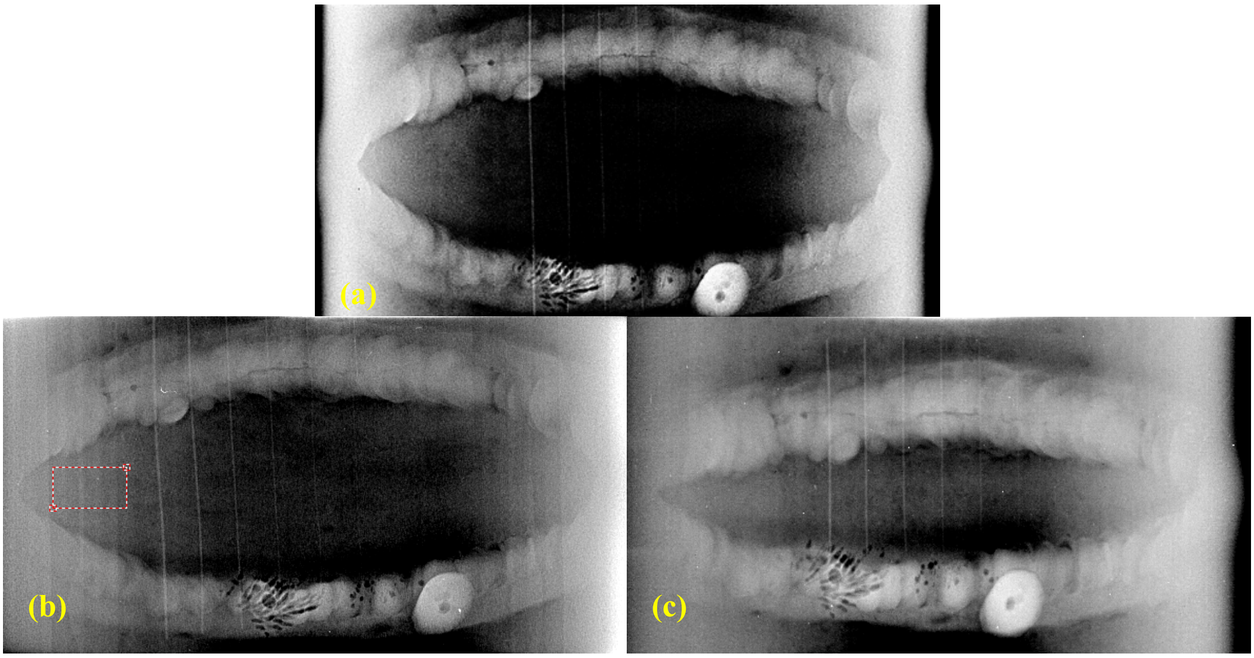

Figure 4– S4: (a)Scanned class I film - contrast W15 D=2.1HD. Tube 2, 140kV and 25mA.min: (b)system 1, sdd=1000mm – W14 SNR_N=308; (c) system 2, sdd=1200mm – W15 SNR_N=204.

Radioprotection optimization with Computed Radiography

Tables VII and VIII show the relation between the energy and exposition values, needed to ensure satisfactory results, with conventional and computed radiography, using tubes 1 and 2, respectively. In S3's and S1's cases, the latter only in Table VIII, the lines have not been filled because the CR systems did not attain equivalent detectability with the test parameters that were adopted.

For the system 2, the exposition values were corrected according to the sdd, whenever necessary, in order to allow the comparison to the conventional type.

Table VII – System 1: radioprotection optimization with CR, tube 1

Sample	Conventional		Computed	
	kV	mA.min	kV	mA.min
S1	150	24	150	15
S2	150	28	160	15
S3	210	14	---	---
S4	180	40	140	40
S5	180	28	150	15

Table VIII – Systems 1 and 2: radioprotection optimization with CR, tube 2

Sample	Conventional		Computed			
			System 1		System 2	
	kV	mA.min	kV	mA.min	kV	mA.min
S1	150	48	---	---	130*	20*
S2	150	48	130	40	130	25
S3	175	48	---	---	---	---
S4	150	48	140	25	140	18
S5	150	60	150	40	150	22

*with use of lead screen

Results Discussion

It was observed that the basic spatial resolution values of the adopted setups fulfill the class B requirements for inspection with films. In the Computed Radiography's case, with use of the system 1, these requirements are fulfilled for the X-ray tube 2, or for distances over 1m, in the first tube's case. The system 2 does not even fulfill the class A requirements, except for the thicker samples' (S3 e S5) case, regardless of source or distance. This is due to the fact that the system 2 resolution does not exceed 80µm (pair 11D) in any of the two scanning directions. Better resolution values for this system could only be obtained with use of microfocused sources and magnification.

In the samples radiographies' case, even for the system 1, the resolution values are inferior to those obtained with conventional radiography in 1 pair of wires. Only in comparison to the class II films does the system attain equal values. With use of tube 2 and system 1, performance was better due to the smaller focus of the equipment, but the results were analogous. The system 2 leaned towards a general resolution of 100µm. Lastly, even the conventional technique has not fulfilled the class B resolution requirements for the most part of the radiographies (see Table IV).

The system 1, a high definition one, was classified as presenting basic spatial resolution equal to 40µm, and in spite of that, according to the aforementioned, it would be equivalent to class II films. This result shows that, in addition to geometrical factors, the structural noise of the IPs must interfere in the resolution, besides limiting the attainable SNR_N values.

As far as sensitivity to contrast is concerned, the class B requirements were fulfilled for CR with kV and exposition values inferior to those of conventional radiography. The conformity to the ASME V, less restrictive, was much more immediate. As for the SNR_N, the CR systems used exceed the regulative requirements even for small kV or exposition values. One interesting observation relating to these two parameters combined was that the SNR_N of the images constantly increased with the increase in exposition or kV of the radiation, which was not true for the sensitivity to contrast, that did not evolve in the same manner. The readings showed a tendency to a constant response from read wires, from a certain exposition/kV value. Table VII shows this tendency. Although not presented here, the results in this sense with the tube 2 were analogous for both systems.

The differences between the radiation sources, in this case, reflected only in slightly higher SNR_N values in images obtained with use of the tube 2, as well as in the observation of an additional wire in terms of contrast (S3, S4 and S5 – see Table V).

Another important observation is that the sensitivity to contrast values attained by CR did not surpass those attained by conventional films.

As far as detectability is concerned, the results have shown that the different systems seem to display different SNR_N thresholds in order to ensure the equivalence to conventional films. It was also observed that the detectability was improved with increases in exposition/kV.

In the adopted test conditions, the system 1 showed a SNR_N threshold in the order of magnitude of 300, provided certain radiation energy (kV) conditions, while the threshold for the system 2 was in the order of magnitude of 200. This system showed better performance in detectability than the high-definition since it needs less exposition/kV and lower SNR_N values, although it shows the faults with less sharpness, what is due to its resolution. For both cases, these thresholds are related to the gain of the photomultiplicator tube, being altered if this value is changed.

There are other CR systems available in the market that attain the same resolution values as the system 2, and are equally capable of providing satisfactory SNR_N levels to the equivalent detection. Because of this, it is recommended that, for weld inspection, the CR systems have limit-resolution of 100µm. This resolution will be applied to most of the cases of inspection of steel components found in the oil industry.

The thicker samples, designated S3, represent a limitation for both the CR systems, since it was not possible to attain equivalence with conventional radiography in DWDI.

The use of the leaden frontal screen damaged the resolution of the system 2 in a pair of wires, reduced the SNR_N value attained under the same test conditions, but did not alter sensitivity to contrast. This behavior is coherent with previous experiences reported in the literature [8]. However, as an opposite effect, the use of the screen improved the detectability of the faults and ensured the equivalence to the conventional technique under lower exposition/kV conditions, but the faults were not as well-defined as under conditions in which the resolution is better.

As far as the optimization allowed by the use of CR is concerned, the Table VII and VIII showed that there was a general tendency for the reduction of needed energy and exposition time. The system 2, for instance, provided an exposition reduction of up to 63% in comparison to the conventional technique.

As specific observations of each system, the blue plates (system 1) have proven to need very delicate handling, since they showed several scratches after a few expositions. The high resolution plates (system 2) displayed erasing problems, having created the need for several re-shots. The scanning also generated artifacts in the plate, which hampered the analysis in certain circumstances, and represented a risk of breaking the detector.

Lastly, it was observed that the radiographies obtained with the use of industrial films are still much better, in terms of resolution and visual contrast of the image, than those obtained with CR. The new technique needs further improvement.

4. ASSESSMENT OF THE DETECTABILITY OF FAULTS WITH THE USE OF DDAs – LABORATORY TESTS

Materials and Methodology

The samples used were the same described in the previous section, and the radiation source was the tube 2 only. Only the S2 and S5 samples were tested.

The detectors used were two DDAs from different manufacturers: model 1, based on a-Si (pixel size of 200µm, 1024x1024pixels matrix) and model 2 (pixel size of 50µm, 2400x2400pixels matrix), based on the CMOS technology.

For both the detectors, a simple multi-gain procedure was followed, adapted from the YXlon Image 3500-DD software, version 2.10, user guidebook, which was used for controlling both DDAs. The voltage used during calibration was 130kV, with variations in this value occurring only during the tests, and the detector-source distance was 600mm for the model 1 and 800mm for the model 2.

Results

Figure 5 shows the images obtained, with use of the tube 2, for S2 through different techniques: (a)conventional radiography with the film class I, 150kV and 48mA.min, sdd=1000mm, (b)CR with system 1, 130kV and 40mA.min, sdd=1000mm (W14 SNR_N=308), (c)Direct Radiography with model 1 detector, 130kV, 13,8mA and 400 frames/s (W14 e SNR_N=182) and (d)Direct Radiography with model 2 detector, 130kV, 9,7mA and 400 frames/s (W15 and SNR_N=330).

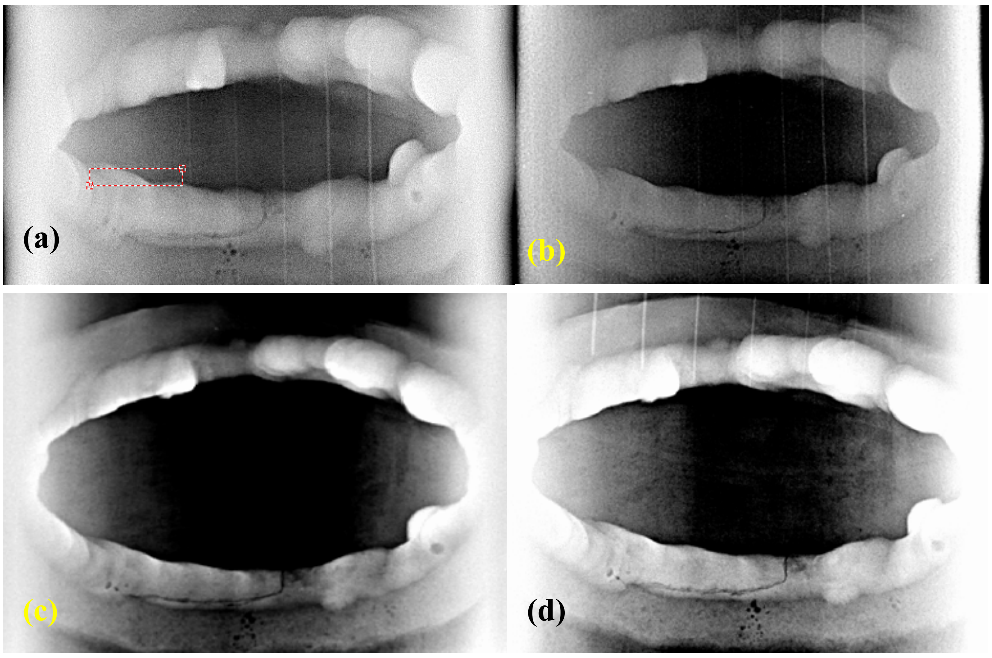

Figure 5– S2: (a) Class I film - contrast W14 D=2.1HD. (b) system 1 (W14 SNR_N=308); (c) model 1 DDA (W14 SNR_N=182); (d) model 2 DDA (W15 SNR_N=330).

Figure 6 shows the results for S5, with the use of the tube 2: (a) conventional radiography, 150kV and 60mA.min, sdd=1000mm, (b) CR with system 1, 150kV and 40mA.min, sdd=1000mm (W14 SNR_N=299), (c) Direct Radiography with model 1 detector, 150kV, 12mA and 400 frames/s (W15 e SNR_N=181). Figure 6(d) shows the magnification of a region from 6(c), in which can be observed faults that were not detected with the other radiography techniques. The model 2 detector was not used for S5.

The DDAs' SR_b was 160µm for the model 1 and 80µm for the model 2. Once more, all the images were presented after a high-pass filter application, in order to make visualization easier.

Results Discussion

The results have shown that, in spite of the limited resolution, and even though much superior SNR_N values than the usual in CR were not attained, due to the simplicity of the adopted multi-gain procedure, the DDAs surpassed the films in terms of detectability, the model 2 standing out. For S5, the model 1 detector was capable of displaying details in the welding cord structure that did not show in any other image.

From the user's point of view, the calibration process of a DDA is not trivial. A simple calibration is not capable of providing all the advantages of this kind of detector; a more adequate procedure could take hours of work. The greatest benefits generated in the process are the increase in sensitivity to contrast and in SNR, as a result of the detector's structural noise reduction. There are virtually no limitations to SNR due to the saturation of the detector, because, when it gets close to saturation, the system resets and a new exposition cycle can be initiated. All the images of a cycle can be worked on by the computer, through mathematic operations of average, and an integrated image is generated. So there are no limits for the exposition time and the quality continually increases [7].

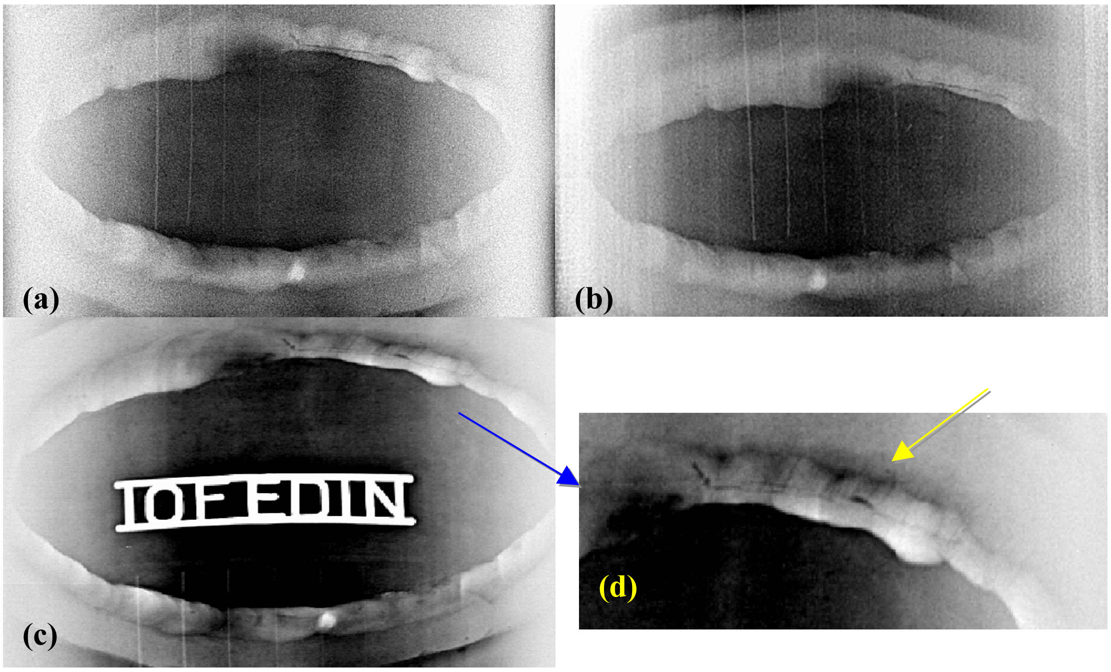

Figure 6 – S5: (a) Class I film - contrast W14 D=2.5HD. (b) system 1 (W14 SNR_N=299); (c) model 1 DDA (W15 SNR_N=181); (d) Magnification of detail in c.

DDAs also have heating problems, and the activities must be interrupted after a few hours of testing. The results are more unstable during the first hour of use. The sensitivity to ambient temperature and humidity conditions and dust are limiting factors for the use of DDAs in field work.

5. CONCLUSIONS

The mere fulfillment to the current regulative requirements for Computed Radiography (CR), basic spatial resolution (SR_b), sensitivity to contrast and normalized signal to noise ratio (SNR_N), does not warrant that the radiographies obtained by this method are equivalent to those obtained by the conventional technique in terms of detectability. It has been shown the necessity of working with a certain combination of voltage and exposition, for a given radiographic arrangement, from which the detectability will be equivalent. This condition seems to reveal itself through a threshold of SNR_N, which has proven to be characteristic of each CR system.

Two CR systems have been tested, and they were reported as system 1 (a high definition one, with SR_b =40μm) and 2. The system 2, in spite of the limitation in SR_b (80μm, at the best), obtained better results relating to the detectability of faults, for having attained equivalence to the conventional technique in inferior voltage and exposition conditions to those of the system 1. However, the faults have been taken care of in a better way with the latter, obviously due to its better resolution.

The use of frontal leaden screens damages the image resolution and reduces the signal-noise relation, but it did not seem to interfere with the sensitivity to contrast, having improved the detectability of the system, through the increase in image contrast, or any other way, through the increase in the contrast-noise relation.

Based on these results, one could think that the spatial resolution is a parameter with little influence on the detectability and that the standard-required values are too rigorous. Indeed, the affirmation concerning the regulative rigor seems to be correct, but in terms of the effect of the resolution on the detectability, one should not undervalue the fact that a good digital image is a compromise between resolution, noise and contrast. The regulation criteria must be reviewed. For weld inspection with computed radiography, an acceptable resolution limit value for most of the situations found in the oil industry would equal 100µm.

Penetrated thicknesses of over 20mm represented a limitation in the application of CR in weld inspection by DWDI.

Detectability has continually improved with the increase in the dose, and equivalence was attained for radiation energy values close to those used for conventional radiography. As far as exposition is concerned, there was a general tendency of reduction. The system 2 provided an exposition reduction of up to 63% in comparison to the conventional technique.

DDAs are detectors through which the images are displayed in real-time. Before the inspection begins, they must be calibrated so the response from the sensor matrix is standardized. These detectors have, in average, worse spatial resolution than that obtained with the Computed Radiography technique, but this can be compensated through an optimized multi-gain calibration procedure, and the quality of the image obtained may exceed the performance of conventional films tenfold or even more. By extension, it can be inferred that Direct Radiography may exceed computed radiography by an even greater factor.

The use of DDAs for field work has restrictions due to the sensitivity of these detectors to factors such as ambient temperature, humidity and dust. The prolonged use also causes the excessive heating of the detector. Another problem is the occurrence of bad pixels in the sensor matrix, the presence of which can only be compensated up to a certain point. There are still no standards regulating the radiographic practice with DDAs, but proposals are being discussed.

The replacement of conventional radiography by digital radiography techniques is perfectly viable. Currently, conventional radiography still provides superior quality to that of CR, while it is surpassed by RD.

6. ACKNOWLEDGMENTS

To Petrobras, for being a company that provides the benefit of prolonged education to its employees and helps Brazilian development with its entrepreneurship.

To the colleagues at Universidade Federal do Rio de Janeiro, Departamento de Instrumentação Nuclear & Departamento de Engenharia Metalúrgica e de Materiais.

To Division VIII.3, Radiological Methods, of the Bundesanstalt für Materialforschung und – Prüfung – BAM, for the hospitality and availability of laboratory resources used for carrying out this work.

REFERENCES

1. Seggern, von H.; “Photostimulable X-Ray Storage Phosphors: a Review of Present Understanding”, *Brazilian Journal of Physics*, **vol. 29**, no. 2, June, pp. 254-268, 1999;

2. Takahashi, K.; “Progress in Science and Technology on Photostimulable BaFX:Eu^{2+} (X= Cl, Br, I) and Imaging Plates”, *Journal of Luminescence,* **vol (100)**, pp 307-315, 2002;

3. Ewert, U., Zscherpel, U., Bavendiek, K.; “Replacement of Film Radiography by Digital Techniques and Enhancement of Image Quality”, NDE 2005, *National Seminar of Indian Society for NDT Proceedings*, Decembre 2 – 4, Kalkutta, India, 2005;

4. BSI BS EN 14784 - Non-Destructive Testing – Industrial Computed Radiography with Storage Phosphor Imaging Plates – Part 1: Classifications of Systems, -2: General Principles for Testing of Metallic Materials Using X-Rays and Gamma Rays, 2005;

5. http://www.cmosxray.com/index.shtml, visited in Dec. 05-2008;;

6. Nondestructive Testing Handbook, 3ºedition: vol. 4, Radiographic Testing, ASNT, 2002;

7. Strategies for Film Replacement in Radiography Films and Digital Detectors in Comparison, Ewert U., Zscherpel U., Bavendiek K., 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China;

8. Improved Procedure for Computed Radiography – A Comparative Study on Weld Tube Sections by Film Radiography and Computed Radiography, Beckmann J., Rachny S., Zscherpel U., Ewert U., 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China.