APPLICATION OF RADIOSCOPY SYSTEM INTO AN AUTOMATIC PRODUCTION LINE IN AUTOMOTIVE INDUSTRY

Michal ŠKEŘÍK

Author: ***Michal Škeřík***
Workplace: ***CTU Prague – Faculty of Mechanical Engineering / ATG s.r.o.***

Abstract

The study is aimed at verification of quality monitoring possibilities in case of car body welding by radioscopic method. The image intensifier with high resolution and digital output, and ordinary X-ray source was used for method capabilities verification. The study shows that the method results are sufficient also in case when ordinary equipment was used and indicate the following steps, which have to be done before the radioscopy system integration into the production line.

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Key words

NDT, radioscopy, integration

INTRODUCTION

In automotive industry the economic aspect of production process has big importance. The push to innovation of the industrial process leads into usage of new materials with advanced mechanical properties. The components produced with these new materials could be (due to this advanced material properties) profitably designed with material savings. The final product will have the correct mechanical properties only when the quality of all of connected parts as well as their joints (usually welds) will be sufficient. For monitoring of the weld quality is for example possible to use some of non-destructive testing method (NDT). In automotive industry the employment of NDT methods in production lines is complicated by fast duty cycle.

The following text will be focused on the examination of the butt laser welds on car bodies. Aim of here-described tests was to verify (or refute) usage of radioscopic testing system (RS) as a part of production line for real time full examination.

EXAMINATION BACKGROUND, PROPOSAL OF RS TECHNIQUE

The verification was done on the specimens of two plates with different thickness (T1 = 1,65mm, T2 = 0,9mm) welded by laser. Consequently it was decided that detection capabilities will be demonstrated on lack of penetration type flaws. Flaws of this type are very harmful for the following manufacturing process. Their detection by radiographic or radioscopic testing is (in case of laser welding) difficult.

For these experiments specimens were manufactured – each with three artificial flaws of same width (0,1mm) and with depths 0,2mm, 0,5mm, and 0 to 0,5mm (triangular cross-section)

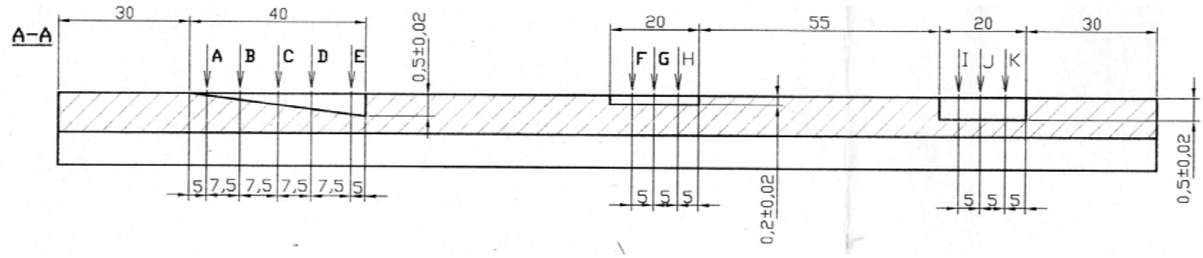

Figure 1. *Dimensions of specimens*

For analysis of implementation possibilities of RS system into an automated production line following process parameters were considered. Weld production: 1m per minute (it corresponds with the real process), under consideration were welded parts with maximal length of weld on one part is 1,2m (weld could be curved, but only in 2D). The weldments wait 1 minute in buffering stock for the next operation.

The radioscopy was considered because it was useful in real-time testing in different industrial sectors and theoretical background is well known. The classical radiography (RT) and the computed radiography (CR) needs image developing (or scanning) – they were not considered due to high time consumption. Suitable alternative to radioscopy could be the digital radiography (DR) – in this case the theoretical background is insufficient.

From geometrical angle of view the basic arrangement (acc. to EN 1435 – fig. 6.1.3) is the most suitable for this application. When this arrangement is used the radiation source is placed on opposite side than radiation detector (in case of radioscopy – image intensifier).

Due to the welding technology used is not possible to load the X-ray equipment on the arm of the weld torch manipulator (the plates are placed on the welding table during the welding and lower side of weldments is inaccessible). Therefore 1 minute of staying in buffer was suggested to use for inspection. In this case the tests will be performed out from the welding area and therefore a question of the detector protection from harmful heat effect of just welded welds is not necessary to consider.

The weight of X-ray equipment is also inconsiderable (tubehead – cca 8kg, image intensifier – cca 22kg, high voltage conductors, hoses with coolant). Inertial effect could be a source of motion unsharpness. Therefore it was considered to move with the weldments (weight – cca 10kg) through the inspection (shielded) area with stationary X-ray equipment. For this purpose the manipulator operating with the buffering stock could be advantageously used. Whole radioscopic system (in case of proper design) could take a place of this buffering stock in the production line.

With this configuration two modes of inspection are possible to use. Firstly inspection in-motion secondly inspection per single shots. For in-motion inspection seems to be more useful to use a linear detector than digital radioscopic system. The productivity of this will be probably higher but some difficulties could occur due to weldments handling requirements. In following step-by-step mode was considered the (step length was done by diameter of input window of image intensifier).

EQUIPMENT

Two basic questions have to be answered by the tests:

a) Is the radioscopy able to provide the images with sufficient quality?

b) Is the image acquisition time so small to enable to system the work in real time?

The minimal image quality was required by viewing of wire W17 Ø = 0,08mm (thinner part) and W16 Ø = 0,1mm (thicker part) of Fe image quality indicator (IQI) acc. to EN 462–1. It's approximately corresponding with 2-2T quality requirement of ASTM based procedures.

For achievement of this quality requirements was used a detector with appropriate internal unsharpness. The radioscopic system with high resolution (up to 3,7 line pairs / mm) and digital output was used. This system allows white noise reducing by time integration of images (up to 256 images).

Through experiments following equipment was used:

X-ray source:	Andrex CMA 208 (focal spot 2,3 x 2,3 mm in acc. with IEC 366)
Image intensifier:	Siemens II9S
Camera (of II):	HiRes 2XR (1004 x 1004 pixels; 12 bit)
Software:	Xplus, IC demo

EXPERIMENTAL PART

The main body of the experiment was focused to data collecting for future construction of "image quality – number of integrated images" diagram.

The following exposure parameters was used:	U	= 80 kV
	I	= 2 mA
	FFD	= 1000 mm
Number of the images to be integrated in time:	int	= 1 to 256

With useage of these exposure parameters was founded this relationship:

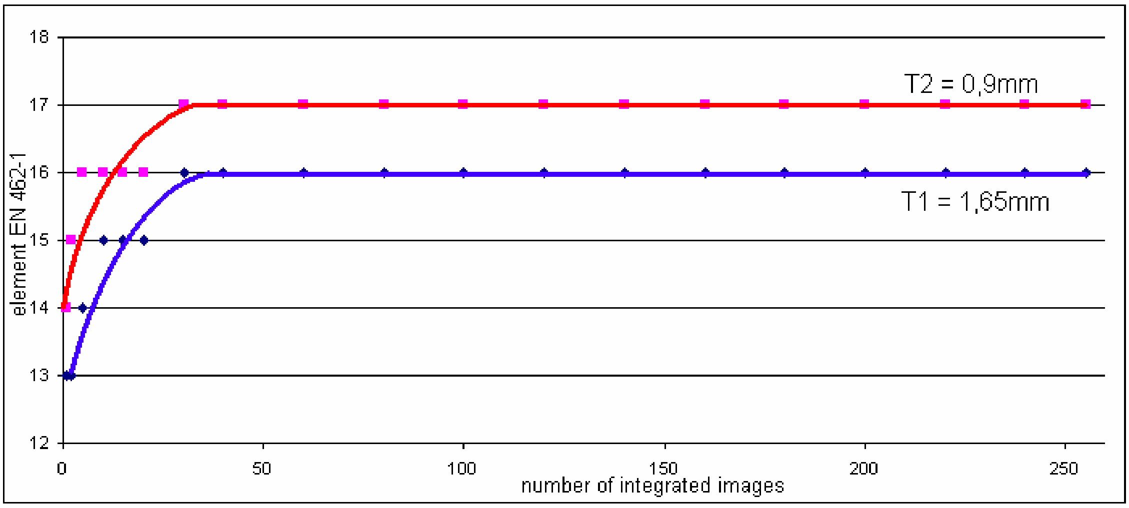

Figure 2. *Influence of the integration number to achieved image quality*

Breakpoint, where the image quality starts to decrease is about 40 integrated pictures.

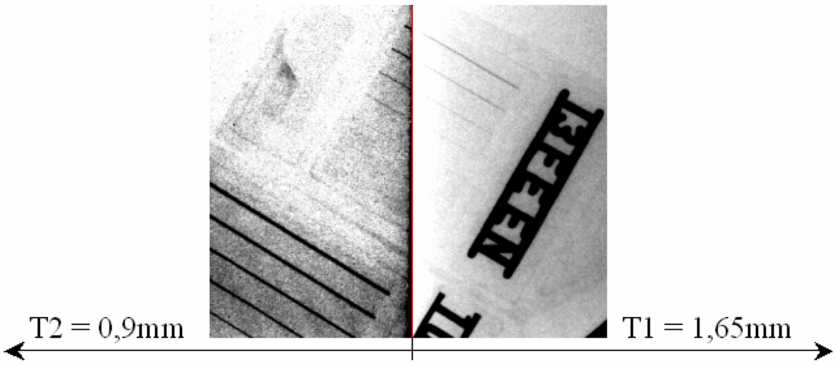

Figure 3. *Pixel line – IQI wire angle: approx. 30°, contrast adjusted for each thickness separately*

From these experiment outcome that estimated image quality is possible achieve with this X-ray source (non-optimal in term of adjustable range of voltage).

DATA ANALYSIS

If the forty images are integrated – exposure time is 1,6s. On every single integrated image 150mm of weld length is possible to display (+ 5mm of appropriate overlap on each side). If the length of the weld is 1200mm than 8 images are needed to cower whole weld length. The sum of exposures times is than 12,8sec and for manipulation with the weldments (and image evaluation) left 47,2s (it’s 5,2s per one move – 9 moves considered).

Consequently the tests with the artificial flaws were carried out. Their images were possible to observe after small histogram corrections – the filtration wasn’t needed.

Reliable detectability of flaw with depth 0,3mm and deeper was verified. The flaw with depth 0,2mm seems to be a bit vague. This fact was partly considered as result of image distortion by modulation transfer function (MTF) of the monitor. The monitor is common source of image degradation.

The system after implementation into a production line won’t need a monitor – evaluation will be done automatically by computer (therefore the problem of suitable monitor is not necessary to solve).

The evaluation will be done on basis of gray values plots of the weld cross-sections. Following figure illustrate the manner of automatic evaluation.

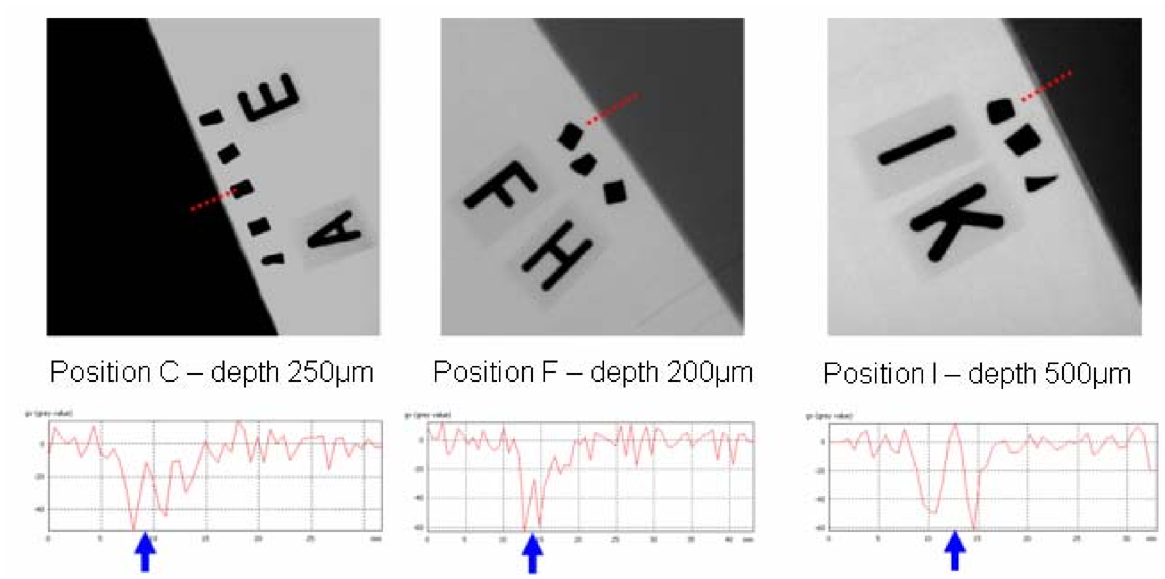

***Figure 4.** The grey value profiles in place of the artificial flaw*

From these profiles outcome that a gray value change could be observed also in case of 0,2mm flaw depth but the signal to noise ratio (SNR) is to small and this fact could result into confusion during final automatic image evaluation. SNR could be improved by usage of higher current of X-ray tube (the higher number of integrated images could provide the same effect, but secondary effect is the exposure time increasing and it's unacceptable.

REQUIREMENTS FOR SUCCESSFUL RS SYSTEM INTEGRATION

If more suitable X-ray source will be used (optimal X-ray setting: 60 – 65kV, current as high as is possible) the final image quality will be improved. Lower voltage increase the contrast, higher current decrease the exposure time (for 5mA – exp. time to 0,64s, for 10mA to 0,32s). In the case of 10mA the total time disposable for weldments manipulation and image evaluation will be equal to 57s. The smaller tubehead focal spot will result into small decreasing of the total image unsharpness and finally it will again improve the image quality.

The Image intensifier is based on the electronooptical principle. Internal electron flows in the tube of image intensifier could be very harmfully influenced by magnetic field. It finally results into the image distortion and heavy decreasing of the image quality. Therefore the residual magnetic field elimination from weldments to be tested is important as well as excluding of surround sources of magnetic field. If the magnetic testing is performed before the radioscopic testing, the demagnetisation is needed.

The digital radiography due the different principles of image acquisition has no problem with the magnetic field. Because the DR testing seems to be suitable alternative to compare booth systems is recommended in the following terms:

- Achieved image quality
- Testing productivity
- The strength of radiation source needs
- Expanses and **working lifetime** of the detector

Lifetime of radioscopic image intensifier is between 5 and 10 thousand hours (up to duty cycle).

In the weld production is common the geometrical imperfection called linear misalignment. Due to physical grounding of radioscopy and used arrangement will be this imperfection hard to detect. Therefore completing of the radioscopy by another suitable NDT method could be useful.

RADIATION SAFETY

Protection of staff, property and environment from harmful effect of ionising radiation in case of implementation of RS system into the production facilities is very important topic. If a common 160kV X-ray source suitable for radioscopy (available on market) will be used an absorbed dose up to 3 mGy/h in 1m distance from focal spot could be expected. For the dose equivalent decreasing under 2,5 μSv/h value required by ministerial regulation [6], lead in thickness of couple mm will be necessary to use as a shielding material (proportionally to the voltage set up).

Well-done design of shielding cabinet allows inserting of weldments into a shielded area through the permanently opened slot. For factory staff and surrounding electronic devices the X-ray source will not present any emergency.

SUMMARY AND CONCLUSIONS

About implementation of radioscopic system into the production line is possible to write generally these statements:

- Radioscopy is able to detect the defects described in the study submission.
- Radioscopy is not only one NDT method, which is able to detect considered discontinuities. It is necessary to compare the RT with the other NDT methods and also with the DR.
- Magnetic field could affect the testing results achieved by RS.
- If will be finally elected radioscopic testing than will be necessary to use:
  a) minifocus tubehead **suitable for radioscopy**
  b) image intensifier with high resolution and digital output

Resume

This study is aimed to detailed analysis of possibilities of the radioscopic inspection system usage for the weld quality inspection fully automated weld production (of the welding line) is considered. Welded semi-product is characterized by small thickness of welded sheets and by cranked path of the weld, which is created by laser technology.

Usage of the radioscopic inspection technology is in this case limited by two main factors. First one of these is imaging properties requirement of the system. This properties have to afford sufficient signal response to fine changes of the inspected material thickness, high spatial resolution of the image as well as sufficient signal to noise ratio. The second factor, which has influence to method usage, is the time. Time is dedicated by cycle of production line.

Before the main part of trial testing started was necessary to estimate the mode in which will be the system operate. It was possible to choose between few different versions. After this was approach to trial testing aimed to determining of relationship between the image quality and exposure parameters. According to this was consequently possible to estimate the time requirements needed for sufficient inspection results.

Finally was necessary to perform trial testing on real parts with artificial defects. This trial was focused on verification of the image quality achieved with the exposure conditions, which are determined in previous step. For this verification samples was manufactured. From

this trials outcomes the limit for minimal detectable thickness change of the material with used configuration of the equipment.

This study is also completed by part focused to radiation safety and as a conclusion are determined next steps to be taken in case, that the radioscopic testing method will be considered to implement into described production system.

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Reviewers

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