Digital industrial radiography – methodic of dimension measurement, accuracy of reached results and their relation to acceptance criterion

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Abstrakt

Starší postupy měření velikosti radiografické indikace v některých případech nepodávají výsledky s dostatečnou opakovatelností. Ve specifických případech je jejich použití technicky nemožné.

Tato studie je zaměřena na určení jednotného postupu. Bere v úvahu rozdílné geometrické podmínky tak, jak odpovídají odlišným výrobním sektorům. Teoretický postup byl sestaven s přihlédnutím k vlivu všech jednotlivých členů zobrazovacích systémů. K ověření jeho přesnosti (stanovení nepřesnosti) byly použity reálné výrobky i simulační software. Z ověření je zřejmé, že při dodržení zde popsaného postupu budou dosažené výsledky jednoznačné a opakovatelné, aby mohly být vyhodnocovány dle normativních dokumentů.

Key words

NDT, Dimension measurement, digital radiography, computed radiography

1 Introduction

The non-destructive testing methods (incl. radiography) allows determination of the internal imperfections dimensions. Each manufactured part includes some internal imperfections. But not all of these discontinuities are so dangerous to disable the usage of the part.

Radiography uses radiograms or images as mean of display (in case of the classic wet film radiography a radiogram was defined as a record on the radiographic film or paper ([1], p. 16). New digital methods don't use this media. Therefore we are talking about radiographic images in connection with.

The evaluation of the displayed imperfections images could be a free level process. The particular levels are called nominal, ordinal and metric.

The Nominal level is restricted for really serious imperfections (e.g. cracks), which can induce the fatal damage of the component and destruction of assembly. In case of nominal judging is only existence of considered imperfection good reason for rejection of the part. Because not all of imperfections are so dangerous the other imperfections evaluation is based on their dimensions.

In casting industry is common to evaluate the discontinuity acceptability by comparison of radiographic image dimensions with the reference images (to compare size). This approach is well established in ASTM standards – in reference catalogues e.g. E 155, E 186, E 466, … ASME Code focused mainly to weldments partly use this approach also.

European standards focused on the weldments criteria of acceptability offer the last of the free mentioned evaluation levels – the mertic evaluation. This level is common and is well entrenched in the EN 12 517 standards.

2 Reason of this study elaboration

The methodic of dimension measurement is in case of wet film radiography well described. The image on the radiography negative is constant in term of image contrast, scale as well as dynamic range (it is impossible to suppress or emphasize some of optical densities against to the rest of dynamic range). If the comparison of radiogram with reference image is needed, both images are placed on a light box side by side. The scale is equivalent for both and if the dimension want were measured, the ruler or magnification glass with scale could be used in this case.

On the other hand the digital image could be deformed at will. Shape and dimensions of displayed part could be changed by scale chase as well as by contrast shift, by filtering etc. The most important image operations that affect the final dimensions of the image displayed by monitor are listed in the following table.

Table 1. *Influences to the real image dimensions*

#	Name	Importance of influence
1	Zoom	Very important
2	LUT (Look Up Table)	Important
3	Gamma correction	Important
4	Contrast shift	Important
5	Filter function	Importance in acc. to filter type

In industrial practice the acceptance criteria are round to millimeters (or tenth of millimeters) after calculation. The accuracy of the measuring aids is on the same level. If some of the evaluated details (some indication) is on the edge of acceptability it is not possible to decide exactly, if the part is acceptable or not (the subjectivity of an interpreter shall be considered also). In this case part is preventively rejected, or the reexamination is required usually. In both cases the expanses are increase. This incident in real practice (with wet film radiography) occurs rarely. Amount of these mistakes is decreased by high stability of radiograms (contrast, scale, …), by good education of interpreter as well as by practice (if one is not sure, could ask the headman worker (on the job education process).

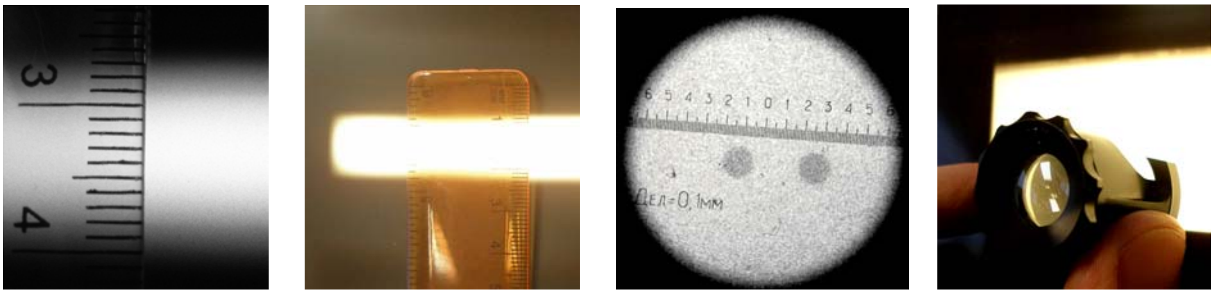
On the other hand – the digital image could be deformed and modified at will. Therefore the digital measuring tools are needed for accurate determination of indications dimensions and why the correct measuring procedure shall be followed.

Nowadays is not possible to obtain this knowledge from older workers. We are the first generation of the digital radiographers. The available literature states different procedures, and software developers usually don’t give us sufficient information about measuring tools usage.

The reason of this study elaboration and at the same time its goal was to summarize necessary procedural steps and surrounding influences, which allows obtaining the result with the same accuracy and reproducibility as in case of wet film radiography. The objective of this study isn’t to establish the procedure, which give us the result accurate to a micron, but the procedure, which allow reaching standard accuracy on all of examined parts manufactured by different technologies. These rules show also good maner for ordinal level of evaluation.

3 Geometrical conditions and its conclusion to ionizing radiation physics

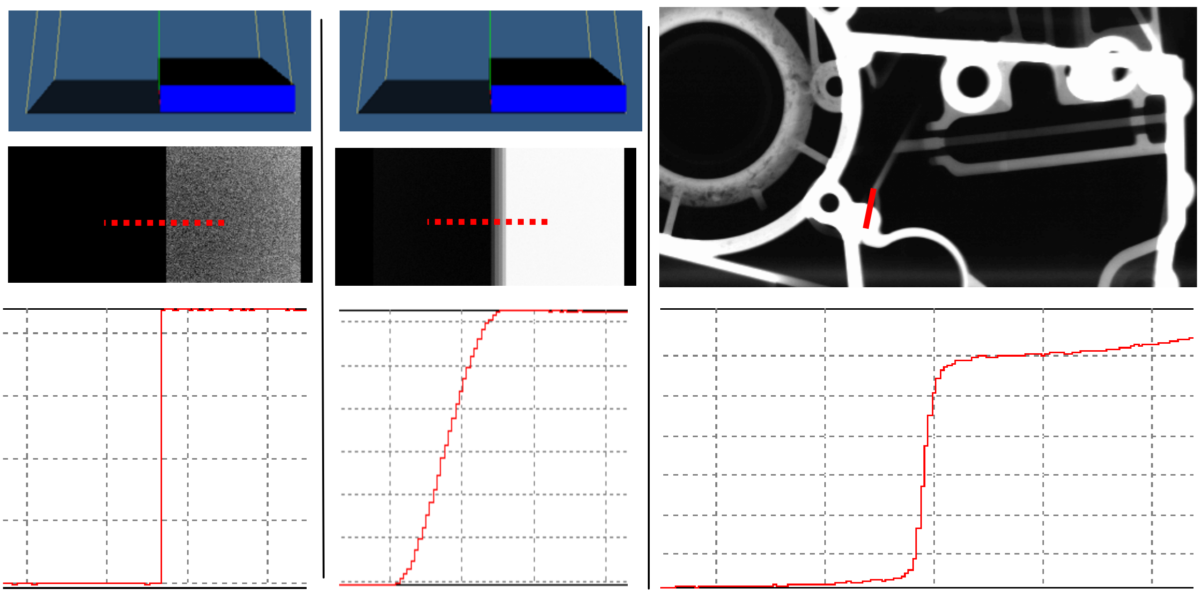
It is true that in case of wet film radiography is the measurement done by ruler or magnifying glass with scale only. The question is where the edges of the measured image are.



Picture 1. *"Undercuted" edge on the RTG image and usage of magnifying glass with scale*

The theoretically sharp image is possible to expect especially in case, when the radiation source has point dimensions and the source - detector distance is endless. Unsharpness is caused by real distance (geometrical unsharpness) as well as by real dimensions of used detector elements (inherent unsharpness). The final radiographic unsharpness consist of both mentioned particular unsharpness and this cause the degradation of theoretically sharp edge into the shape shown in the next image.

If the radiation source will be really point sized the image edge will be getting neat to the theoretical line edge. If this point source will be placed in endless distance from detector, the image of the part will be without geometrical magnification. This endless configuration is impractical due to rule called „square law" [5]. Common distance is about 700mm. Due to this geometrical configuration the radiographic image is geometrically magnified (its dimensions are bigger than real part). The distance object – detector also change the dimensions of the radiographical image as well as above-mentioned unsharpness.

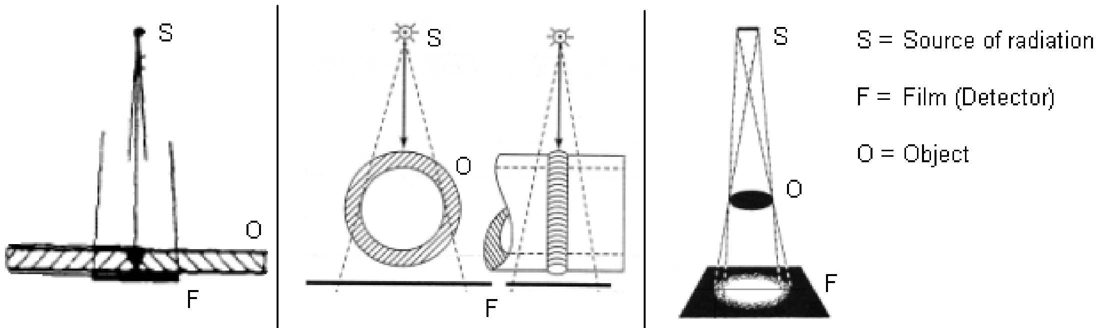


a) without distortion b) distorted model c) real part

Picture 2. *Edge profile degradation by the unsharpness influence*

Note 1: *If we are talking about radiographic images, we can talk about density profile (of gray level profile). It was generally accepted, that all shades of image (traditionally in gray scale) is possible to represent by numbers. If every shade will obtain its oven number systematically (e.g. white = 0, and each darker shade will get previous number + 1), will be possible to represent the image by 3D model and each its cross-section will be possible to express graphically.*

The following test will be intent on the simplest geometrical configuration as recognized by standard EN 1435 (basic configuration [2], p. 9) or by ASME Code (ASME G, [7], section V, p. 34), in the sense of the following picture. Other configuration could cause additional geometrical distortions, which shall be speculating about in the specific cases.



a) EN 1435 b) ASME G c) geometrical unsharpness

Picture 3. *Geometrical configuration and its influence to distortion of radiographic image*

4 Criteria of acceptability

For better understanding of evaluation and criteria of acceptability let's mention the next typical standards.

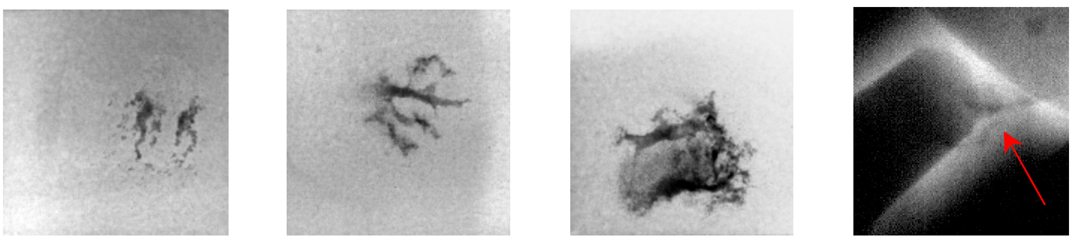
Metric evaluation: according to EN 12517-1
Ordinal evaluation: according to ASTM E 155

In case of EN 12517-1 limit dimension of indication is determined for imperfection like porosity or inclusion. The criterion is calculated on the base of material thickness. Typical calculation formula (for Metallic inclusion) is in [3], p. 8. For 2nd level of acceptablility is valid (1).

$$l \leq 0{,}3s \qquad l_{max} = 3\ mm \tag{1}$$

Where: l = indication length [mm]
s = nominal weld thickness [mm]

On the other hand reference catalogues holds the typical images of common imperfection in different sizes. For better view some samples (E 155) are listed below supplemented by real image of casting.



Picture 4. *Preview of the reference catalogue ASTM E 155 – shrinkage, wall thickness ¼ in.*

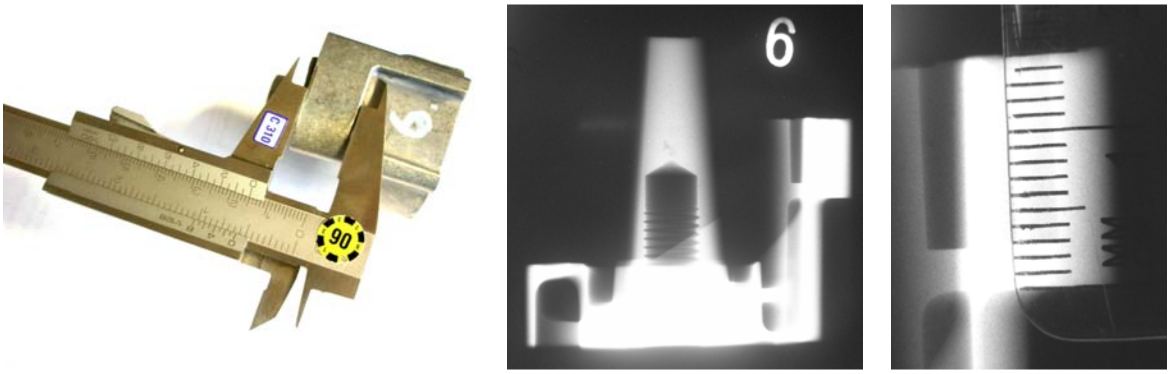
Important is, that criterion is established for dimension of indication (not for dimension of imperfection). Therefore the above-mentioned unsharpness and geometrical magnification could be leaved out. Technical practice includes also some tasks, which need to determine real dimensions of the part (or its geometrical shape).

5 Evaluation of image dimension and real part dimension

In case that the dimension of indication is evaluated on the film radiogram the ruler is used commonly. Read out is depend on subjective assessment of image edge. If any fundamental error is excluded, the result will not be influenced by this potentially wrong assessment of edges (as well as the alignment error in case of calculation of criteria of acceptability is not calculated).

The case when real dimension readout is needed is more difficult. This could occure in case of dimension of drilled hole in material or in case when the real position of some part in assembly is unknown. In this case is the image unsharp – the correct edges shall be assessed, and than dimension of measured indication should be recalculated due to the geometrical distortion.

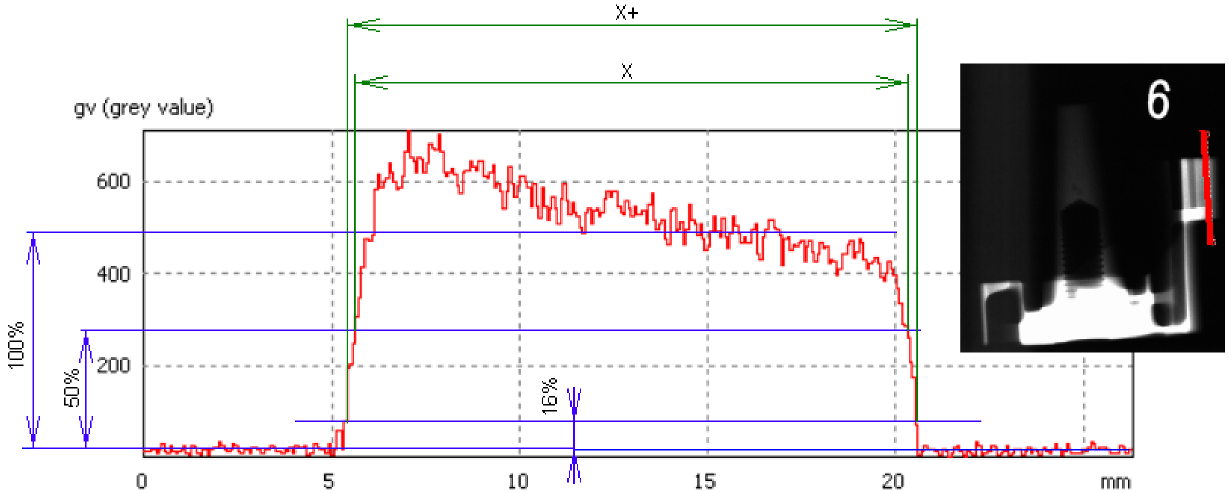
Due to unsharpness of the measured part (or shape) are edges unclear. If the dimension could be determined with some tolerance zone the edges position on the image will be stipulated according to operator consideration.



Measured by caliper – 15,1 mm Image dimension (measured by ruler) – 15 mm

Picture 5. *Casting dimension measurement*

In case, when exact result is needed, microdensitometer measurement of optical density profile is possible. On the base of this profile the edge could be determined by the specific shade level (for example the method of equivalent fields could be used (cca 50%) or Klasens' method (16%); [4]).



Picture 6. *The optical density profile usage for dimension measurement*

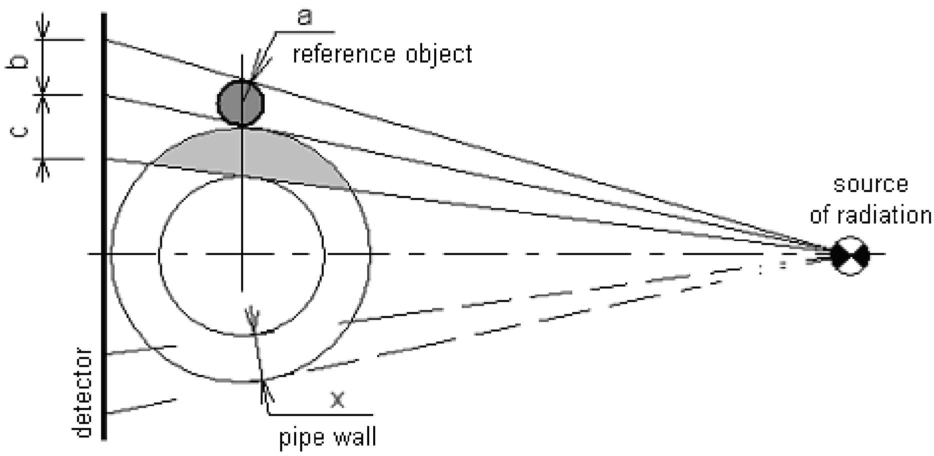
After the dimension readout from profile is important to determine the detector to source distance and calculate the correction for geometrical distortion. It is not easy in some cases and that is why the reference object is used commonly. If the measured and reference object are in correct configuration it is possible to use the geometry and simplify the calculation algorithm.

Note 2: *As the reference objects are used not only external parts but also some known geometrical shapes of measured part. For example if the depth of drilled hole in the material is needed to measure, as reference object the known diameter of measured hole is possible to use.*

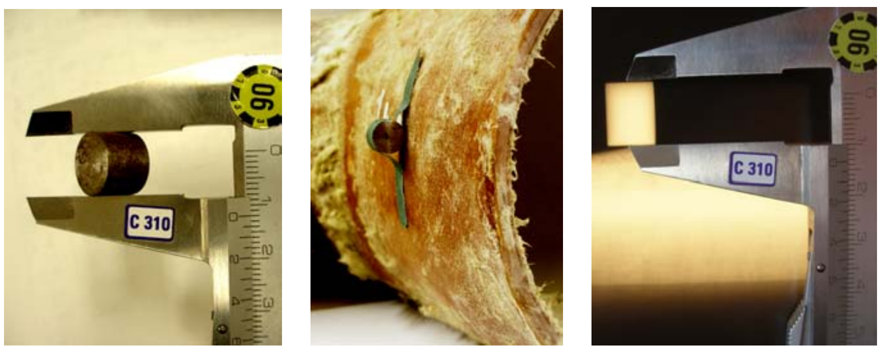
The most typical kind of this task is determination of residual wall thickness (corrosion decrease) in chemical and petrochemical industry. In this case the criterion of acceptability is the nominal thickness computed during design. The dimension assessment is the same like in the previous case. The reference body is external (the pipe don't offer suitable shape detail).

The readout of dimension isn't easy in this case. The operator must be skilled. In practice all helping aids are welcomed. This is reason why the caliper (which can cause the scratches of negative film) is used. In case that this kind of inspection is needed in higher amount, special aids that enable a direct readout are used.

Determination of pipe wall thickness measurement (tangential method):



Picture 7. *Tangential geometrical configuration*



Picture 8. *Measurement of reference object dimensions and the wall thickness*

Real diameter of reference object is 12 mm radiographic image - 13,5 mm. The same geometrical magnification has influence on the image of wall. Calculation of real wall thickness is possible according to equation (2).

$$x = \frac{a \cdot c}{b} \quad (2)$$

Where: x = real thickness of the wall
a = real diameter of the reference object
b = dimension of the reference object image
c = dimension of the wall thickness image

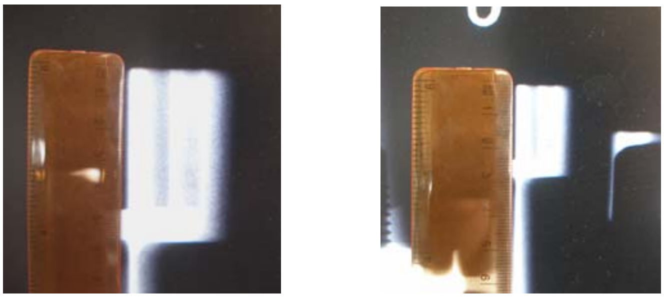
6 Digital industrial radiography, its benefits and risks

One of the most important benefits (in conclusion to dimension measurement) is the possibility of easy creation of gray value profile (it is not possible to talk about optical density due to its definition [5]). Possibility of easy analyze again opens the question of the edge position assessment.

The wet film radiography offers two simply models of edge determination:

- Orientation assessment (without exact definition of the shape start and end)
- Assessment of optical density level like edge (50%, …)

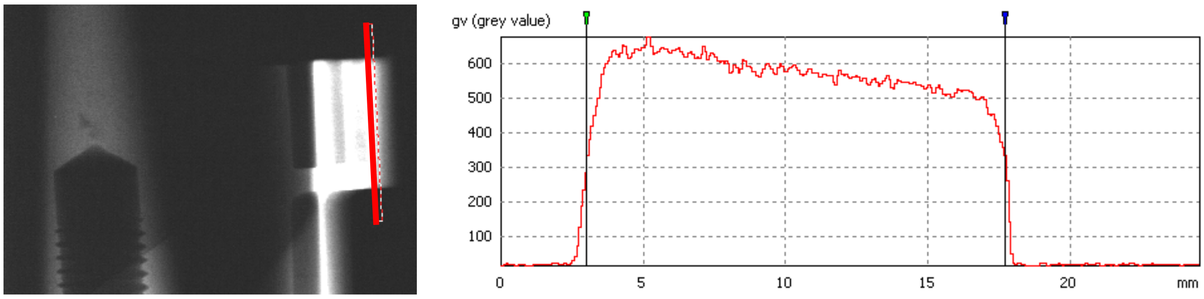
Orientation assessment is useful for first overview. In case, when we will try to readout any dimension, we will find out, that the definition of one pixel dimension is needed (otherwise the dimension will be declared in „pixel“ units). The digital image real dimensions (of monitor) could be changed by zoom tool. This fact shall be considered. We have again two ways how to define the image dimensions. One of them is usage of the reference objects again. Another one is to calibrate the pixel size directly.



Picture 9. *Scale change of the monitor view (left - 1:1; right 2:1)*

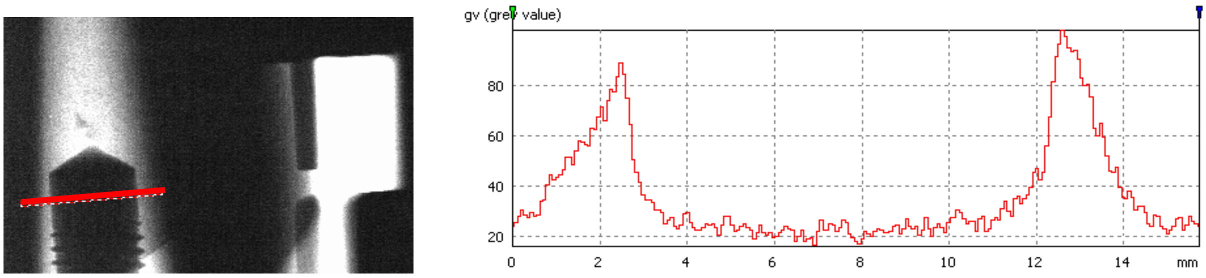
Note 3: *„1:1“ means, that one pixel of saved image (or used detector) is viewed as one pixel of monitor.*

For pixel calibration to have detailed information about detection apparatus setup is important. If these details are available it is possible to read dimensions of all images acquired by this configuration (geometrical, SW and HW). In case of reference object usage is possible to determine the dimension of pixel dimension (the geometrical conditions shall be considered). Also it is possible to determine the dimension of measured object directly. In case, of the direct assessment is important to decide, which gray value represents the real edge of the object.



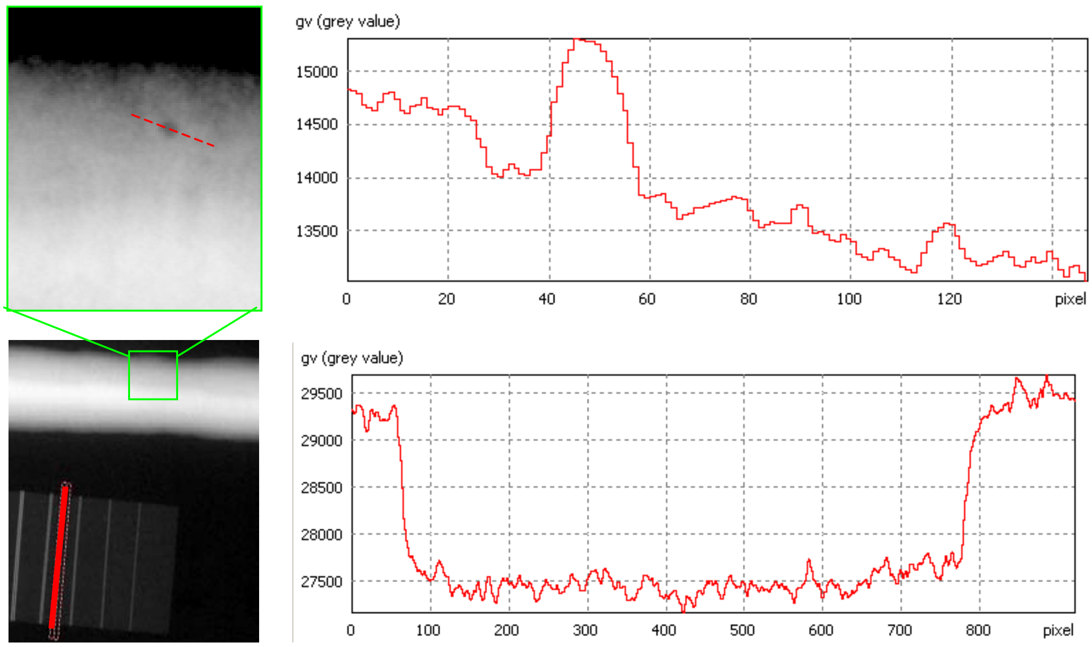
Picture 10. *Real object dimension was measured as 15,1mm. For image measurement was chosen gv (gray value) level 300 (50%)*

Some theory tell us, that it is not important, which level of gray we will choose, only to take the same level on the reference object as well as on the measured object is important. This procedure gives good results but is useful only in case that both geometrical shapes are represented by same region of dynamic latitude (it means that the reference object has be suitably placed).



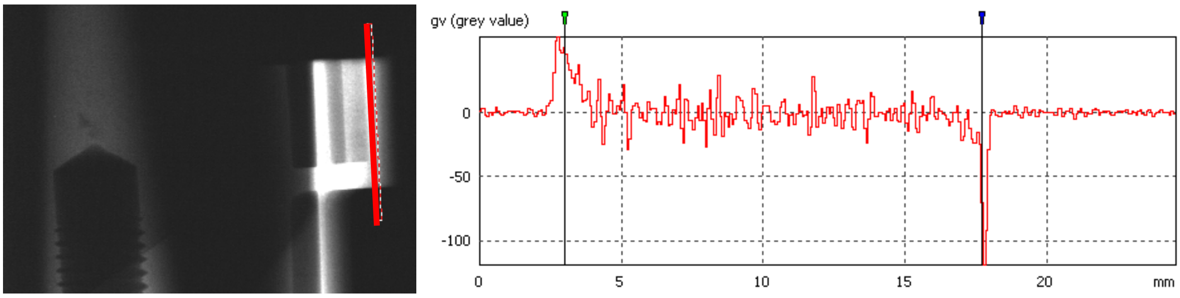
Picture 11. *Reference area (on the picture 11) is calibrated at gv level 300. Measured part is shown between levels 0 and 100.*

It is possible to say, that we can use lover levels for calibration. On the picture no. 7 is shown, that change of calibration level will affect also measured dimension. True reason why is impossible to use low gv is, that some configuration don't offer the suitable levels. This is valid mainly in case of weldments, where is used the duplex wire image quality indicator (IQI) as the reference object.



Picture 12. *Duplex wire IQI is represented by gv from level 26.000 up to 30.000 indication of pours - 13.000 up to 16.000*

Thanks to digital processing to analysis of gv profile is easy. Therefore to calculate the first derivation is easy. This shows in place of change in gradient of profile curve a local extreme and this point is suitable place for assessment of edge position.



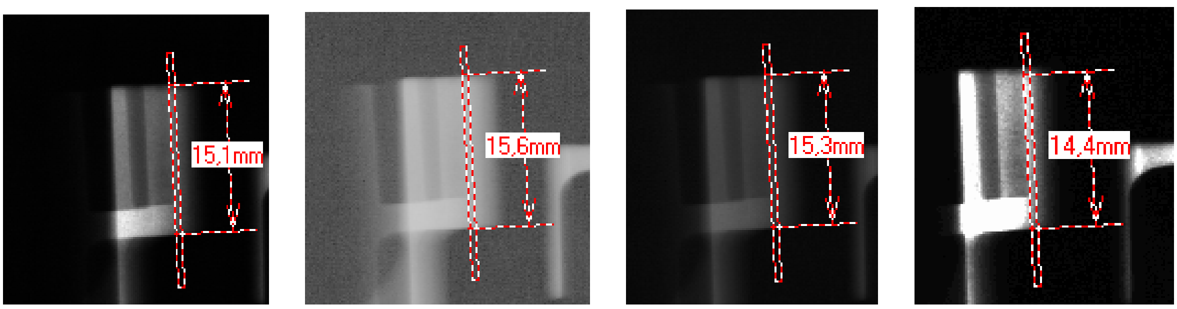
Picture 13. *First derivation of gv profile (shown on the picture no. 8). Vertical lines represents the position of shape edges assessed on 50% level. Dimension deviation is 0,2mm.*

Demands to usage of the first derivation are same as in the case of orientation assessment of edges. That is why is the first derivation becomes a standard tool.
From above mentioned outcome, that digital industrial radiography give us the tool, which allows more exact measurments. Therefore is also possible to expect that the results will be more accurately. To fulfil these expectations is important to accept some basic rules of image processing.

Introduction of this text lists some important factors, which can affect the digital image size on the monitor

1) Zoom
Influence of zoom tool is eliminated by pixel calibration. If it is done correctly, the measured dimension will be accurate independently on the used scale. On the other hand the scale change has influence on displayed image and therefore some indications can become invisible (in case of magnification the sharp edges becomes softer and in case of image reduction can some information disappear from monitor).

2) LUT
Look Up Table assignee the numerical values to gray values and vice versa. The linear assessment is generally presumpted. The practical imaging systems use also another kinds of LUT (exponential, logarithmic, …). Offset is also common. In case of incorrect LUT application will reduction of some gv disable not only correct assessment of the edges but whole detection of some objects. This is documented by the next pictures, where the calibration was done (with usage of first derivation) on the linear LUT and than was LUT changed without recalibration.



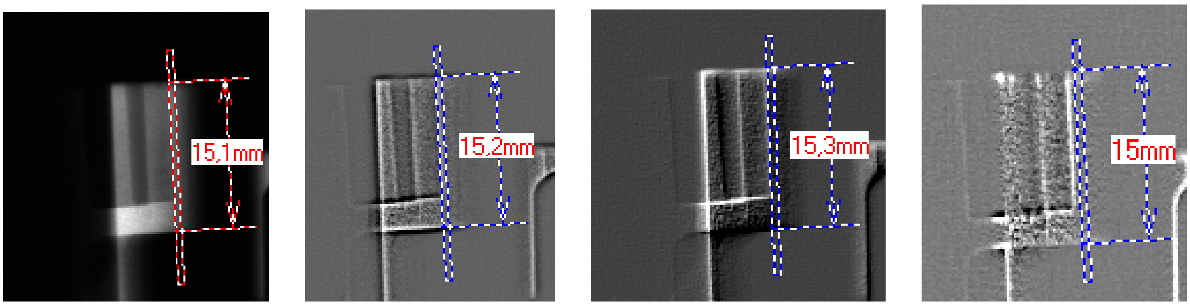
Picture 14. *Influence of LUT (from left side: 16bit linear LUT, 16bit logarithmical LUT, 16bit cubic LUT, 12 cubic LUT)*

3) Contrast and gamma shift

Contrast and gamma are powerful tools, which enable us to improve the visibility of some details (represented by specific latitude of gv, the other areas of gv are suppressed). If the mechanism of this operation isn't considered, the orientation assessment of the edges absolutely fails. This is again reason for usage of first derivation of gv profile.

4) Image filtering

While above mentioned operations changes only the image viewed on the monitor (the gv profile stay unchanged) the filtering will change displayed image as well as gv profile. Different filters are available. Some of them can reduce a noise (and also high frequency details), others can highlight suitable oriented edges, … After filtering operation are the image edges shifted.



Picture 15. *Filtration influence (from left: no filter, running mean, emboss, high pass a running median)*

7 Conclusion

From above mentioned outcome that if we want to use the new digital industrial radiographic techniques with traditionally good accuracy (offered by wet film radiography) we shall follow some general rules.

- To analyze image in 1:1 scale
- To analyze image before filter application
- Use the first derivation of gv profile to asses real edges of image.

If the mentioned rules will be followed, the accuracy of the results will be repeatable in case of weld as well as casting and other inspected products.

These rules shall be followed also in case of ordinal evaluation level.

For purpose of comparison both images shall be viewed with the same scale (1:1 if it's possible). It means, that pixel dimensions of both images have to be same. New reference catalogues respect it and offer this possibility.

If any image modification is proceed, (e.g. filtering, gamma shift, zoom, …) this shall be proceed on both images by the same way.

8 *Used symbols*

l	indication length	[mm]
s	nominal weld thickness	[mm]
x	real thickness of the wall	[mm]
a	real diameter of the reference object	[mm]
b	dimension of the reference object image	[mm]
c	dimension of the wall thickness image	[mm]
gv	gray value	[-]

9 References

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