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CONTRAST GRADIENT DETERMINATION IN DIGITAL RADIOGRAPHY TO OPTIMIZE THE CAPABILITY IN DEFECT DETECTION

Enkelejda Sotja, Dhimitraq Sotja, Giuseppe Nardoni, Pietro Nardoni

Original scientific paper

Digital radiography is a growing technique in X-ray examinations. It is the aim of the present work to study the main parameters that affect the quality of image in terms of contrast and definitions. A number of tests have been carried out on a calibrated stepped wedge exposed to different levels of energy and related time. The range of thickness involved has been between 5 and 20 mm. The steps' change value has been between 0,2 and 1 mm. Two fundamental diagrams have been traced after the experimental tests: grey level/relative exposure relation and contrast gradient/ grey level relation. Another important thing has been taken into consideration during the test; changes of hundreds of millimetres (mm) in wire diameter can cause a level of sensitivity higher than 2 % which is, consequently, not accepted by the code. This change, in our opinion has no effective impacts on the detection of defects such, lack of penetration, porosity, cracks and slag inclusion.

Keywords: *contrast, digital radiography, quality of image*

Određivanje gradijenta kontrasta u digitalnoj radiografiji radi optimiziranja sposobnosti u otkrivanju kvarova

Izvorni znanstveni članak

Digitalna radiografija je rastuća tehnika u rendgenskim ispitivanjima. Cilj je ovoga rada proučiti glavne parametre koji utječu na kvalitetu slike u smislu kontrasta i definicije. Provedeni su brojni testovi na kalibriranom stupnjevanom klinu, izloženom različitim razinama energije i odgovarajućem vremenu. Raspon uključenih debljina je između 5 i 20 mm. Vrijednost promjene koraka bila je između 0,2 i 1 mm. Izrađena su dva temeljna dijagrama nakon eksperimentalnih ispitivanja: odnos između sive razine i relativne izloženosti i odnos između gradijenta kontrasta i sive razine. Drugo važno razmatranje je provedeno tijekom ispitivanja; nekoliko dijelova milimetra promjene u promjeru žice može uzrokovati razinu osjetljivosti višu od 2 %, a time i neprihvatljivu propisom. Ova promjena po našem mišljenju nema jači utjecaj na POD vrste oštećenja kao što su nedostatak penetracije, poroznosti, pukotine i uključci šljake.

Ključne riječi: *digitalna radiografija, kontrast, kvaliteta slike*

1 Introduction
Uvod

Industrial radiography is a non-destructive method that uses the penetrating and ionizing (X-ray or gamma-ray) radiation that passes through the object, and the detector of the radiation. This method of NDT is very important in detecting defects (internal and surface ones like porosity, cracks, lack of fusion, lack of penetration, foreign inclusions), differences in thickness, changes in structure, assembly details etc. in quality assurance of the piece, or structure conform standards, specifications or technical requirements.

The detector can be 1) photographic film, held in a light-tight cassette that allows the rays to pass through the piece. Chemicals are needed to develop the image on film. This process is known as conventional radiography. 2) radiation – sensitive detectors that do not require the use of chemicals to produce the image. This process is known as digital or computer aided radiography (CR) or direct digital radiography (DR).

In digital radiography a radiograph is created, not on conventional silver halide film, but with the use of another device that allows the radiograph to be represented as an array of discrete digital intensity values or pixels. The types are:

Film Digitization – a process whereby a radiograph is produced in a conventional manner on a normal sheet of industrial X-ray film. The film is then placed in a reader, the image is read and digitized for viewing and archiving on software.

Direct Radiography (DR) – the image is captured directly on a flat plate and the image is transmitted directly to the computer. No intermediate steps or additional processes are required to capture the image.

Computed Radiography (CR) – uses an imaging plate that contains photo sensitive storage phosphors which retain the latent image. When the imaging plate is scanned with laser beam in the digitizer, the latent image information is released as visible light. This light is captured and converted into a digital stream to compute the digital image. A valuable point in the use of flexible storage phosphor plates and CR systems is that any exposure source that can be used with conventional X-ray films can also be used with this filmless technology and the flexible storage phosphors imaging plates can be directly substituted for the film. They can be used in the same film holders and cassettes as those used for the film and can be used in applications requiring a flexible medium, such as bending them around a circumferential specimen. This compatibility with existing sources and cassettes makes the transition from traditional film radiography to CR fairly uncomplicated and inexpensive proposition.

The fundamental parameter of CR system is the relationship between plate and dimensions of scanner's spot that can be considered as "film system" in conventional radiography.

Quality of image is very important in interpretation of defects. In conventional radiography QI is influenced by sensitivity of film, development process, human factor most of all; in CR it is influenced by the kind of plate (plate IPC2 is more sensitive than plate IPS), scanner's parameters, quality of hardware (resolution of monitor, etc) and software, so here the influence of human factor is decreased.

2
CR system parameters
Parametri CR sustava
2.1
Exposure charts
Dijagrami izloženosti

Very important parameters for image quality are such as kV, mA and exposure time. An exposure chart gives us the relation of 1) material thickness, 2) energy kilovoltage (kV); 3) intensity and time of exposure, (mA/min). A simple method for preparing an exposure surface is to make a series of radiographs of a stepped wedge sample consisting of a number of steps, Fig. 1.

We used stepped wedge of 1 mm to 15 mm placed over a steel plate of 5 mm thickness, first two millimeters were with steps of 0,2 mm difference between each other, radiographed at several different exposures at each number of kV. In Fig. 2 the relation between thickness-grey value and exposure (mA/min) was obtained from experimental data, where a desirable grey level was selected as the basis for the preparation of chart.

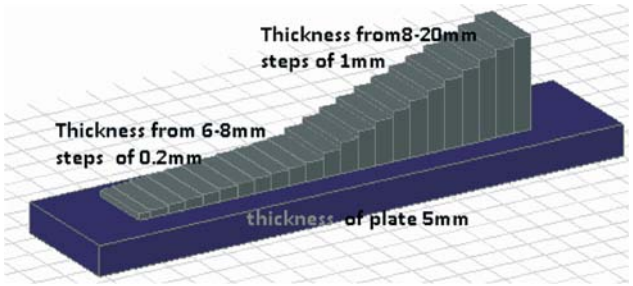

Figure 1 *Stepped wedge*
Slika 1. *Koračni klin*

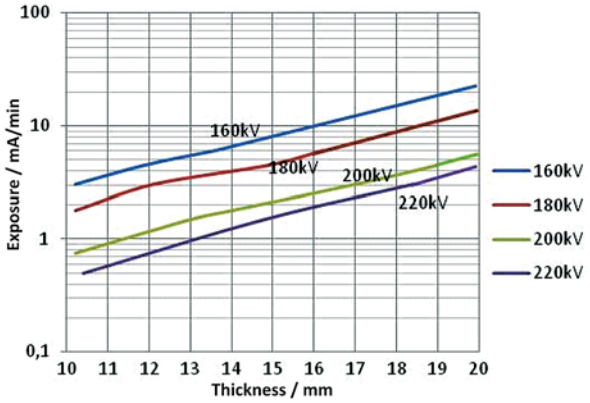

Figure 2 *Exposure chart, scanner CR50P (Pegasus), plate IPS, source-detector distance 700 mm, digital value 20 000 counts*
Slika 2. *Dijagram izloženosti, skener CR50P (Pegasus), ploča IPS, udaljenost između izvora i detektora 700 mm, digitalna vrijednost 20 000 točaka*

2.2
Characteristic curve
Karakteristična krivulja

Fig.-s 3 and 4 shows characteristic curve based on experimental data for IPS plate scanned with CR50P, to express the relation between exposure and grey level in the image. The characteristic curve data can be obtained using the same step wedge used for exposure chart, radiographed at the same energy (kV), intensity (mA) at different time.

The charts show 1) characteristic curve are linear, 2) optimal grey level is from 20 000 to 45 000 counts, 3) wide latitude has advantages in non uniform thickness specimens (such as, small castings, assemblies with presence of specific components, different material and materials which have space between components), or disadvantage when is used to detect defects with small dimensions.

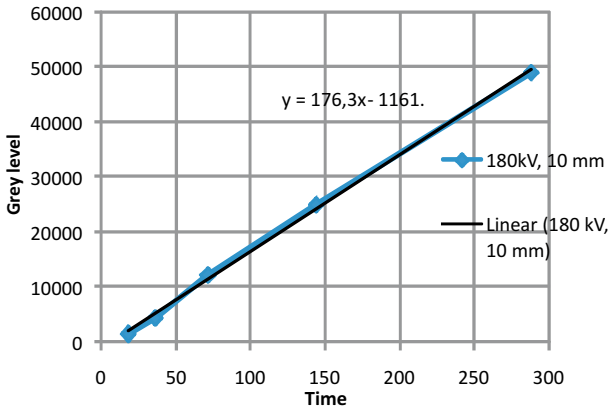

Figure 3 *Characteristic curve for IPS plate scanned with CR50P 7*
Slika 3. *Karakteristična krivulja za IPS ploču skeniranu s CR50P 7*

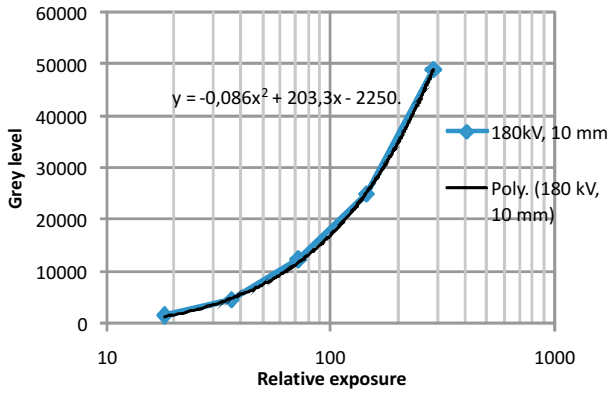

Figure 4 *Characteristic curve for relative exposure*
Slika 4. *Karakteristična krivulja za relativnu izloženost*

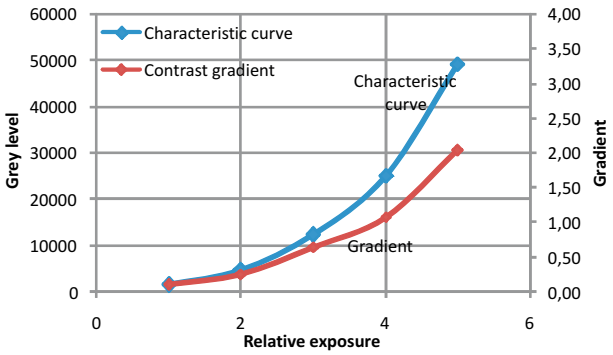

Figure 5 *Contrast gradient chart and characteristic curve*
Slika 5. *Shema gradijenta kontrasta i karakteristčna krivulja*

2.3
Energy
Energija

Chart in Fig. 6 expresses the relation between thickness and grey level, for different levels of energy. Diagram is obtained using the same steps wedge used for exposure chart, radiographed at the different energy (kV).

In the experiment, increase of the energy is done with the equal portions (20 kV) starting from 140 kV.

Increase of grey level is not with equal values. Grey level differences are bigger in exposure to high energy.

So the contrast obtained using higher kV is better than the contrast obtained using lower kV.

The range of grey level to obtained higher contrast is from 25 000 to max 45 000 to, taking present that interval of time in which, from the max point, the plate can go on saturation, is very shorter.

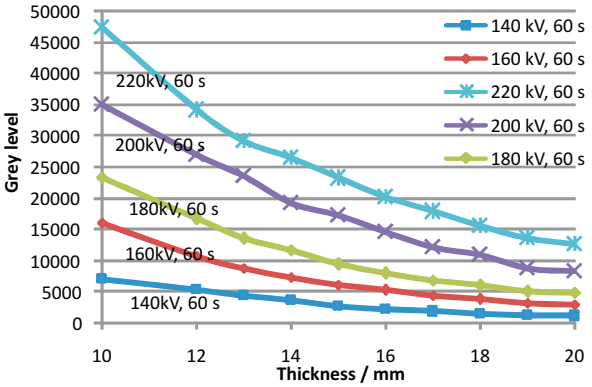

Figure 6 *Preliminary chart of different levels of energy and same exposure*
Slika 6. *Preliminarni dijagram različitih razina energije i jednakih izloženosti*

Higher contrast means higher sensitivity to detect defects, so to obtain good contrast we need to radiograph with the highest possible energy, as the higher the energy the better the sensitivity.

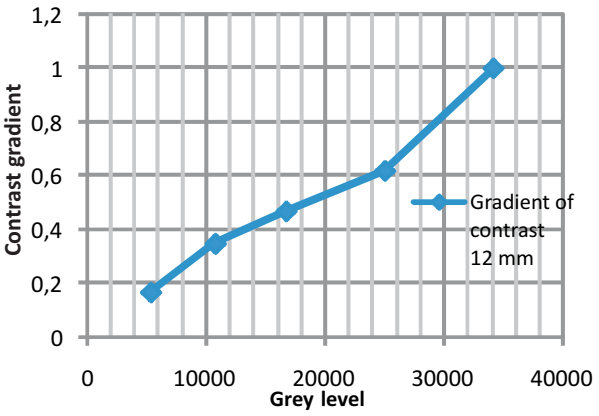

Figure 7 *Contrast gradient*
Slika 7. *Gradijent kontrasta*

A desired grey level possibly is obtained by using lower kV and higher mA or using a higher kV and lower mA in a material of a given thickness.

Fig. 8 shows influence of two techniques, technique 1: 150 kV (4,2 mA, 60 s), technique 2: 250 kV (1 mA, 60 s). Both techniques can produce the same level of grey 31 000 counts, at thickness 10,5 mm. Using technique 1 the curve is steeper than that obtained using technique 2. This indicates that the contrast obtained using technique 1 is better than that obtained using technique 2.

To obtain the desired grey level and the maximum possible contrast, a kV as low as possible and a mA as large as possible should be used. Alternatively, to obtain desired

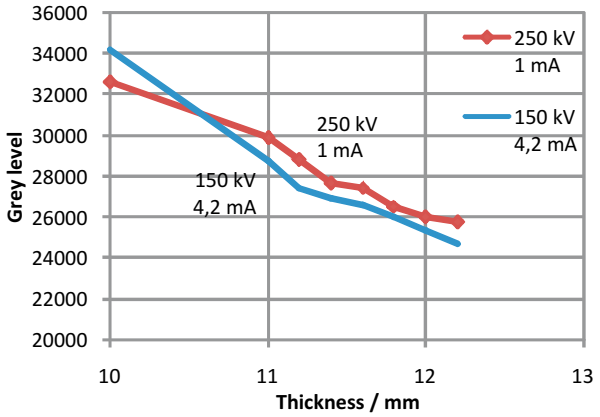

Figure 8 *Influence of two combinations: low energy-high intensity and high energy-low intensity*
Slika 8. *Utjecaj dviju kombinacija: niska energija-visoki intenzitet i visoka energija-nizak intenzitet*

grey level and the maximum possible latitude, a kV as high as possible and a mA as small as possible should be used.

2.4 Sensitivity Osjetljivost

System performed parameters must be determined initially and monitored regularly to ensure the results. According to UNI EN 462-5 the best measure system is to use the Duplex Wire, Fig. 9. According to UNI EN 1478-1, a pair wire are "resolved" if the dip between the wires expressed in grey level, is greater than 20 % of the difference between maximum grey level end grey level of wire.

For the 10 mm plate we can see the element 7D (Fig. 10), diameter 0,20 mm. We can guarantee the 2 % sensitivity for class A. If class B is needed the difference is only 0,04 mm (diameter 0,16 mm) and the digital radiography is not accepted.

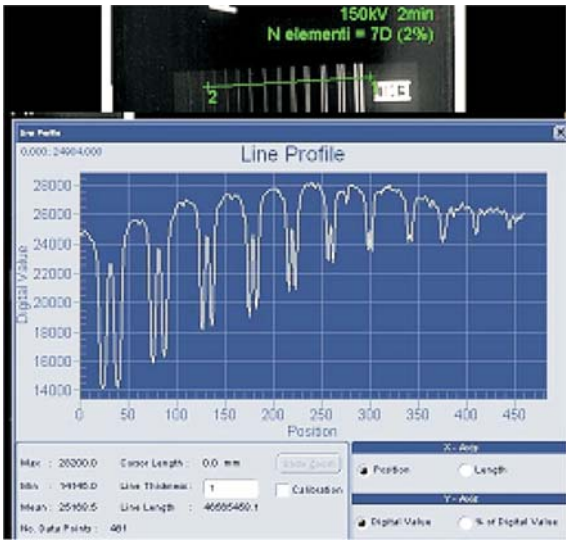

Figure 9 *Image of Duplex Wire expressed in grey level by Line Profile*
Slika 9. *Slika dvostrukog ispisa izražena u sivoj razini pomoću linije profila*

The results express that conventional film has high sensitivity, higher resolution and good borders definition

compared with CR system where the size of pixel is around 30-200 μm compared with 5 μm for the conventional film.

3
Experimental tests
Eksperimentalna ispitivanja

Digital radiography is applied over different kind of geometry and materials in the experiments:

1. high porosity welded plate with lack of inclusion, Fig. 10a and Fig. 10b
2. welded tube of diameter 296 mm, Fig. 11.
3. corrodes tube of diameter 48 mm, under coating material, Fig. 12.

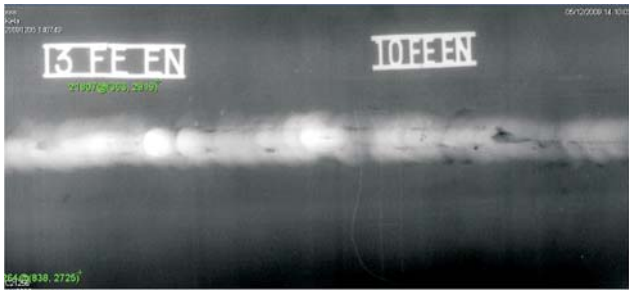

Figure 10a / Slika 10a

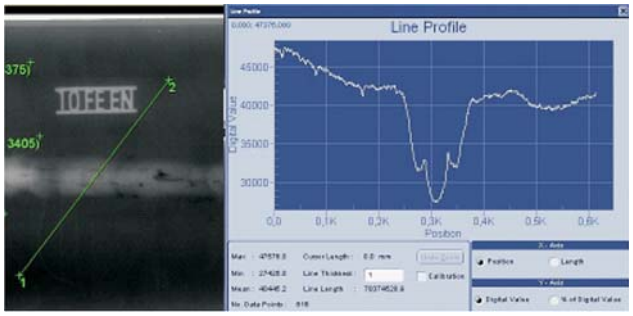

Figure 10b / Slika 10b

Figure 11 *Welded Al tube with diameter 296 mm*
Slika 11. *Zavarena Al cijev s promjerom 296 mm*

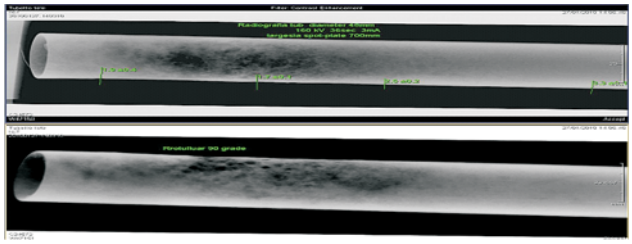

Figure 12 *Corroded tube with diameter 48 mm*
Slika 12. *Korodirana cijev s promjerom 48 mm*

From images is proved that with post-processing is possible 2 % sensitivity, and is possible to measure all defects inside (Fig. 13).

Tubes of heat systems with diameter 48 mm and thickness 4 mm are radiographed in two directions without removal of coating. Using the program we can easily measure the tube corrosion.

4
Conclusions
Zaključci

Digital radiography has significant advantages like: exposure time reduction, no need for chemical development process, making it friendly to environment, easy post-processing, accurate corrosion measurement, no material limitations, no temperature limitations and no need for preparation work or to remove coatings or insulation.

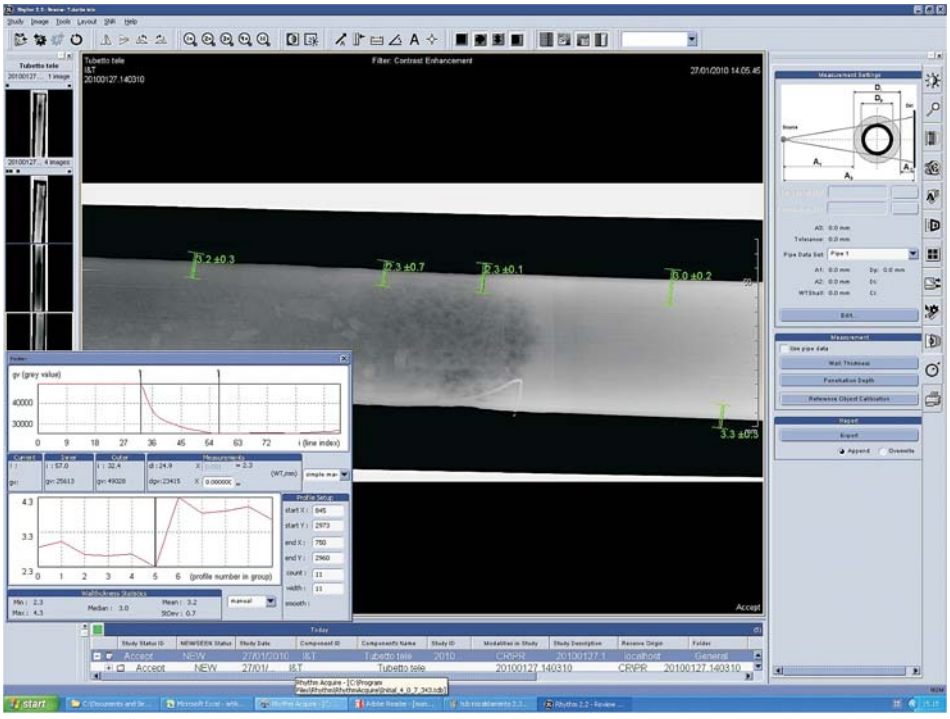

Figure 13 *Corrosion dimensioning*
Slika 13. *Dimenzioniranje korozije*

In the light of obtained results we can recommend in digital radiography CR a level of grey from 25 000 to 45 000, because in this interval the contrast is higher.

Another important consideration has been raised during the test; few cents of millimeters in wire diameter can cause a level of sensitivity more than 2 % which is consequently not accepted by the code.

In our opinion this change does not have effective impacts on detection of defects such, lack of penetration, porosity, cracks, and slag inclusion.

5
References
Literatura

[1] Industrial Radiography – Image forming technique. // GE Inspection Technologies – 2007 General Electric Company; GEIT-301158 (01/07).
[2] ASNT 144 / 144WCD. Non-Destructive Testing Handbook, Third Edition: Volume 4. // Radiographic Testing. American Society for Non-destructive Testing (ASNT), USA, 2002.
[3] Oceaneering Computed Radiography. http://www.oceaneering.com/oceandocuments/brochures/inspection/INS – Computed Radiography.pdf
[4] Bai, Weimin; Bueno, C.; Wong, B. S.; Wang, Xin. Generation of radiographic techniques for digital radiography applications. // Insight, 51, 6(2009), 327-331.
[5] Ewert, U.; Zscherpel, U.; Bavendiek, K. Replacement of film radiography by digital techniques and enhancement of image quality – 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China
[6] Bianchi, M. Introduzione della radiografia digitale – Bytest Srl, Volpiano [TO], Italia, 2008.
[7] Patel, R. J. Digital Applications of Radiography, www.ndt.net – 3rd MENDT – Middle East Nondestructive Testing Conference & Exhibition – 27-30 Nov 2005, Bahrain, Manama, http://www.ndt.net/article/mendt2005/pdf/08.pdf (2011-1-14)
[8] Bianchi, M.; Rivara, F.; Rusca S. Caratterizzazione della radiografia computerizzata (CD/DR) con schermi al fosforo e confronte con la radiografia convenzionale a film, Instituto Italiano della Saldatura – Giornale AIPnD – Il giornale delle Prove non Distruttive Monitoraggio Diagnostica, Settembre 2009, 16-20.

Authors' addresses
Adrese autora

Enkelejda Sotja, Lecturer
Polytechnic University of Tirana
Tirane, Albania
esotja@yahoo.com

Dhimiter Sotja, PhD
Mechanical Department
Polytechnical University of Tirana
Tirane, Albania
sotja@icc-al.org

Nardoni Giuseppe, General Director
I&T Nardoni Institute S.R.L.
Brescia, Italy
nardoni@numerica.it

Nardoni Pietro
I&T Nardoni Institute S.R.L.
Brescia, Italy
nardoni@numerica.it