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Improved Procedure for Computed Radiography - A Comparative Study on Welded Tube Sections by Film Radiography and Computed Radiography -

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Abstract

Different girth welds of tube sections have been inspected by elliptical projection technique according to the EN 1435. The radiographic images were taken by using both film radiography and computed radiography. The purpose of this study was to compare a C3 (AGFA D4) film system and a Duerr HDCR 35 NDT / HR IP imaging plate system with respect to the exposure time, image quality and the detection of fine weld imperfections. The results indicate to a dominant influence of the lead screens on the image contrast sensitivity if doing the inspection according to the EN 14748 -2 for imaging plate exposures. New screen combinations had been applied to make a computed radiograph of a testing class B quality possible.

Key words: Film, digital radiography, computed radiography, image quality.

1. **Introduction**

Daily, industrial radiography is using X-ray and gamma ray radiation to detect defects in airplanes, pipelines, storage tanks, engines, and other non-human objects.
Since more than 100 years X-ray films are used to make the radiographic absorption image visible for the human eye. Special film systems for Non Destructive Testing (NDT) applications have been developed which have a better image quality than a medical film. NDT film systems have a lower speed, a high spatial resolution and a high gradient over granularity ratio, but in consequence a higher level of radiation exposure. This is based on by the usage of lead screens, which substitute the fluorescence intensifying screens in medical film combinations (low dose application). Nowadays, modern medical X-ray detectors issue digitized datasets of the x-ray image in the computer, which facilitates the automated image assessment because the stored images can be visualized on the monitor and simultaneously enhanced by intelligent processing algorithms and procedures. For that reason, digital detectors replace the X-ray film and amend the consisting radiological techniques in medical applications in the last few years. Industrial radiography could benefit from that progress as well, if medical solutions have been transferred and adapted in an appropriated way to NDT applications. This is also necessary for imaging plate systems, which have been in use for medical radiology since 1980’s. Various computed radiography (CR) systems with different inherent spatial resolution and sensitivity are offered today for industrial radiography. All of them have been developed as medical systems and modified for NDT applications afterwards. Today, computed radiography systems are an effective and efficient method of delivering radiographic images. Due to technological developments CR hardware became much smaller and portable. Improvements in storage phosphor materials, new approaches for optical

collecting systems and laser scanners result in modern CR systems which have a basic spatial resolution down to 40 µm. Additionally, the dynamic range of CR systems and the ability to adjust levels of image brightness on the PC made CR systems more viable for various casting and pipe weld inspection applications in praxis. First standards and guidelines for CR in industrial areas have been issued in Europe (EN 14784) and America (ASTM E 2445 and E2446) recently, to ensure good workmanship, the correct handling and to avoid incorrect flaw detection as well as undue image noise. Nevertheless, the discussion on CR in NDT hasn't been finished on the laboratory scale yet, but also started on the test fields in practice. In the following, a report is given on results of a comparative study on radiographic images produced from different girth welds of steel tube sections by using both film radiography and computed radiography.

2. Experimental: Radiographic Inspection

Procedural guidance for the radiography examination is provided by the European Standards EN 1435 (Non-destructive testing of welds - radiographic testing of welded joints) and EN 14784-2 (Non-destructive testing – Industrial computed radiography with storage phosphor imaging plates). The configuration and operating parameters for the radiography were determined by the external tube section diameter, penetrated wall thickness of steel and the focal spot size (acc. to EN 12543-2) of the X-ray tube. The ranges of the tube section diameter, the wall thickness as well as the weld width allowed the elliptical double-wall penetration (Figure 11 in EN 1435) arrangement in most cases. Otherwise the perpendicular double-wall penetration arrangement (Figure 12 in EN 1435) has been applied. The film system, the imaging plate system selection as well as the source to object distances were adjusted according to the requirements of testing class B (improved technique). In all cases a C3 film system were used. The exposure quantity was set according to the class B requirements. First film radiographs were produced on the test samples. In all cases an Agfa D4 film in combination of 0.025 mm front and back screen of lead has been used. The films were machine developed by using Agfa Eco Dev developer and Agfa fix fixer in a 5 min cycle. All film radiographs have an optical density of $D \geq 2.3$ in the weld area. Single wire IQIs in accordance to EN 462-1 and duplex wire IQIs according to EN 462-5 were used as quality indicators to verify and to evaluate the image quality of both the digital images and film radiographs. All exposure experiments were performed with an X-ray tube having a spot size of 2.8 mm. A film-focus-distance of 1000 mm and a tube voltage U=130 kV was selected in all cases. Table 1 describes the representative set of steel tube sections used for the experiments.

Table 1: *Size description of the sample and exposure conditions and arrangement*

Object	*Diameter [mm]*	*Wall thickness [mm]*	*EN 1435 Arrangement*	*U=130 kV; FFD =1000 mm; [mAmin]*
W 10	60.4	3.0	Figure 11	23,1
W 14	60.8	3.3	Figure 11	36,4
W 28	21.1	3.1	Figure 12	54,0
W 40	60.4	3.0	Figure 11	23,1
W 41	60.3	3.0	Figure 11	27,3
W 42	88.9	4.0	Figure 11	32,9

3. HD-CR Digital Imaging System

A Duerr HD-CR 35 NDT scanner in combination with HD-IP imaging plates as shown in Figure 1 was selected for the comparative study. The reader system is remote controlled by a customary personal computer. The BAM Isee! Image viewer software (http://www.kb.bam.de/~alex/ic.html) was used to visualize the digital radiograph stored on the computer during the read out procedure. The software also assists the operator for image quality evaluation and weld discontinuities assessments.

Fig. 1: *Duerr HD-CR 35 imaging plate scanner system (right) equipped with a personal computer (left) for data storage and image evaluation on a high contrast display.*

A LUT for linearization can be applied on the loaded image in case the scanner does not directly provide the data according to a linear gray value - dose - correlation which is needed for the IP class assignment of the digital radiograph based on the measurement of signal to noise ratios. This function was used for comparison to scanners of other brands than Duerr. First, the basic spatial resolution of the HD-CR scanner in combination with the later used HD–IP imaging plates was measured by means of the duplex wire IQI (EN 462-5). X-ray – CR qualifications are based on EN 14784 -1. The image of the duplex wires of the computed radiograph were analysed by a line profile plot as shown in Figure 2. The double wire IQI measures the system unsharpness which is equivalent to the double of the basic spatial resolution (BSR). The value of the BSR is an important quantity which is used for normalisation of the Signal to Noise Ratio (SNR) of the Region of Interest (ROI) selected on the digitized radiograph. Later on, it will be shown, that the normalized SNR is needed for the IP classification of the radiograph. CR systems should be operated at pixel sizes which are smaller than the unsharpness of the imaging plate. The unsharpness of the complete scanner system consists of a scanner and an imaging plate contribution and has to be explored first, before it is used in praxis. The two duplex IQI images on the radiograph demonstrates in Figure 2 that the above described system is able to separate the wires pairs up to the element 13D with a dip between the wires of more than 30% which is equivalent to a system BSR_{max} of 40 µm (see EN 14784-1). Previous experiments indicated an influence of scanning parameters on the maximum reachable BSR. That is why the BSR performance strength is only defined for both the used scanning parameters such as scanner speed, photomultiplier gain and other soft switches

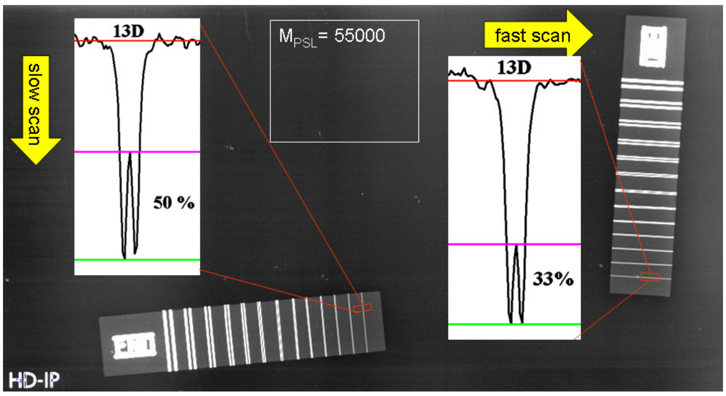

Fig. 2: *CR image of two duplex IQI located parallel to the two different scan directions; X-ray exposure conditions: U= 90 kV; I = 4 mA; t= 50 s; SDD = 900 mm;*
Scanner: pentaprism speed = 2000 rpm; U_{PMT} *= 620 HV*

defined in the initial data set of the computer program as well as the quality of the imaging plate itself. A BAM – Certificate on design-type testing according to EN 14784-1 and ASTM E 2446 was released in 2007 to the company Duerr for this system set-up.

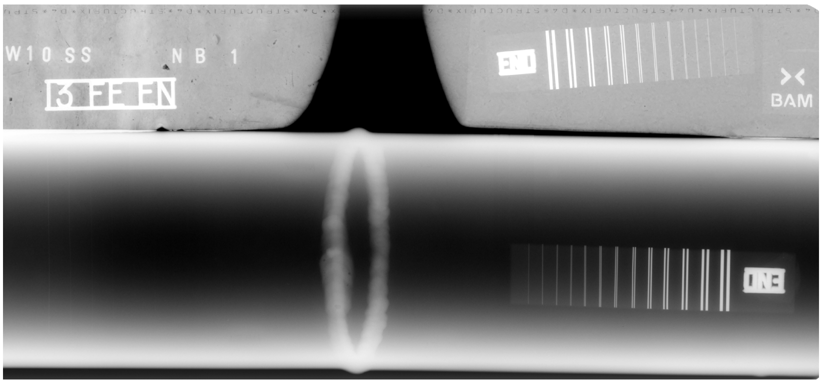

Fig. 3: *Digitised film radiograph of steel tub section W10.*

For further experiments all computed radiographs were produced by means of the Duerr HD-IP's which were scanned with a Duerr HD-CR 35 NDT system operating with a pentaprism speed of 2000 rpm and a PMT voltage of 620 V. The exposure conditions for imaging plates have been hold equivalent to those selected for the film radiography, to determine if both techniques deliver the same image qualities for the same objects. In contradiction to film radiography 0.1 mm front and back lead screens in combination with the IP have been used because it is a requirement in the EN 14784-2 for the selected X-ray tube voltage. The Figure 3 shows the film radiograph of a tube section digitised with the film laser scanner Array 2905 HD operating with a pixel size of 50 µm and a digital resolution of 12 bit (DB-9 scanner according to ISO EN 14096). The image in Figure 3 represents the characteristic assembling of the wire IQIs. Digital radiography requires a minimum spatial system resolution value (as well as a maximum scanner pixel size) in dependence on energy and wall thickness. A clear regulation on the location of the duplex wire IQI is not given in the standards. For that reason, two duplex wire IQIs have been used to control the unsharpness value of the image at two different positions. The first double wire set was usually located on the top of the tube (source position - SP), the other one was arranged in the vicinity of the outer surface of the tube on the top of the film or IP (film position – FP), respectively. Figure 4 depicts the computed radiograph of the same object shown in Figure 3.

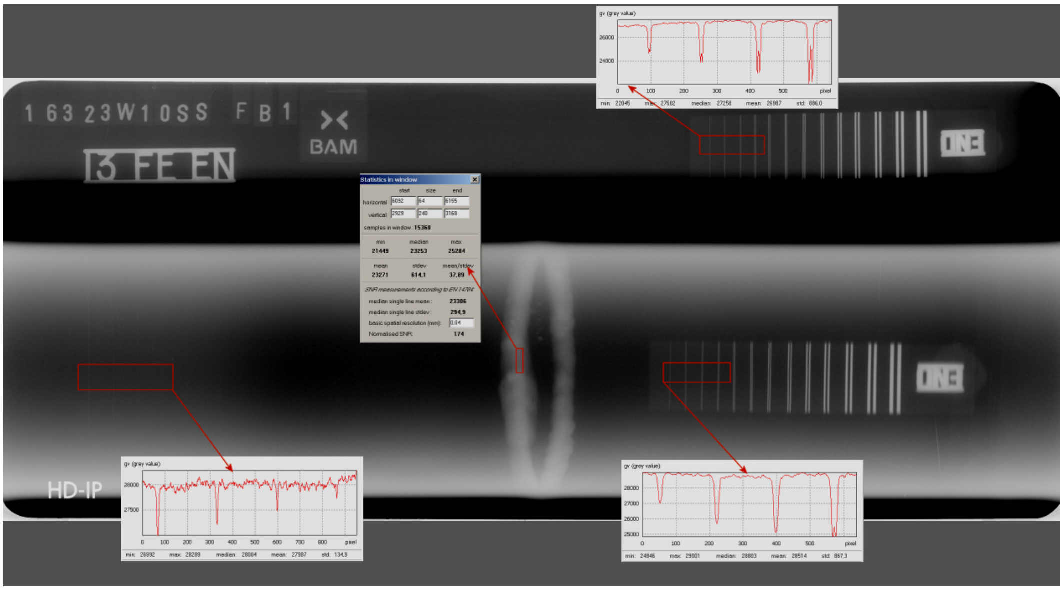

Fig. 4: *CR of W10. The software tools such as line profile plot and statistic windows can be used to quantify the SNR of the ROI (weld area) un-sharpness of duplex wire IQI (right) and single wire IQI contrast (resolved wire number).*

Apparent differences between the images couldn't be observed on the monitor. It was found that the image of the digitized film has already a lower spatial resolution as the CR image due to the spatial resolution of the used film scanner.

4. Results

The Figures 3 and 4 demonstrate the option to quantify the achievable image quality of both detectors for the different X-rayed objects. First, the optical density of the film on the light box and SNR of the computed radiograph on the monitor in the ROI were determined. As already described, the experimental conditions were selected in a manner that an optical density grater than 2.3 on the film in the weld area could be achieved. CR produced on the same object with the same exposure conditions an image, which was analysed computer based, and a normalized SNR greater than 130 at the preselected ROI was measured. In both cases the images fulfil the testing class B requirements. In a second step the image quality and unsharpness of both radiographs had been quantified in a similar way. Table 2 describes the initially measured results for representative objects exposed according to the standards EN 1435 and EN 14784-2 respectively.

Table 2*: Observed wire number and un-sharpness for different representative objects. Exposure condition were strictly selected according to the standards EN 1435 and EN 14784-2*

Object	*EN 1435*		*D4* (*C3 film system,* EN 1435*)*				*HD-IP* (*IP1/40 class,* EN 14784-2)			
	Class B		*single wire EN 462-1*		*Duplex IQI EN 462-5*		*single wire EN 462-1*		*duplex IQI EN 462-5*	
	FP	*SP*	*Pos. A*	*Pos. B*	*FP*	*SP*	*Pos. A*	*Pos. B*	*FP*	*SP*
W10	W16	W16	F16	F16	13D	11D	14	15	12D	10D
W14	W15	W15	F16	F16	13D	11D	14	14	12D	10D
W28	W15	W15	F16	F16	13D	11D	15	14	13D	12D
W40	W16	W16	F16	F16	13D	11D	14	15	11D	9D
W41	W16	W16	F16	F16	13D	11D	14	14	12D	10D

The results in Table 2 document that the selected exposure conditions were sufficient to get the required image quality for Class B on the radiographic film. In contradiction to that, the computed radiographs achieved only a testing class A image quality, though the exposure conditions weren't changed.

5. Discussion

Comprehensive investigations on the influence of the lead screens on the image quality were started to understand the above shown results. Metallic screens are generally used in conjunction with film radiography. The screens are placed on both sides of the double emulsion films. The screens have two principle effects for the film radiography: (1) Electrons are generated in the screen by the primary photon beam, which increase the film sensitivity; and (2) the lower energy scattered radiation emanating from the test object under study is preferentially absorbed in the metallic screens relative to the primary radiation.

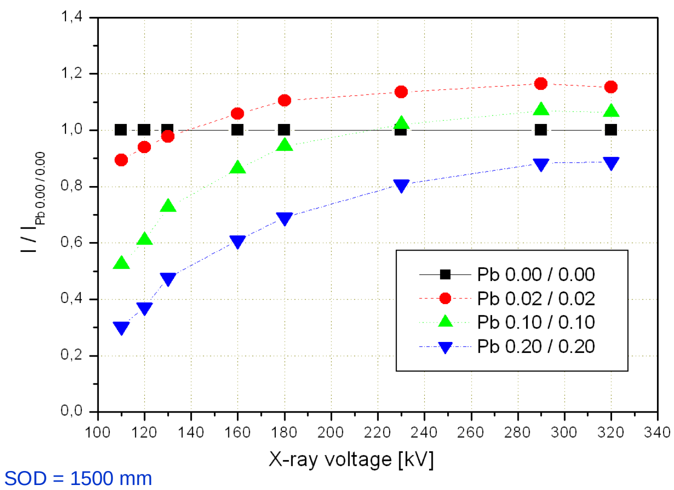

Fig. 5: *Influence of front and back lead screens on the image intensity in comparison to screenless radiography.*

This latter effect is increasing the contrast in the radiographic image. Imaging plates are different designed. The sensitive photostimulated layer, which holds the virtual image, is located inside of the imaging plate. The layer is covered by a 10 µm thick protection layer and supported by a 1000 µm thick plastic sheet. The electrons enforce only slightly the image formation on the IP, because there energy must be high enough to penetrate the sheets besides the photostimulated layer. Other effects such as the scattering contribution of fluorescent radiation caused by the primary radiation within the metal sheets and the primary radiation scattering itself are the dominant factors for intensifying the imaging plate sensitivity. The relatively high distance of the metallic sheets to the photostimulated layer as well as the undirected scattering radiation causes additional inherent unsharpness. Experiments were carried out to measure the intensifying effect of IP-lead screens (see Figure 5). The intensifying effect is compensated by the hardening effect of the front screen at lower X-ray energies. The intensification is less than 20% at higher energies. The intensification can be improved by using only a back screen. An increase of the image intensity to 40% at 220 kV was observed by using a 0.4 mm thick lead back screen only. A significant increase of the unsharpness on the resulting image caused by the fluorescent radiation of the back screen could also be verified.

Table 3: *Observed wire number and un-sharpness for different representative objects. IP was exposed without a lead front screen. Lead back screen is covered by 0.5 mm thick metallic screen.*

Object	*EN 1435 Class B*		*D4 (C3- EN 1435)*				*HD IP (0Pb/0.5 Fe)*			
			single wire EN 462-1		*Duplex IQI EN 462-5*		*single wire EN 462-1*		*duplex IQI EN 462-5*	
	FP	*SP*	*Pos. A*	*Pos. B*	*FP*	*SP*	*Pos. A*	*Pos. B*	*FP*	*SP*
W10	W16	W16	F16	F16	13D	11D	F16	F16	13D	11D
W14	W15	W15	F16	F16	13D	11D	F16	F16	12D	11D
W28	W15	W15	F16	F16	13D	11D	F16	F16	13D	11D
W40	W16	W16	F16	F16	13D	11D	F16	F16	13D	11D
W41	W16	W16	F16	F16	13D	11D	F16	F16	13D	11D
W42	W15	W15	F16	F16	13D	10D	F15	F15	13D	10D

Further exposure experiments on lead screen combinations also demonstrated that front lead screens reduce the contrast on imaging plates as long as the penetrated wall thickness doesn't exceed about 10 mm steel. Second, it is recommended to avoid a direct lead screen contact on the backside of the IP above 120 kV. It was found that covering the lead back screen by means of at least 0.5 mm thick steel or copper sheet absorbs the unwanted fluorescent radiation of the lead backside screen. Based on the gathered results the computed radiography experiments had been repeated by using the film radiography exposure conditions.

In contrast to the earlier experiments, the EN 14784-2 specifications had been changed by covering the lead back screen with a 0. 5 mm thick steel plate. Also the front lead screen recommended in the standard had been omitted. The new results, shown in Table 3 clearly demonstrate that the testing class B requirements could be fulfilled by this way.

6. Summary

The results indicate a strong influence of the lead screens on the image contrast sensitivity of imaging plates. Metallic screens can reduce the unwanted scattering radiation of the test object and test environment. Design differences between film and imaging plates demand a different approach for the application of metallic screens. Although the influence of metallic screens on the image quality of the computed radiographs has been already considered in the EN 14748-2, but an optimisation for the procedure of the usage of metallic screens is required. The proposed arrangements of the metallic screen combinations increased the image quality for the selected X–ray tube energy and penetrated wall thicknesses. The new screen combinations, different from the requirements of EN 14784-2, made a computed radiograph of a testing class B quality possible.

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