RADIOGRAPHIC INSPECTION OF WELDINGS BY DIGITAL SENSORS

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Abstract: The newly available digital sensors for radiographic inspection are suitable for the application in several areas of welding inspection.

Flat panel detectors with 50µm pixel size are applicable for longitudinal and circumferential welds in the lower dimension range and application of x ray sources. Digital linescan x-ray cameras with 86µm pixel size are applicable in the range of maximum 250kV x ray energy as well as imaging plate systems with scanner resolutions up to 50µm for unlimited energy ranges. A special software has been developed for the uniform application of all systems which allows easy system control of the whole calibration and exposure process up to nearly complete automatic inspection reporting so that after the end of exposure the several inspection reports are available immediately.

The possibilities and limits for the practical application of the different systems are discussed together with practical experience in the piping production area. In most cases the resulting image quality of the different systems is comparable to high quality film radiographs.

An overview about the economical efficiency in relation to film radiography shows the high potential of these new possibilities in their suitable ranges of application.

Introduction: From the digital sensor systems available on the market at this time three different types have been chosen which have a pixel size of 86 µm and less. These systems provide an adequate radiographic resolution suitable for weld inspection. Two systems, the Hamamatsu C7942 flat panel detector (see fig. 1) and the imaging plate system Fuji ST 6 combined with the portable scanner VistaScan from Duerr (see fig. 2) can be used for mobile and stationary inspections while the NTB digital linescan x-ray camera (see fig. 3 and 4) may only be used for stationary inspection installations. The technical data of the used systems are listed in table 1.

Flat panel detectors and imaging plates may be mounted to the test object similarly as film cassettes. The digital linescan x-ray camera additionally needs a manipulator because detector and radiation source must be fixed and correctly aligned to one another (see fig. 4) so that the test object can be moved through the radiation beam or the source detector combination can be moved along the inspection length (see fig.5).

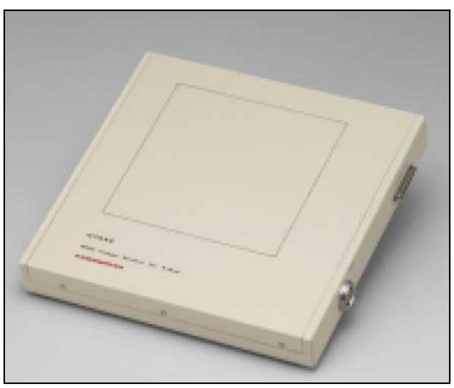


Fig.1: Flat panel detector Hamamatsu C7942

Fig.2: Scanner VistaScan for image plates

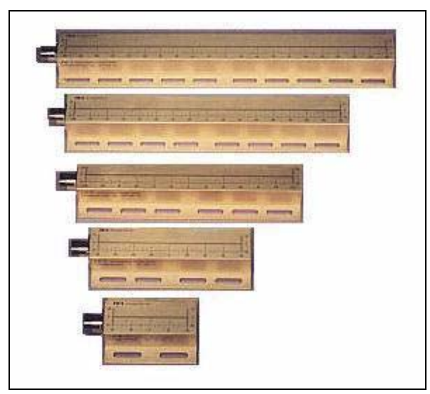


Fig. 3: NTB digital linescan x-ray cameras 80 – 400 mm length

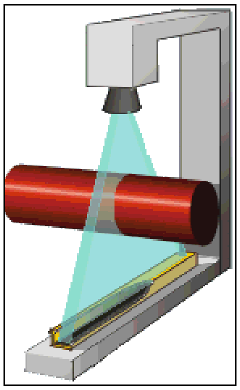


Fig. 4: Principle of linescan application

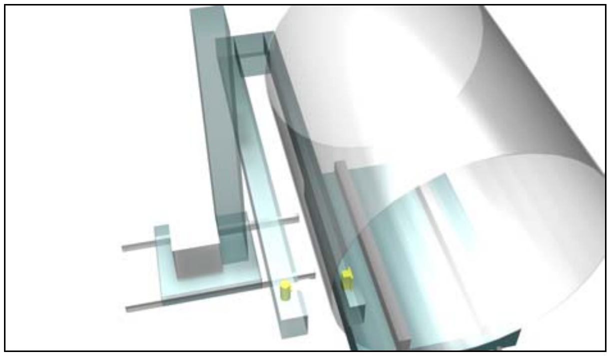


Fig 5: Manipulator for scanning longitudinal welds in pipes with bigger diameter

For example the manipulator for scanning longitudinal welds in pipes with bigger diameter shown in fig. 5 has a length of 3 meters. For the line scanner a very narrow radiation beam in the scanning direction is used so that scattered radiation is not influencing the image contrast. Due to the required scanning in case of the line scanner exposure times are higher compared with the other systems.

	Flat panel Hamamatsu C7942	NTB digital linescan x-ray camera	Imaging plate system Fuji ST 6 with portable scanner VistaScan (Duerr)
technology	CMOS	CMOS	Imaging plates
pixel size	50 µm	86µm	50 µm (scanner)/80 µm (plate)
pixel resolution	12 bit	12 bit	12 bit
outer dimensions	200x200x30 mm	80x34mm length: 80 – 480 mm	cassette: max.320x430 mm
image size	120x120 mm	max. 480 mm x (depending on scanner length)	max. 320x430 mm
weight	3 kg	2 kg	plate (240x300) in cassette:1 kg / scanner: 16 kg
shape	flat, rigid	linear flat, rigid	flat rigid/flexible
energy range	10 - 150 kV	10 - 250 kV	no limit
scanning time	440 ms	1 - 4000 ms per line	50 sec (240x300 mm)
exposure time	30 s	300 mm scan length: 5min (i.e. 86 ms per scan)	30 sec
file size	10 MB	depending on scan length	appr.10 MB depending on size
mobile/stationary	mobile/stationary	stationary	mobile/stationary
scanning velocity	-	1-2 mm/sec	-

Table 1: Technical data of the used digital radiographic systems

Results: To evaluate the suitability of the chosen systems for weld inspection the IQI sensitivity has been measured. The first set of measurements was done on aluminium step wedge objects with a step thickness range between 1 and 50 mm. Radiation energy was varied between 55 kV and 130 kV and had been increased every 5 mm, tube current was appr. 2 mA, exposure time 30 s in the case of flat panel and imaging plates. Comparable film radiographs needed higher exposure times between 60 and 180 seconds. The length of the applicated line scanner camera has been 320 mm. The exposures by line scanner camera required higher exposure times comparable with film radiographs.

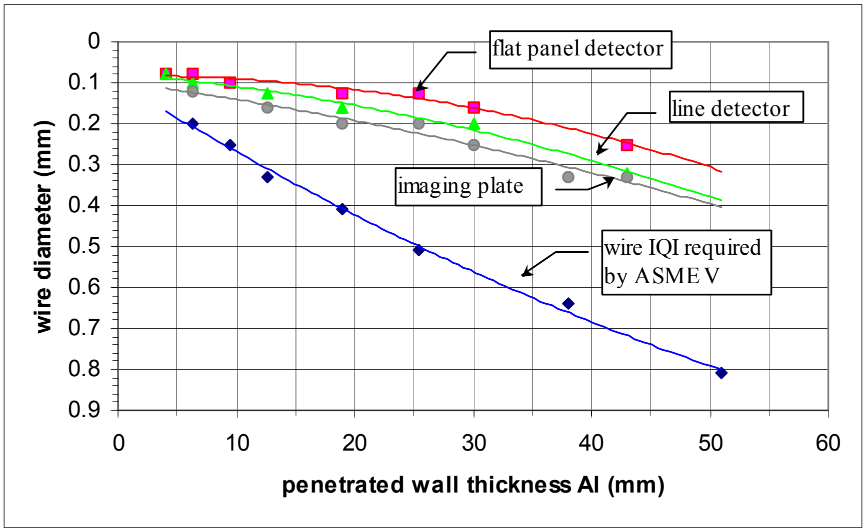


Fig. 6: Achieved wire IQI sensitivities for the used digital radiographic systems compared with the requirements of ASME V

At each step thickness at the upper end of the thickness range defined by ASME V, Art. 2 the required hole type IQI was fixed and additionally a wire IQI on each 5mm thickness step. The images have been evaluated on the computer monitor using optimised density and contrast display as well as optimised zoom factor for each thickness step.

Regarding the hole type IQI sensitivity in all cases the image quality of 2-1T is achieved. The results of wire type image quality are shown in fig. 6. The lower curve represents the image quality required by ASME V, Art.2.

In all cases the wire type IQI sensitivity is quite better than required by ASME. Due to the lowest pixel size best results are represented by the flat panel detector followed by the line scan camera and the imaging plate system. However line scan camera and imaging plate system results do not differ significantly. Measurements using steel step wedge objects showed similar results.

These results demonstrate clearly the capability of the chosen digital sensor systems for weld inspection.

For easy application and changing between the systems a uniform software system presenting just one user interface for all systems was developed (RADIS system) which contains all necessary functions for the calibration of all systems, exposure control, image acquisition, image processing, evaluation of radiographs and full inspection documentation ending with print out of inspection report (see fig. 7). The same computer set up can be used for all imaging sensors like imaging plates scanner (RADIS 400), flat panel (RADIS 401), line scanner (RADIS 402). Changing of systems is just done by selection of the wanted system. To complete the system a device for digitising already existing film radiographs has been integrated as well (RADIS 403).

The main functions are shown in fig. 8. After defining the different sensor systems completely (see right window in fig. 8) the actual system is activated via this window. Images exposed by the selected system are displayed in their real size independent whether

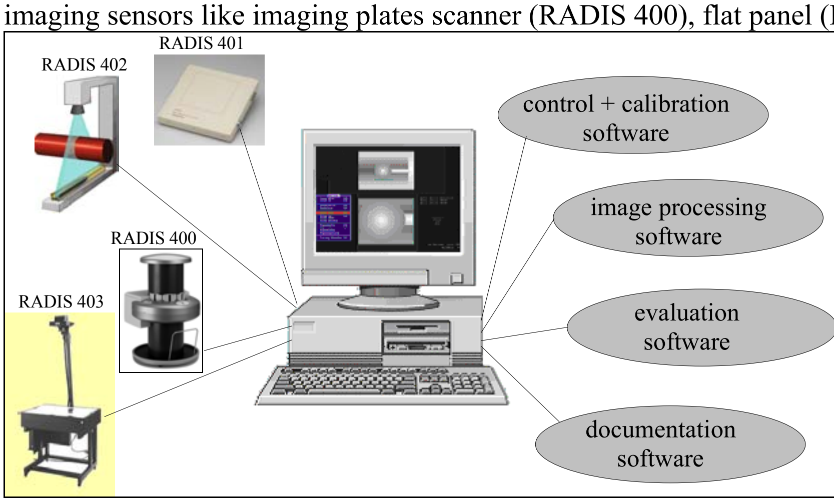


Fig. 7: Software structure of RADIS system

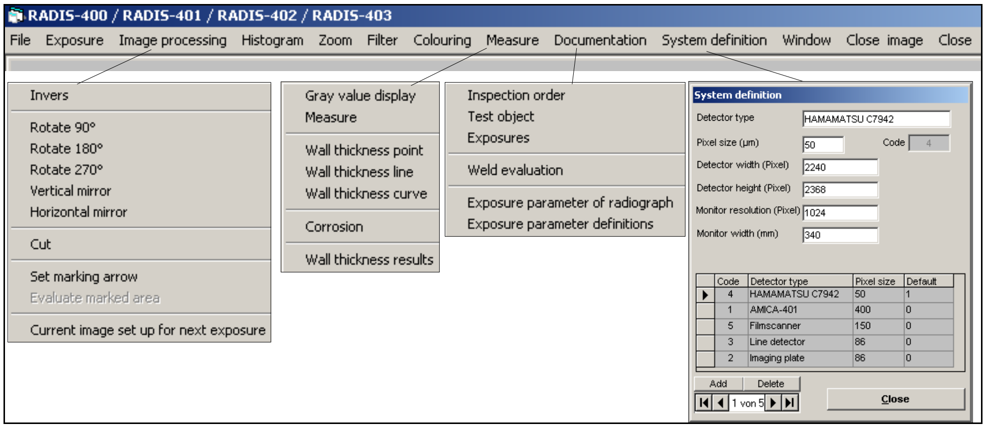


Fig. 8: Main functions of RADIS system software

just exposed or re opened (100% zoom assumed). System calibration functions and starting of exposure (or scanning in case of imaging plates) are activated via "Exposure" menu. The integrated image file formats are "bmp", "tif", "dig" and "RAW". They can be opened, saved and converted from one to another via the "File" menu. The actual set up of display parameters can be stored so that series of exposures from similar objects are displayed with the same parameters once optimised for the actual task.

After the image is shown on the display several image processing functions are available. The image can be inverted, rotated by several angles, mirrored. Marking arrows may be added. For enhancement of the visibility of details sometimes the application of filter functions or colouring is useful. These are available via "Filter" or "Colouring" menu. The "Histogram" function enables the adjustment of displayed contrast and grey value range. The integrated zoom factors are running from 25% up to 600%. Optimised conditions for the evaluation of radiographs are achieved by controlling the combination of zoom factor, displayed contrast and grey value range. The original images are not changed by these settings. The settings values are stored individually for each evaluated image in a data base.

Measuring functions are available via the "Measure" menu. It is possible to show the grey value course along a drawn cursor line, to measure distances or indication dimensions by cursor marking, to measure wall thickness from the tangential wall projection of tubes if the geometrical exposure data are defined for the image, and wall thickness reduction perpendicular to the radiation direction e.g. in case of internal corrosion. Measured wall thickness values may be listed.

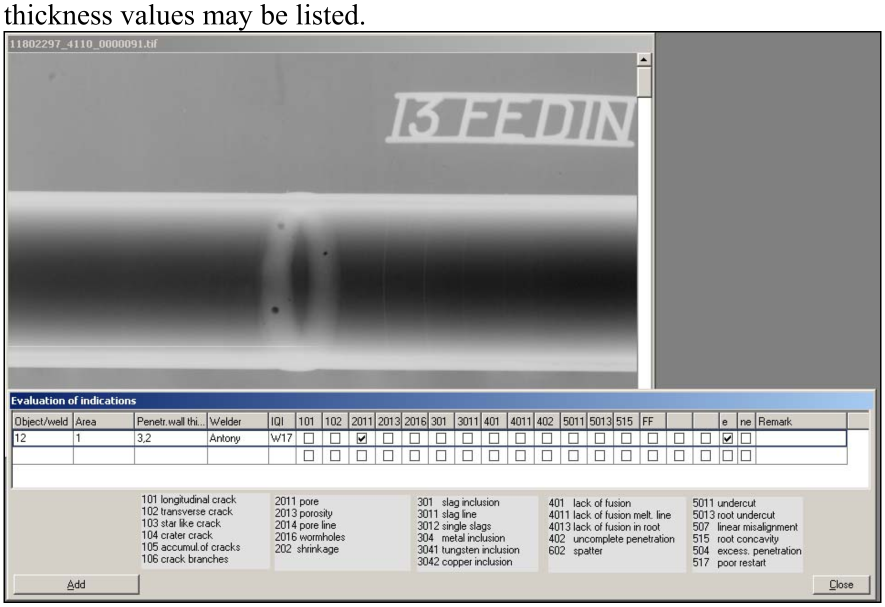
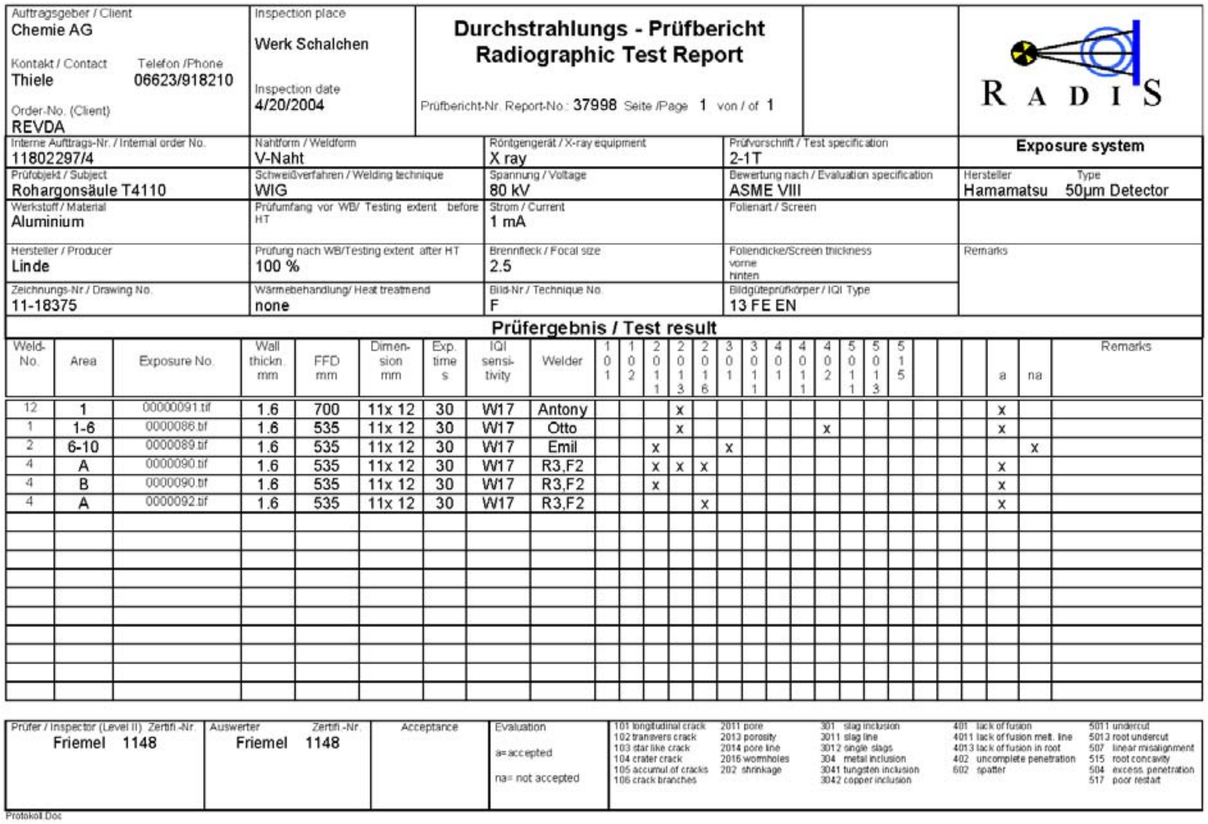


Fig. 9: Evaluation window for weld radiographs

The documentation functions are available via "Documentation" menu. Complete information about inspection order, test object and exposure parameter can be defined after activating the corresponding windows. General exposure parameter sets can be defined as well and assigned automatically to new exposures.

Directly after exposure or later by re opening the images weld indication evaluation may be performed via the corresponding evaluation window (see fig. 9).

When inspection is finished the complete inspection report may be printed out immediately (see fig. 10). The used report form is defined as WORD document and can be changed or adapted to user requirements by the user himself.



Auftragsgeber / Client Chemie AG Kontakt / Contact: Thiele Telefon /Phone: 06623/918210 Order-No. (Client) REVDA	Inspection place Werk Schalchen Inspection date 4/20/2004	**Durchstrahlungs - Prüfbericht** **Radiographic Test Report** Prüfbericht-Nr. Report-No.: 37998 Seite /Page 1 von / of 1		R A D I S
Interne Auftrags-Nr. / Internal order No. 11802297/4	Nahtform / Weldform V-Naht	Röntgengerät / X-ray equipment X ray	Prüfvorschrift / Test specification 2-1T	**Exposure system**
Prüfobjekt / Subject Rohargonsäule T4110	Schweißverfahren / Welding technique WIG	Spannung / Voltage 80 kV	Bewertung nach / Evaluation specification ASME VIII	Hersteller: Hamamatsu Type: 50µm Detector
Werkstoff / Material Aluminium	Prüfumfang vor WB/ Testing extent before HT	Strom / Current 1 mA	Folienart / Screen	
Hersteller / Producer Linde	Prüfung nach WB/Testing extent after HT 100 %	Brennfleck / Focal size 2.5	Foliendicke/Screen thickness vorne hinten	Remarks
Zeichnungs-Nr / Drawing No. 11-18375	Wärmebehandlung/ Heat treatmend none	Bild-Nr / Technique No. F	Bildgüteprüfkörper / IQI Type 13 FE EN	

Prüfergebnis / Test result

Weld-No.	Area	Exposure No.	Wall thickn. mm	FFD mm	Dimension mm	Exp. time s	IQI sensitivity	Welder	101	102	2011	2013	2016	301	3011	401	4011	402	5011	5013	515				a	na	Remarks
12	1	00000091.tif	1.6	700	11x 12	30	W17	Antony				x													x		
1	1-6	0000086.tif	1.6	535	11x 12	30	W17	Otto				x						x							x		
2	6-10	0000089.tif	1.6	535	11x 12	30	W17	Emil			x			x												x	
4	A	0000090.tif	1.6	535	11x 12	30	W17	R3,F2			x	x	x												x		
4	B	0000090.tif	1.6	535	11x 12	30	W17	R3,F2			x														x		
4	A	0000092.tif	1.6	535	11x 12	30	W17	R3,F2					x												x		

Prüfer / Inspector (Level II) Zertifi.-Nr.	Auswerter Zertifi.-Nr.	Acceptance	Evaluation					
Friemel 1148	Friemel 1148		a= accepted na= not accepted	101 longitudinal crack 102 transvers crack 103 star like crack 104 crater crack 105 accumul.of cracks 106 crack branches	2011 pore 2013 porosity 2014 pore line 2016 wormholes 202 shrinkage	301 slag inclusion 3011 slag line 3012 single slags 304 metal inclusion 3041 tungsten inclusion 3042 copper inclusion	401 lack of fusion 4011 lack of fusion melt. line 4013 lack of fusion in root 402 uncomplete penetration 602 spatter	5011 undercut 5013 root undercut 507 linear misalignment 515 root concavity 504 excess. penetration 517 poor restart

Protokoll.Doc

Fig. 10: Weld inspection report generated by the RADIS system software

Discussion: The application possibilities of the selected systems have to be discussed according to the max. wall thickness which can be penetrated and the geometrical dimensions of test objects.
Depending on the maximum allowable radiation energy (see table 1) following application ranges for the several imaging systems can be derived related to the penetrated wall thickness:

	Flat panel Hamamatsu C7942	NTB digital line scan x-ray camera	Imaging plate system Fuji ST 6 with portable scanner VistaScan (Duerr)
aluminium welds	max. 70 mm	no limit	no limit
steel welds	max. 15 mm	max. 40 mm	no limit

Table 2: Approximate maximum thickness values for aluminium and steel test objects to be tested by the used digital radiographic systems

Due to the size of the Hamamatsu C7942 flat panel detector (see table 1) first is applicable for all circumferential welds up to diameters of 89 mm can be inspected according to the exposure arrangements F and G of ASME Code Section V Article 2. One example is shown in fig. 9 (steel weld 21.3x1.6 mm, 110 kV, exposure time 30 s, optimised contrast and grey value range, zoom 250%, 1 mm drill holes, 1 mm deep).
There are no problems for longitudinal welds as well in the thickness range given in table 2.
In the case of circumferential welds with bigger diameters there are differences to the test arrangements used with films because the detector is flat and rigid and cannot be bent to the tube curvature. If the geometrical conditions for these cases are regarded as shown in fig. 11 we follow that the flat panel detector is applicable

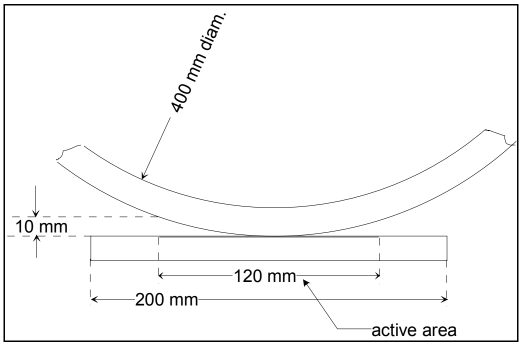


Fig. 11: Geometrical situation in the case of circumferential welds inspected by flat panel detector

for circumferential welds with diameters of 400mm and above as well. The active length of the image is 120mm.The curvature of the weld results in a max. distance of 10mm between detector surface and weld at the image edges so that this distance can be neglected assumed that the requirements for geometrical unsharpness are met at this point. This distance between detector and weld surface becomes less with growing diameter.

As example the image in fig. 12 shows a radiograph taken by flat panel detector from a circumferential weld with the dimension of 400x18mm. The images of the drill holes at both ends of the exposure compared with those in the middle section demonstrate clearly that no distortion of the drill hole images is evident.

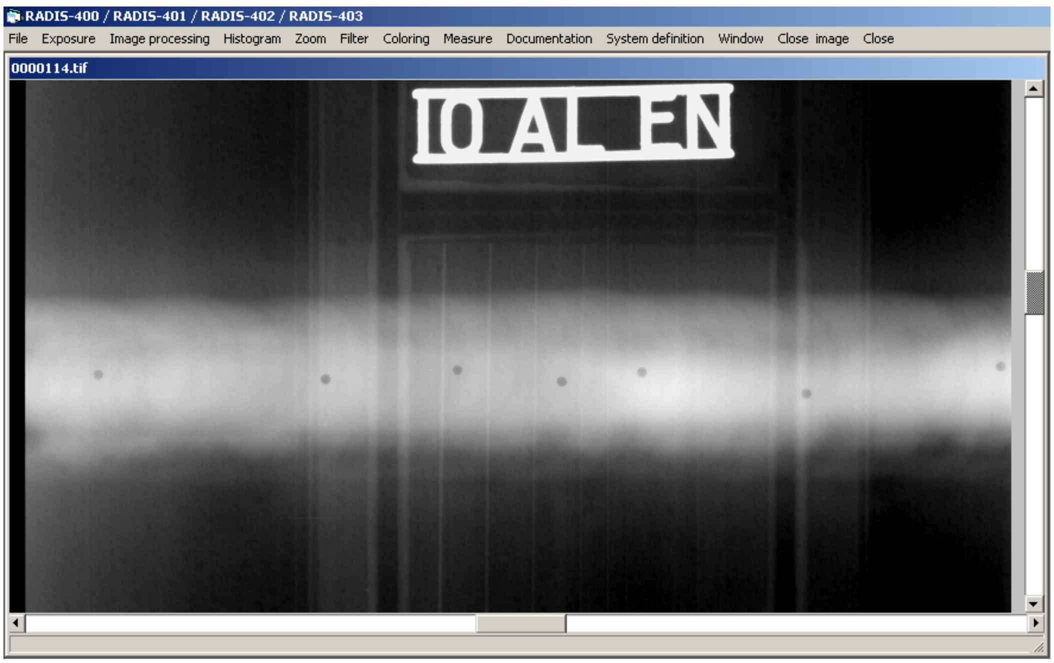


Fig. 12: Digital radiograph of a circumferential weld (Aluminium 400x18 mm, single wall exposure, 60 kV, 30s, 1mm drill holes, 1mm deep, zoom 250%)

The digital linescan camera is mainly applicable for longitudinal welds in the tube production area for wall thickness values shown in table 2. The required exposure times are higher than in the case of flat panel detectors and imaging plate systems (see table 1). As example the scanning time for a 300 mm longitudinal section of a steel pipe with the dimension of 21.3x1.6 mm in a production line of heat exchanger tubes exposed by 110 kV radiation energy required 5 min. However this system is only applicable in stationary installations because of the additional need of adequate manipulation systems.

The application range for the imaging plate system is not restricted by geometrical conditions nor by limitations for radiation energies. However the image quality is slightly less than of the other systems. A new field of application for the imaging plate system is checked at this time in a pilot project in a heat exchanger production mill for aluminium heat exchangers. Test objects are the tube to bottom welds in the heat exchanger bottoms (see fig. 13). Similar inspections have been performed some years ago on heat exchangers from steel using a special Ir 192 equipment and films with a hole cut through the center.

The films shall now be replaced by imaging plates. Because of the material (aluminium) low radiation energy is needed, so a special microfocus x ray tube with a nozzle like anode is used. The principle is shown in the sketch of fig. 15. A small imaging plate (100x100mm) is used within the appropriate cassette where a hole is cut

Fig. 13: Tube to bottom welds in a heat exchanger bottom

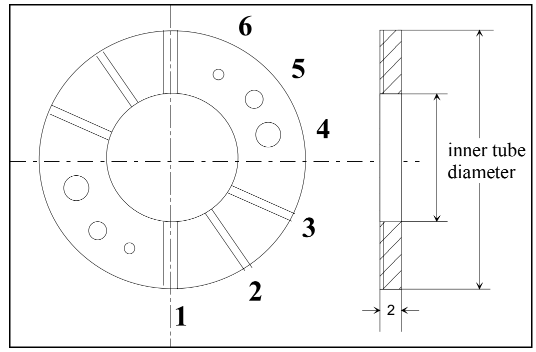


Fig. 14: IQI for quality check of radiographs from tube to bottom welds in a heat exchanger bottom

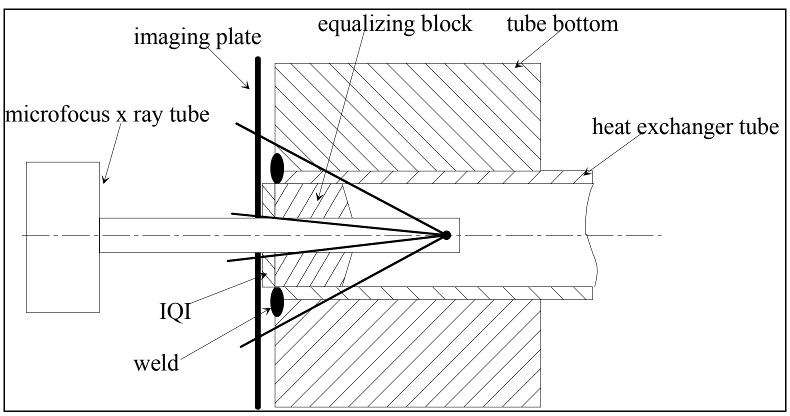


Fig. 15:Principle for the inspection of tube to bottom welds in heat exchanger bottoms

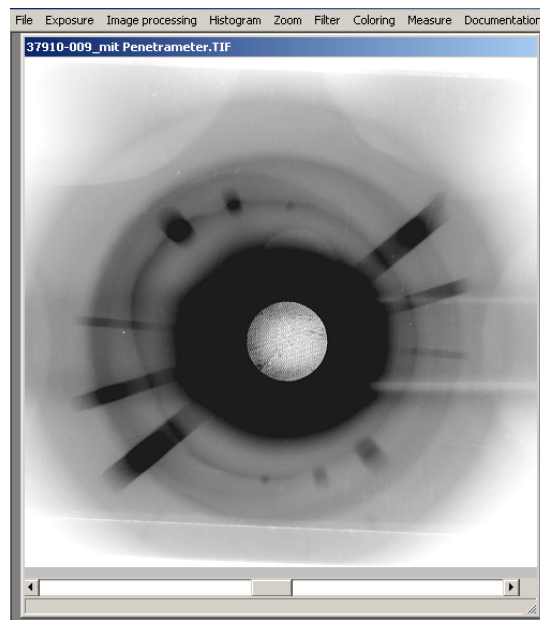


Fig. 16: Digital radiograph from tube to bottom weld using an imaging plate

through its centre. The hole diameter fits to the nozzle diameter of the tube. The imaging plate cassette is positioned on the weld. The nozzle of the x ray tube is inserted into the tube and fixed by an equalising block. The radiation direction is backwards. An IQI as shown in fig. 14 is used for image quality check. This IQI contains notches and drill holes as artificial imperfections. The dimensions of these imperfections are: notch width and depth = 0.5, 1.0 and 1.5 mm as well as hole diameter and depth = 0.5, 1.0 and 1.5 mm. The imperfections are faced to weld surface. The quality of the radiographs is judged as ok if all imperfection are visible.

The source size of the tube was 50 µm. The radiographs are taken with 90 kV, 1 mA with an exposure time of 15 s. Fig. 16 shows an example of the achieved digital image (zoom 250%). The image quality is excellent. All test imperfections are visible. The imaging plates can be used repeatedly many times so that a big economical advantage is gained by using this new digital technique.

A calculation of full expenses for radiographic testing in a heat exchanger production line using flat panel detectors in comparison to film radiography was performed and showed that this new technique can help to save money considerably in spite of the comparable high investment expenses.

	1000 exposures/year	2000 exposures/year	3000 exposures/year
film exposures (format 10x48cm)	33,42 €/exp.	30,06 €/exp.	28,27 €/exp.
digital exposures using Hamamatsu flat panel	35,94 €/exp.	21,98 €/exp.	17,33 €/exp.

Table 3: Results from calculation of expenses for digital radiography with flat panel detectors and films

Following main differences between film and digital radiography where taken into account for this calculation:

- expenses for film material and chemicals
- expenses for waste chemical disposal
- film development time (personnel expenses)
- expenses for film archiving
- expenses for documentation (personnel expenses)
- investment for detector system (amortization time: 5 years)
- maintenance contract for the detector and software system

The differences in exposure time are not taken into account because the overall inspection time per weld (including positioning) will not differ much.
The results of the calculation are shown in table 3. The break even point is even evident at approximately 1300 exposures per year related to one system.
Conclusions: First pilot projects using digital radiographic sensors for weld inspection could show that the selected systems assembled to the RADIS system are suitable in regard of required image quality. The developed RADIS software combines all system components under a uniform user interface and presents very simple calibration functions for the system components and for changing from one system to another. Examples of practical applications and cost calculation demonstrate the high application potential of the new systems. A further big advantage of digital radiographs is the possibility of zooming, adjustment of contrast and displayed grey value range during image viewing as well as the measuring possibilities during evaluation of welds so that indication dimensions can be checked immediately independent from the actual zoom factor.