Qualification of two Tube Inspection Systems for High Quality in-Process Digital Radiographic Testing of Longitudinal Welded Tubes

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Abstract. Similar to the medical radiographic technology, within the industrial radiographic technology a change from conventional radiographic inspections with X-ray films to digital radiographic technology using digital, high resolution line or array detectors as image producing systems takes place in the last years. This technology is increasingly used for process integrated fabrication inspection and is at this time subject of current standardisation procedures.

The company Butting has put into operation in their new longitudinal welded tube production lines two fully automated inspection systems for radiographic testing of tubes with two different digital, high resolution array detectors. The digital X-ray image can be digitally saved and also be visualized on a monitor. With the radiographic facilities tube wall thicknesses from 4 to 90 mm can be tested by X-ray. By an annual inspection output of about 150,000 meters weld seam the inspection systems fulfil highest requirements to inspection quality and economic efficiency.

TÜV NORD EnSys Hannover has accompanied the initial operation of the digital radiographic facilities and qualified them in accordance with the draft standard DIN EN ISO 10893-7 and DIN EN ISO 17636-2. Within the qualification process the performance of the inspection systems concerning image quality, image sharpness and long-term stability were examined by means of the requirements of the draft standards. Therefore a concept for controlling and supervising image quality, performance and long-term stability in the way of periodical system monitoring was developed by company Butting and TÜV NORD EnSys Hannover.

This contribution shows the new digital radiographic facilities at company Butting and their performance in comparison to conventional radiographic inspection using X-ray films. Signal to noise ratio, image quality, basic spatial resolution and image unsharpness will be demonstrated and the compensation principle will be discussed in this context. With the help of representative quality indicators the detectability of typical weld seam flaws in comparison to X-ray film technology will be presented.

Introduction

In industrial X-ray technology there is a change from conventional radiographic inspections to digital radiographic technology with the intention to save time and costs. Following this trend Company Butting put into operation in their new longitudinal welded tube production lines two fully automated inspection systems for radiographic testing of tubes with two different digital, high resolution array detectors.

Respecting customer demands Butting asked TÜV NORD EnSys Hannover to accompany the initial operation of the digital radiographic facilities and qualify them in accordance

with actual draft standards, taking into account the performance of the inspection systems concerning image quality, image sharpness and long-term stability.
A main question was the performance of the new digital radiographic facilities in comparison to conventional radiographic inspections using X-ray films.

Fully automated inspection systems for radiographic testing of tubes

Company Butting put into operation two fully automated inspection systems for radiographic testing of tubes with two different digital, high resolution array detectors. Both testing facilities, the X-Pipe Twin and the X-Pipe are used for digital X-ray inspection of longitudinal welded tubes. The tubes which can be tested have a dimensional range from outer diameter 60mm to 1260mm and a wall thickness from 3mm to 90mm, a tube length of 3000mm to 18200mm and a maximum tube weight of 13t.
Both radiographic testing facilities have the possibility for automated readjusting of machine axes to fit for the different tube sizes. Figure 1 shows a sketch of the X-Pipe Twin with the X-ray tube in vertical beam direction, the detector, the film/detector holm and the tube bearings. The three main optical distances, Focus Object Distance, Focus Detector Distance and Object Detector Distance will be adjusted automatically to the demanded value.
The focus sizes of the Isovolt 225kV, which is used at the X-Pipe, are 1.5 / 0.4 mm and of the Isovolt 450kV, which is used at the X-Pipe Twin, are 1.0 / 0.4mm. With optimal adjusted machine axes the magnification of the X-Pipe is 1:1.06 and of the X-Pipe Twin is 1:1.25. The used digital detector at the X-Pipe has a pixel matrix of 4200x1040 with a pixel size of 50µm and at the X-Pipe Twin has a pixel matrix of 1024x1024 with a pixel size of 200µm.

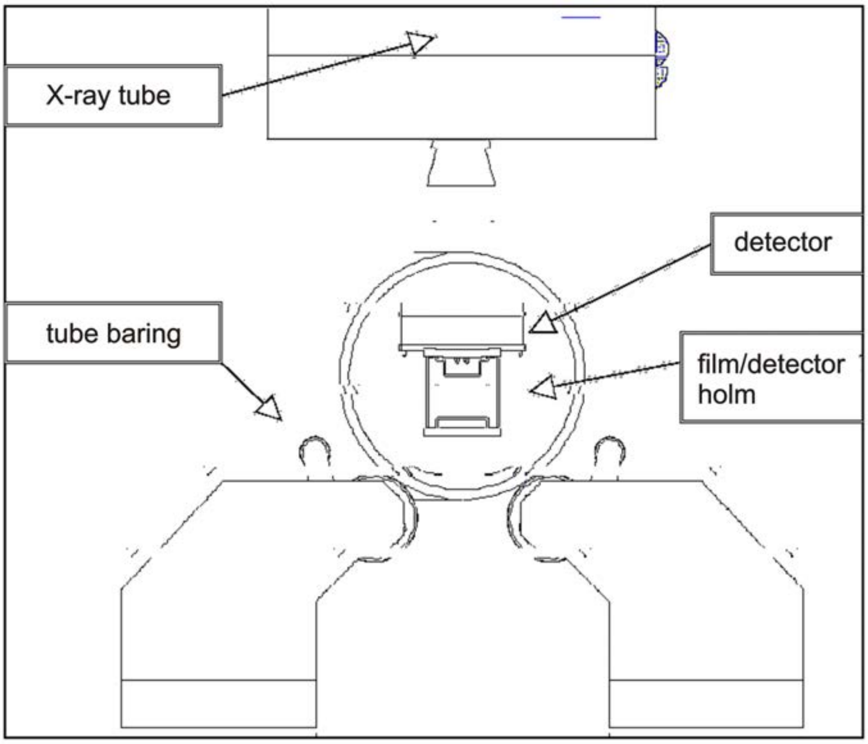

Figure 1. Sketch of X-Pipe Twin

The annual operational capacity (output) of the automated radiographic testing facility is about 146,000m weld seam. Figure 2 shows the inspection results of one testing facility per year. The standard Butting test category is inspection quality class B.

About 30% are weld seams without indication, 66% are weld seams with minor indication, 1% weld seams where the indications has been sized and control pictures has been taken by X-ray film. Only 1.92% have a weld seam defect and have to be repaired which shows the high manufacturing quality at Butting.

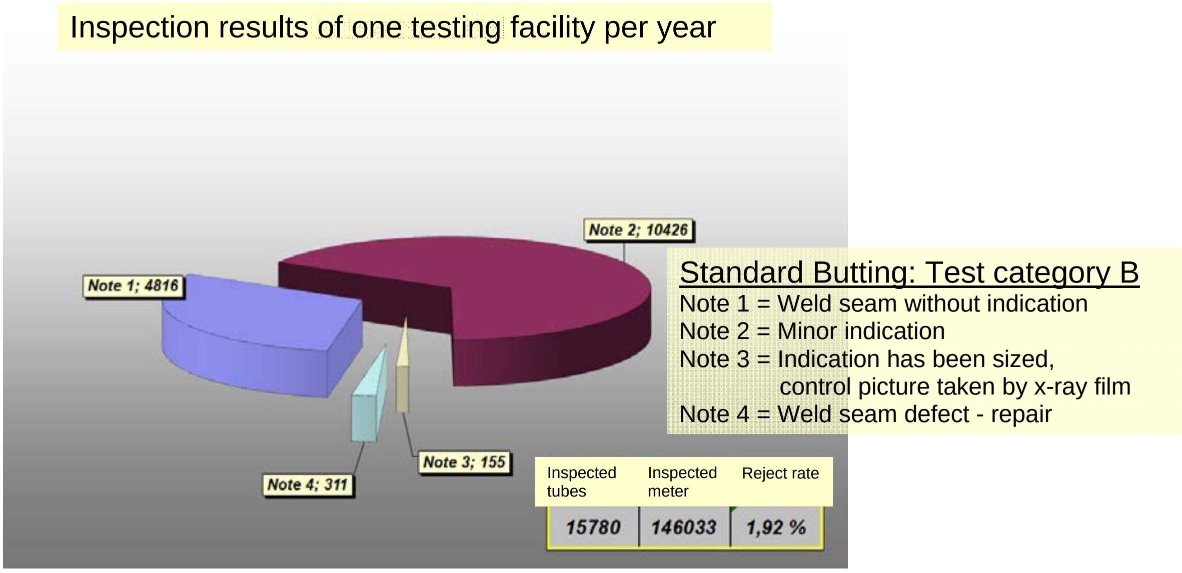

Figure 2. Annual inspection performance

The evaluation of images is done by qualified and certified personnel. Additionally an image processing system is used for automated evaluation of images. This automated system supports the evaluation personnel. Using thresholds for gray scale values, these features make it possible to detect weld seam defects in a proper way. Also the measuring of defect size is possible.

Qualification of digital radiographic tube testing facility

During the implementation of the new radiographic testing facilities several rules and standards were used, for example DIN EN 444 or DIN EN 1435, which deals with the general principles for radiographic testing or DIN EN 13068, which deals with the image properties, the long term stability and general principles of radioscopic testing.
In 2009 the draft standards DIN EN ISO 17636-2 and DIN EN ISO 10893-7 as standards for digital radiographic testing have been published and used in practice.
Because of customer demands Butting asked the department of Non-destructive Testing at TÜV NORD EnSys Hannover for the qualification of their new testing facilities based on draft standard DIN EN ISO 17636-2, which deals with X- and gamma ray techniques with digital detectors and DIN EN ISO 10893-7, which deals with digital radiographic testing of the weld seams of welded steel tubes for the detection of imperfections.
The image quality of digital radiographic pictures is considerably improved in comparison to X-ray films. Especially the contrast resolution enables an inspection sensitivity which is higher than the expected values. For example at a wall thickness of 12mm steel penetrated by radiation the IQI value for wire type is 5 wires better than the preset values given by DIN EN ISO 17636-2. This leads to an inspection sensitivity of 0.52% of wall thickness instead of required 1.65%.
For the whole wall thickness range from 3 to 23mm steel actual IQI values for wire type are better than required (Figure 3).

In practice there is a problem to achieve the standardised signal to noise ratio (SNRnorm) value for inspection quality class B with the X-Pipe. In the new draft standards the SNRnorm values are not required according to 6 X-ray film classes in dependence of the wall thickness as it was in DIN EN 584-1, but according to 2 fixed values for inspection quality class A and B. In the range from3 to 23mm the SNRnorm value is only for 12mm steel higher than the required value of 100 according to DIN EN ISO 17636-2. To solve this problem and reach the required SNRnorm values image averaging is a solution. But the disadvantages of image averaging are rising inspection times and costs.

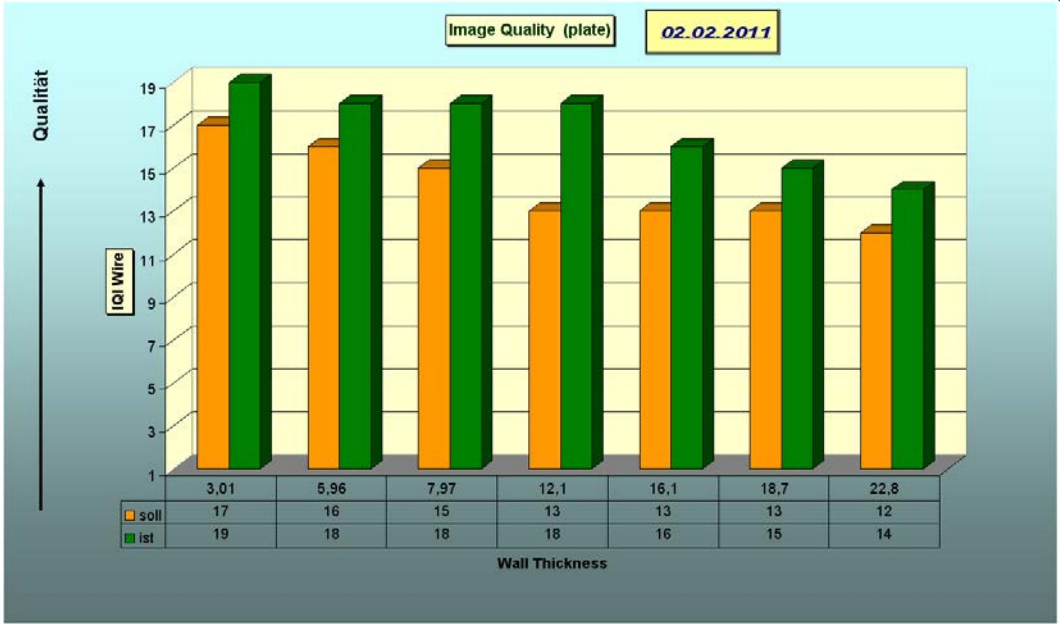

Figure 3. Image quality measured with wire IQI

Defect catalogue

An extensive program is started to clarify whether real weld seam defects can be found save and whether there is an improvement in comparison to conventional X-ray film technology, or not. The digital pictures and X-ray films are compared and for some defects metallurgical examinations are done, which give information about the real dimensions of the defects.

A defect, lack of fusion, can be easy detected in steel with a penetrated wall thickness of 41.26mm by digital radiographic testing. The same defect is hard to detect on the X-ray film. In the direction of penetration there is a defect extent of 590µm as could be measured in the micrograph.

Another example in the defect catalogue is a slag inclusion which can be detected very good at the digital picture but on the enlargement of the X-ray film it can not be detected.

The defect catalogue contents a lot of such examples who show the quantum jump in radiographic inspection technology by using digital, high resolution array detectors.

At figure 4 there is another defect, lack of fusion, which can be detected in steel with a penetrated wall thickness of 41.26mm. The defect has a width of about 110µm with an extent of more than 100µm in direction of penetration, measured from the micrograph. The width is smaller than the pixel size of 200µm of the DXR detector but can be detected properly. The same defect can not be detected on the X-ray film.

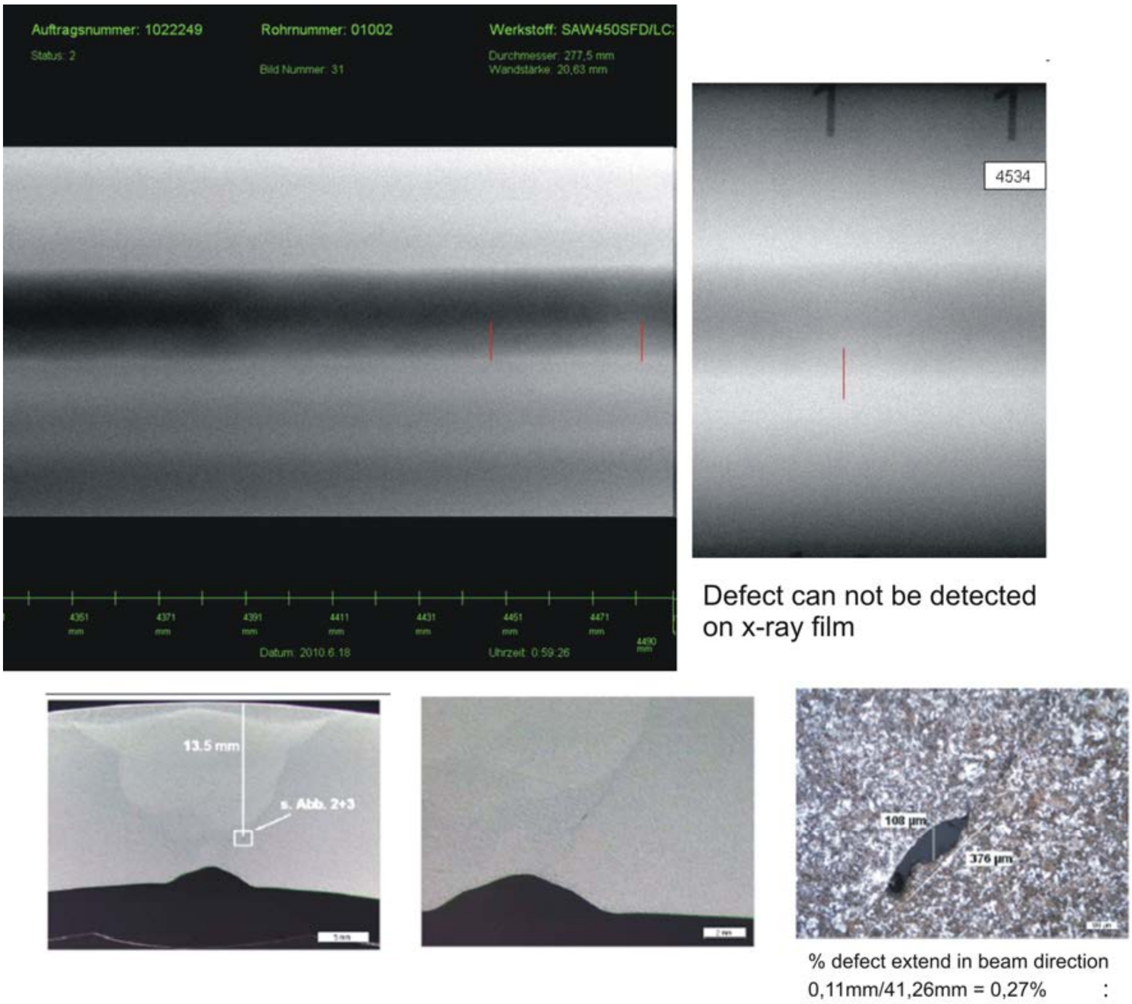

Figure 4. Defect lack of fusion

Another example for weld seam defect lack of fusion has been detected with conventional X-ray film technology at TÜV NORD EnSys Hannover and later with the new digital radiographic facility X-Pipe Twin at Butting. Within the qualification of the new X-Pipe Twin the comparison of the two X-ray films proved the performance of the new digital radiographic facility. The defect on the digital picture could be seen as good as on the film or even better.

Monitoring concept for image quality, resolution and long-term stability

For the qualification of the digital radiographic facilities the well known IQIs wire type, step/hole type and duplex wire type are used. Figure 5 shows as an example the required values and actual values for the 3 IQIs for 50mm wall thickness. From a wall thickness of 50mm up to 90mm the target IQI values for wire type, step hole type and duplex wire type are fulfilled. As an example for a wall thickness of 4mm the required values cannot be fulfilled. There is a required value of 13 by duplex wire and actual 9, 4 steps less than required. For wire type there is a required value of 16 and actual 19, 3 steps more than required.
The SNRnorm is for all wall thicknesses higher than the requirement.

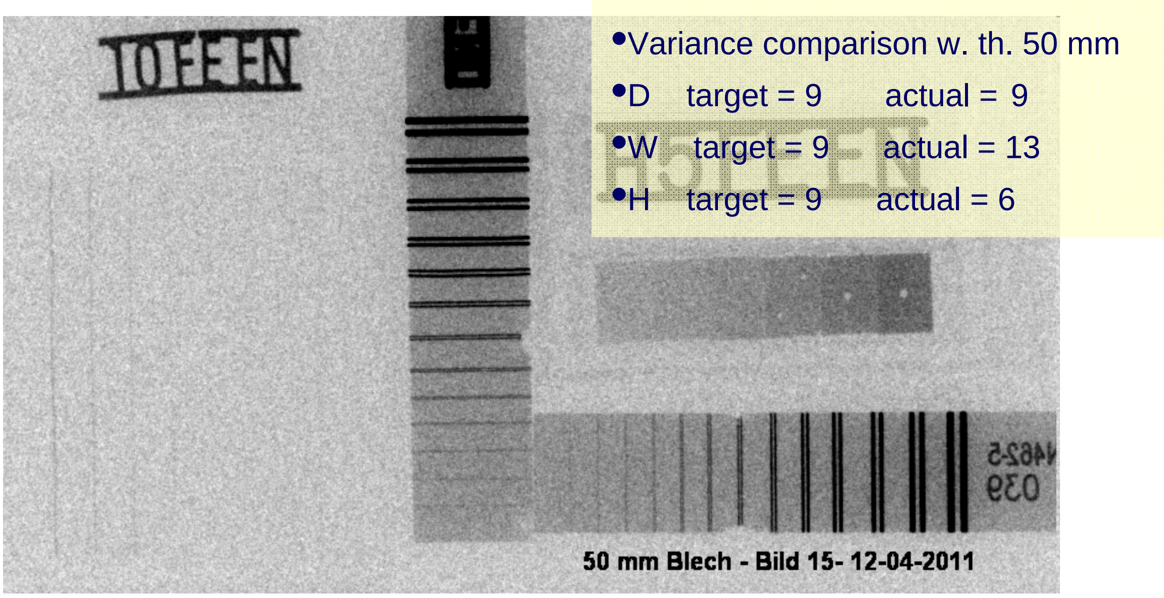

Figure 5. IQIs for system monitoring

With the aim to evaluate the image quality, resolution and long-term stability of the new digital radiographic facilities, a monitoring concept has been developed. The complete range of wall thicknesses has been tested monthly as follows:

Steel plates and pipes with different thicknesses have been located upon the detector to evaluate the image qualities as a function of wall thickness.

The IQIs wire type, step/hole type and duplex wire type have been put on top of the stack of steel plates. Now the pictures were taken and IQI values, the radiographic parameter and SNRnorm values have been evaluated and saved.

The IQI values for wire type are over the whole range of wall thicknesses better than required. For step/hole type there are up to 80mm wall thickness better values than required. For duplex wire type the required values have not been achieved from 4 to 40mm wall thickness. Nevertheless we can reach quality class B according to the draft standards by using the compensation principle.

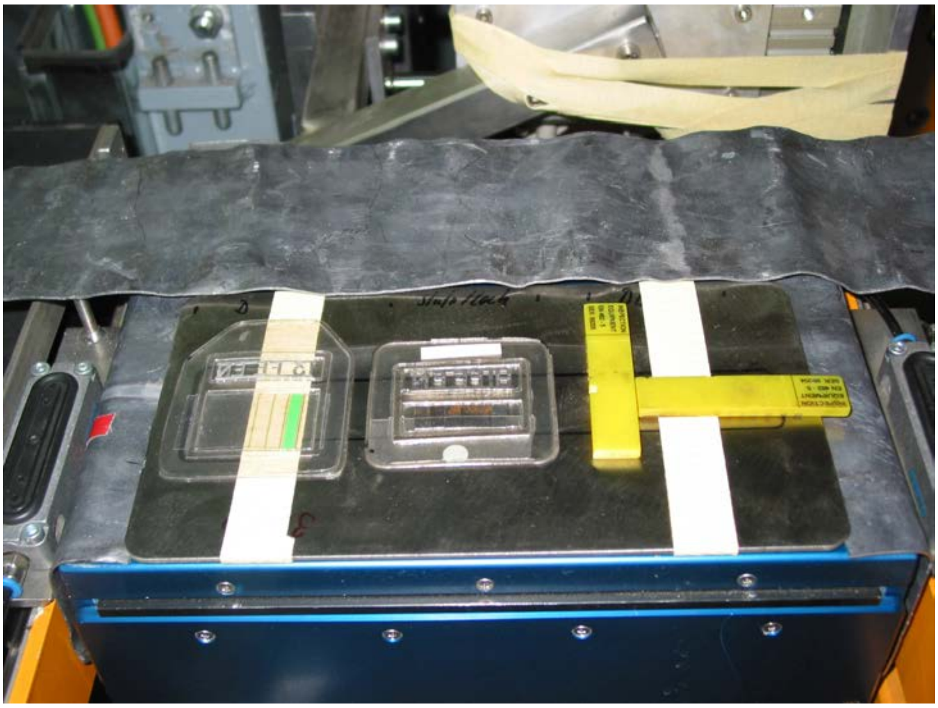

Figure 6. IQIs on stack of plates for monitoring concept

Compensation principle

With digital radiographic inspection using high resolution array detectors it is possible to detect quite smaller defects than required because of the high contrast sensitivity. Hence the requirements to the spatial resolution can be decreased. With the intention to consider this fact and to reach inspection quality class B according to DIN EN ISO 17636-2 and DIN EN ISO 10893-7 these draft standards contain a compensation principle, which works as follows:

The IQI-values for duplex wire type do not fulfill the requirements. The IQI-values for wire type or step/hole type are higher then the requirements. Not achieved IQI-values for duplex wire type can be compensated by higher IQI-values for wire type or step/hole type. A Limitation is given in DIN EN ISO 17636-2 – Maximum 2 IQI-values of wire type can compensate 2 missing IQI-values of duplex wire type and in agreement with the customer 3 IQI-values can be compensated. In DIN EN ISO 10893-7 no limitation is given.

As an example for 5mm penetrated wall thickness the drop between two peaks at duplex wire 8 is 38% and at duplex wire 9 no drop can be found (Figure 7). So the duplex wire 9, which means 0,26mm represents the unsharpness of the picture. But 3 steps are missing to achieve inspection quality class B.

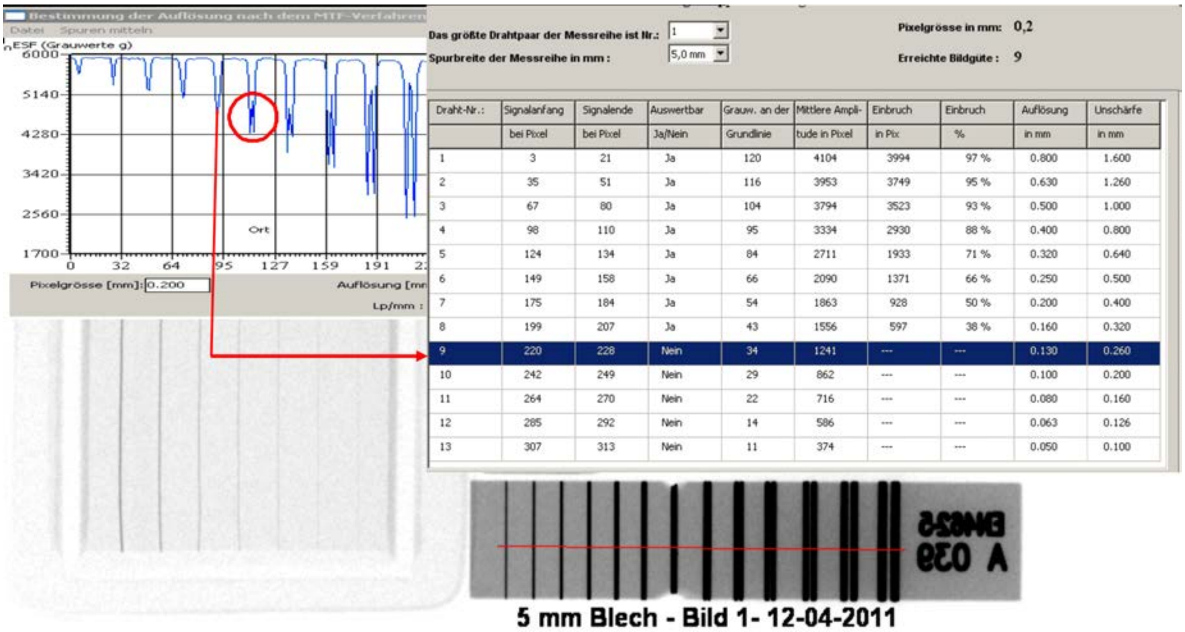

Figure 7. Evaluation of IQI duplex wire

For the IQI of wire type, which represents the contrast sensitivity, wire 19 can be detected. This is 3 steps more than required. The missing basic resolution can be compensated by the high contrast sensitivity. Inspection quality class B is fulfilled.

With the help of the compensation principle inspection class B can be achieved for wall thicknesses from 10 to 40mm according to DIN EN ISO 17636-2 and DIN EN ISO 10893-7 (Figure 8). For higher wall thicknesses no compensation principle is needed to achieve inspection class B. But for wall thicknesses lower than 10mm we have to compensate more than 2 steps which is not allowed according to DIN EN ISO 17636-2. Only after customers consent 3 steps are possible. For 4mm wall thickness we would have to compensate 4 steps of duplex wire but we have only 3 steps of wire type. Inspection class B can not be achieved for this wall thickness at the X-Pipe Twin.

Figure 8. Compensation principle (3 steps) to achieve inspection class B

Summary

TÜV NORD EnSys Hannover and company Butting made good experiences with the new digital radiographic inspection systems. Small defects in optically magnified images can be seen much easier than by evaluation of X-ray films without magnification. The automated evaluation of images supports the evaluation personnel. Using thresholds for gray scale values, these features make it possible to detect weld seam defects in a proper way.
The actual draft standards serve very well as theoretical base for digital radiographic inspection and changing the draft standards to valid standards will lead to a high acceptance of this technology by customers and experts.