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Industrial X-ray testing without intermediate data carriers of information

Przemysłowe badanie rentgenowskie bez pośrednich nośników informacji

ABSTRACT

The new direction of radiography is Flash-radiography (FR) which doesn't have intermediate data carriers (films and storage plates). FR produces a quick image. It provides low testing cost, and capability of multi-angle real time internal defects monitoring of the objects.
In film radiography, if relative photometric density is more than 4, then the snapshots become virtually unreadable and they can be difficult to be digitized. Current film-free technologies do not have this disadvantage and, besides, give results in a digital form without special digitizing systems.
Digital data contain radiation images of internal defects, expand the flaw-detection possibilities and reduce testing cost. Flash-radiography is based on portable X-ray television, which allows the observation of X-ray testing results on a monitor screen. The internal defects examination from different angles may be carried out.
Flash-radiography with digital solid-state transducers is the most perspective one with sensitivity up to 0.1% of examined metal's thickness at resolution exceeding 10 pairs of lines per mm. Application of small-size movable solid-state transducers opens new technological capabilities. They can be located and moved in the zones where positioning of film holders and storage plates is impossible. The new X-ray mini technology expands the application of NDT. The examples of practical application of solid-state miniature transducers are presented.

Keywords: *Film radiography, Flash-radiography, digital image, scintillator, solid-state transducer, X-ray mini technology*

STRESZCZENIE

Nowym kierunkiem radiografii jest radiografia błyskowa (ang. flash radiograpy, FR), która nie ma pośrednich nośników danych (błon i płyt pamięciowych). FR tworzy szybki obraz. Zapewnia niskie koszty testowania oraz możliwość monitorowania obiektów pod kątem błędów wewnętrznych w czasie rzeczywistym. W radiografii błonowej, jeśli względna gęstość fotometryczna jest większa niż 4, migawki stają się praktycznie nieczytelne i mogą być trudne do digitalizacji. Obecne technologie wolne od błon radiograficznych nie mają tej wady, a poza tym dają wyniki w formie cyfrowej bez specjalnych systemów do digitalizacji.
Dane cyfrowe zawierają obrazy promieniowania z defektów wewnętrznych, rozszerzają możliwości wykrywania wad i zmniejszają koszty testowania. Promieniowanie błyskowe jest oparte na przenośnym aparacie rentgenowskim, który umożliwia obserwację wyników badań rentgenowskich na ekranie monitora. Można przeprowadzić badanie wad wewnętrznych pod różnymi kątami.
Promieniowanie błyskowe z cyfrowymi przetwornikami półprzewodnikowymi jest najbardziej perspektywiczne z czułością na poziomie do 0,1% badanej grubości metalu przy rozdzielczości przekraczającej 10 par linii na mm. Zastosowanie przenośnych przetworników półprzewodnikowych o niewielkich rozmiarach otwiera nowe możliwości technologiczne. Można je lokalizować i przemieszczać w strefach, w których nie jest możliwe pozycjonowanie uchwytów błon i płyt do przechowywania. Nowa mini technologia rentgenowska rozszerza zastosowanie NDT. Przedstawiono przykłady praktycznego zastosowania miniaturowych przetworników półprzewodnikowych.

Słowa kluczowe: *Radiografia błonowa, radiografia błyskowa, obraz cyfrowy, scyntylator, przetwornik półprzewodnikowy, technologia przenośnych urządzeń X-ray*

1. Introduction

Radiation methods are preferred to be used in quality of welded and brazed joints testing as well as in mastering the number of process solutions due to illustrative results. This method is also used to validate other NDT methods.

Significant qualitative changes took place in recent years expanding the possibilities of the non-destructive radiation testing, first of all due to appearance of new multi-element semiconductor radiation image detectors as well as intensive implementation of means for producing, processing and analysis of digital images, which are illustrative, easy for archiving and electronic transmission. Such detectors use electronic means and transform ionizing irradiation, passed through examined object containing information about its internal defects, into an electric signals package. After that the signals are digitized, processed and used to make a digital image of the object being examined.

Digital image (DI) can be observed directly during inspection, i.e. in real time. Such a method of radiation testing without intermediate carriers of information is called Flash-radiography. Virtually, it is portable X-ray television with electronic record of information, which can be delivered to a customer, uploaded on the internet, archived and stored on memory cards without additional digitalizing and decoding.

A distinctive feature of the flash-radiography is the absence of intermediate carriers of information, radiographic films, semiconductor (SC) store plates with photo-stimulated memory.

Adjustment of mode in widespread technologies with intermediate carriers of information requires multiple exposures, highlighting, processing and expensive devices for digitizing and reading information. Therefore, absence of intermediate carriers of information (films, semiconductor plates) provide increased efficiency and significant cost reduction of quality testing.

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2. Methods of radiation digital images producing

Examination of the object's internal defects with the help of portable X-ray television equipment having digital image processing provides principle changes in technology of non-destructive radiation testing. Commonness of optical and radiation digital images (DI) application has increased in recent time. Hardware and software used for processing and digitization of X-ray films and providing digital images are more widely distributed. The digital images can also be produced by means of storage plates instead of X-ray films. Methods and algorithms of DI processing are the same for all three variants of radiation testing (Figures 1-3). This is an important direction in current radiation flaw detection. Now digital images are typically produced by means of X-ray patterns digitization. Rarely, it is produced by processing latent image being read from re-usable storage plates. The same result can be received from flash-radiography digital detectors without additional expenses related with intermediate information carriers.

The digital image produced by any of three indicated methods, shall have similar interpretation. The processing results of radiography DI shall not be inferior to sensitivity and resolving power of the results of radiographic film received via film viewer. An image quality is evaluated using the reference specimen images. On DI they shall be similar to the reference specimen images of X-ray films examined using film viewer.

There are three technologies (see Figures 1,2,3) for receiving DI-results of radiation testing in electronic form, but the principles of processing and further decoding of these images are the same.

Figure 1 shows a classical process of DI production by means of X-ray film patterns digitization. This traditional technology is well known in all branches of industry. It requires preparation of film cartridges and screens. Chemical treatment, film drying, reading information on film viewer and digitizing the results with the help of corresponding computer complex follow up inspection. This technology is mainly used for compact archiving of NDT results in digital form and receiving additional information which cannot be obtained without digitization.

Figure 2 gives a scheme of more perfect technology for digital image production based on storage plates, that is called CR. In comparison to previous scheme of DI production, this technology provides the possibility of multiple use of intermediate carrier of information (storage plate). This makes the process quicker, but does not reduce its price, since it requires qualified personnel, a lot of time for auxiliary operations and expensive readout equipment. Often the storage plates have their inherent defects. Eliminating the details of this method disadvantages, it is necessary to note an appearance of "sandwich" technology which allows exposing on film and storage plate simultaneously.

World film manufacturers such as Agfa, Fuji, Kodak etc, kept the way of film replacement with semiconductor multiple storage plates. Various equipment was developed for this technology realizing. The E. O. Paton Electric Welding Institute spent a lot of time on implementation of selenium plates and other intermediate carriers of information. All these technologies with re-usable carriers of information did not gain ground because of two reasons, i.e. due to expensive equipment and necessity of highly skilled personnel.

Figure 3 shows a scheme of X-ray technology (flash-radiography) based on fluoroscopic and solid detectors. This is the quickest and cheapest method to produce digital image in e-form, which does not require processing and reading equipment and corresponding additional time.

Both types of radiation testing without X-ray films (Figures 2, 3) can provide better results, than the digitized images produced with the help of X-ray film. It is known that the higher optical density and the more exposure provide more information exposed film contains. Therefore, a good scanner is necessary to digitize high density films to collect all the data available on the film. Many reading devices and

Fig. 1. Traditional scheme of radiographic testing with film and X-ray patterns digitization: (1) cartridge with X-ray film; (2) processing of X-ray film; (3) image scanning; (4) digital image

Rys. 1. Schemat tradycyjnych badań radiograficznych z digitalizacją błon i wzorów rentgenowskich: (1) kartridż z błoną rentgenowską; (2) przetwarzanie błony rentgenowskiej; (3) skanowanie obrazu; (4) obraz cyfrowy

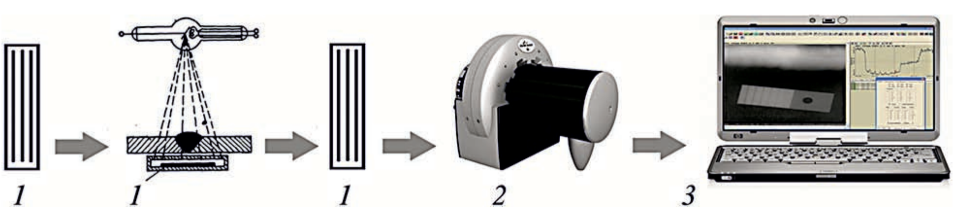

Fig. 2. Scheme of inspection using storage plate: (1) cartridge with store plate; (2) readout of information from plates; (3) digital image.

Rys. 2. Schemat kontroli z użyciem nośnika informacji: (1) wkład z płytą; (2) odczyt informacji z tablic; (3) obraz cyfrowy.

cheap scanners cannot provide high quality digitization of X-ray images, if their relative optical density is above three. All the attempts to receive satisfactory DI from the denser films have not been successful. Thus, satisfactory DI in the film variant (see Figure 1) is possible, if optical film density is in 1.5-2.5 range. At such values the digitizer noises do not introduce irreversible distortions in DI. Experience in digitization of film images with 3-3.2 order density has already shown unsatisfactory results. Fine information is difficult for displaying. For example, images of small pores less than 0.2 mm diameter and cracks with small opening are lost. Therefore, film digitization has significant limitations. Part of the defects, detected with the help of film viewer, is not found on DI. This is a significant disadvantage of traditional film radiography, which is virtually impossible to eliminate in real production.

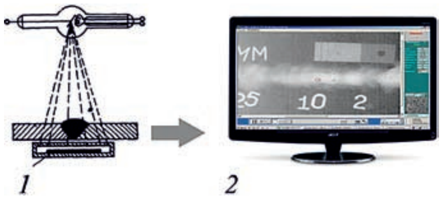

Fig. 3. Quick X-ray inspection scheme without intermediate carriers of information: (1) solid flash-transducer; (2) digital image
Rys. 3. Schemat szybkiego prześwietlenia rentgenowskiego bez pośrednich nośników informacji: (1) przetwornik błyskowy; (2) obraz cyfrowy.

Technologies without film in Figure 2 and 3 do not have this disadvantage; they differ by large dynamic range that expands the possibilities of non-destructive testing. Analysis of DI by technological schemes of Figures 2 and 3 verified that a detectability of small pores, cracks and various inclusions in the welded joints exceeds information about them on the film. Technology from Figure 3 based on solid or optoelectronic transducers are particularly perspective. It provides possibility, after DI computer processing to obtain up to 0.1% sensitivity and examine moving object. The defect detectability is increased due to the fact that moving small images are better distinguished by human eye, than that in static form. It is possible to change the inspection direction if intermediate carriers of information are absent during inspection in Figure 3.

DI received by using three technologies, shown in Figures 1,2,3 is easily archived and webcasted. Time consumption and cost of information being received using presented technological schemes approximately refer correspondingly as 10:5:1 and 5:20:1. Film radiography in Figure 1 offers large number of procedures, which sometimes is repeated several times to get the satisfactory results. There are no such procedures during FR. Film radiography is approximately 10 times longer than FR (Figure 3) to receive the same result. When using the storage plates less auxiliary procedures are needed to obtain the same information of object. Therefore the time spent is correlated approximately as 10:5:1.

As for the cost, the ratio of 5:20:1 means that during X-ray technologies in Fig. 1,2 the equipment for information reading, highly qualified specialists as well as repeated exposures should be used to receive the same results as at FR.

The technologies represented on the Fig. 1 and 3 do not need expensive maintenance. Certainly the numbers 5:20:1 depend on many factors, including the level of life in given country.

For FR the time and the cost were taken to be 1. Two other techniques (Figures 1, 2) take more time 10:5:1 and cost 5:20:1. The exposure at the dentist or fluoroscopy in the hospital is performed for a few seconds, and the picture costs few cents. While the similar results based on the technologies shown in the Fig. 1 and Fig. 2 are significantly longer and much more expensive.

In a short time, detection of the internal defect corrosion damages with the help of portable flash-radiography equipment would become mandatory for all oil-and-gas auxiliary pipelines, which virtually have no control at present time, since X-ray film testing is expensive and ultrasonic testing is less efficient.

Figure 4 presents structural schemes of radiation testing image production in digital form on three described technologies (see Figures 1-3). Procedures of these technologies differ in a stage of digital image production, and DI processing is the same for all three schemes. Therefore, expenses for realizing these procedures and equipment for DI receiving are also different.

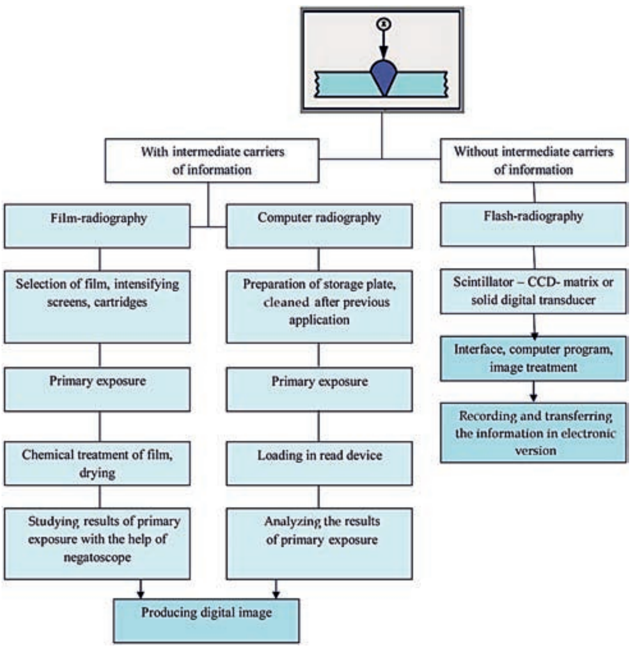

Fig. 4. Structural scheme of process procedures for getting the results of radiation testing in electronic form with film (see Figure 1), computer (see Figure 2) and flash-radiography (see Figure 3)
Rys. 4. Schemat strukturalny procedur procesowych służących uzyskaniu wyników badań radiacyjnych w formie elektronicznej za pomocą błony (patrz rysunek 1), komputera (patrz rysunek 2) i radiografii błyskowej (patrz rysunek 3).

A general disadvantage of the first two technologies with intermediate carriers of information (see Figures 1 and 2) is necessity of re-inspections, sometimes multiple inspections for determination of optimum values of anode voltage, exposure time, focal distance as well as auxiliary procedures with intermediate carriers of information. Usually, an operator, when working with new unknown objects, needs to find the correct inspection mode and procedure for intermediate carrier of information. Typically, it is performed by means of selection, multiple exposures, i.e. repeating all preparatory operations before inspection.

The most important advantage of the technology, presented in Figure 3, is possibility to observe image changes on the screen during inspection. This is the way to determine the optimum modes. Besides, there is a possibility of multi-angle examination of image of internal defect.

Technologies based on small, few square centimeters, solid digital electron transducers are in specific interest. They do not have limitations related with cartridges, screens, and storage plates. Mobile transducers can move freely over the object surface. Such possibilities are included in diagnostics widely used on practice [8] large custom objects which can have unlimited size. Testing such objects with the help of intermediate carriers of information (films, storage plates) is virtually unreal [8]. Miniature solid transducers can be used on structures of different shape. Images from separate small transducers are joined in general image of object having complex form.

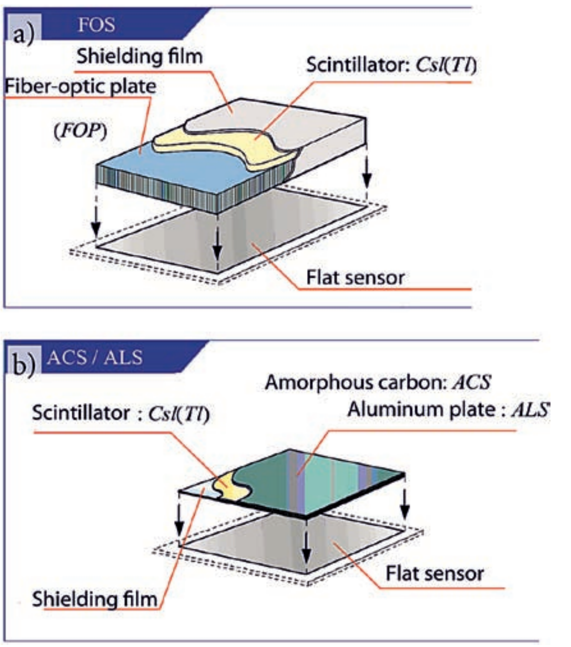

Fig. 5. Design variants of flat flaw detectors of Hamamatsu Photonics company (a) design in which image from screen to sensor is transferred by fiber-optic plate; (b) design with direct positioning of scintillation screen over sensor (CCD-matrix)

Rys. 5. Warianty konstrukcyjne płaskich defektoskopów firmy Hamamatsu Photonics a) konstrukcja, w której obraz z ekranu na czujnik jest przenoszony przez płytę światłowodową; (b) projekt z bezpośrednim pozycjonowaniem ekranu scyntylacyjnego nad czujnikiem (matryca CCD).

Flash-radiography allows varying all main parameters (focus distance, exposure, anode voltage and current) and observing the changes in the image on display screen in real time mode. This significantly reduces the time and consumables. Besides, artifacts from films, screens, storage plates, cartridges in the technologies with intermediate carriers of information are difficult to remove. In the case with real time image, i.e. on technology shown in Figure 3, with possibility to change testing mode parameters, the artifacts are easy to detect and further remove. There are algorithms for electronic images operation. They provide accumulation and extraction of separate fragments in DI.

The USA, Japan, Germany, Russia and other countries carry out intensive works on improvement of solid electron transducers, mobile X-ray television flaw detectors, which replace ultrasonic equipment thanks to better detection capabilities. In time, this tendency will also come in other countries. Therefore, it is necessary to study process capabilities of flash-radiography. A lot of companies manufacture different scintillation panels. Significant part of such devices is described in work [3]. The E. O. Paton Electric Welding Institute cooperates with Hamamatsu Photonics company (Japan). Figure 5 shows two principles of design of solid detectors of this company, and Table 1 provides characteristics of some of them.

Tab. 1. Characteristics of scintillator panels Csl (Tl) of Hamamatsu company

Tab. 1. Charakterystyka paneli scyntylacyjnych Csl (Tl) firmy Hamamatsu

Panel	Panel type	Size, mm	Effective area, mm	Substrate thickness, μm	Scintillator thickness, mm	Light relative output, %	Contrast transfer function, lp/mm
FOS	J6673	50x10	47x7	3	150	70	10
	J6673-01				150	40	
	J6677	50x50	47x47	3	150	70	10
	J6677-01				150	40	
ACS	J8734	50x50	48x48	0,5	150	125	10
	J8734-01				150	150	
	J8977	468x468	440x440	2	600	250	3
ALS	J8978	50x50	48x48	1	150	70	10
	J9857	468x468	440x440	1	600	150	3

The following designations are taken in the Table 1: FOS - Fiber Optic Plate with Scintillator; ACS - Amorphous-Carbon Plate with Scintillator; ALS - Aluminum Plate with Scintillator. Light output and contrast transfer function (CTF) were measured with the help of CCD-matrix at 60kV voltage on X-ray tube. Aluminum filter of 1 mm thickness was used.

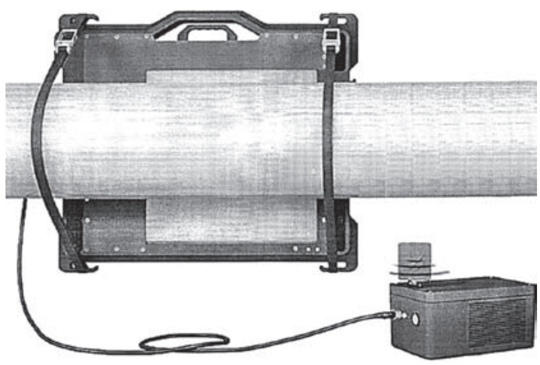

Fig. 6. Pipeline corrosion damage examination with a usage of DRP2020NDT

Rys. 6. Badanie uszkodzeń korozyjnych rurociągów za pomocą DRP2020NDT

A lot of companies in the USA, Japan and Europe produce solid digital transducers virtually to prevent any problems of radiation testing. Figure 6 shows the pipeline corrosion damage examination process with the help of solid transducer of DRP2020NDT type [9], providing wireless transmission of digital image on the screen.

3.“X-ray mini” technology capabilities

Inspection X-ray system can be developed based on mini R-transducers (Figure 5). At that, the X-ray transducer [12] is moved over the object surface as it takes place in ultrasonic testing.

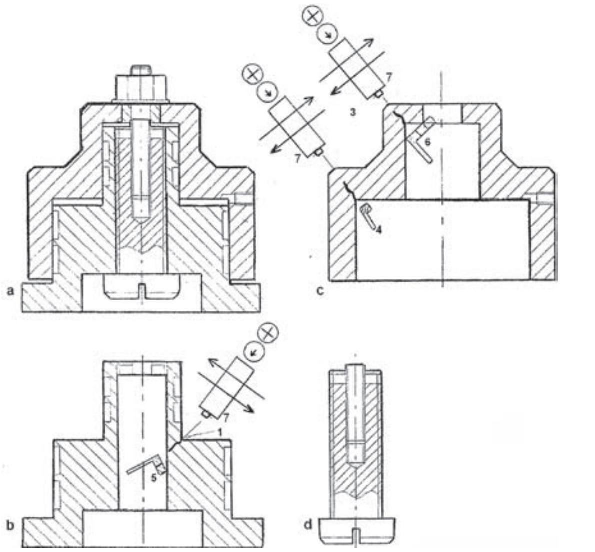

Fig. 7. Test bench for bolts of nuclear reactors: (a) total view; (b) plunger; (c) body; (d) bolt being tested; (,2,3) cracks in the plunger and body appearing in testing of high-strength bolts; (4) one; (5) two; (6) three-section solid-state radiation transducers; (7) radiation source (isotope, R – tube).
Rys. 7. Stanowisko badawcze do śrub reaktorów jądrowych: (a) widok ogólny; (b) tłok; (c) korpus; (d) testowana śruba; (2,3) pęknięcia w tłoku i korpusie pojawiające się podczas testowania śrub o wysokiej wytrzymałości; (4) jeden; (5) dwa; (6) trzyczęściowe przetworniki promieniowania półprzewodnikowego; (7) źródło promieniowania (izotop, R - rura).

The solid-body transducers allow eliminating exposure of large areas and checking only small zones, where interval defects are expected. Such a mobile flash-radiography was used (Figure 7) for examination of testing bench with critical bolts used for joining power reactors, where internal defects can’t be found by other methods. Mini R-transducers are recommended for the objects similar to shown in Figure 7. Such a variant of flash-radiography is called “X-ray mini” technology. We realize it using any solid-stare transducers including shown in Figure 5. Mobility of the R-transducer as well as R-emitter (isotope, ceramic tube) is used in X-ray mini technology realizing. Mini-detectors which are ten times smaller than large-panel ones (Figure 6) can easily be used in tangential inspection [13,14] of pipes and stop valves in heat and nuclear engineering. X-ray mini technology should find wide application in monitoring the technical condition of aircraft, lifting and other dangerous equipment. Mobility of the R-transducer as well as emitting source is expanding the capabilities of NDT.

Fig. 8. Digital image of honeycomb structure airplane wing fragment with defective rectangle zone selected for further testing by digital solid-state transducer S10811-11of Hamamatsu Company (Japan).
Rys. 8. Obraz cyfrowy fragmentu skrzydła samolotu o strukturze plastra miodu z wadliwą prostokątną strefą wybraną do dalszych testów cyfrowym przetwornikiem półprzewodnikowym S10811-11 firmy Hamamatsu Company (Japonia).

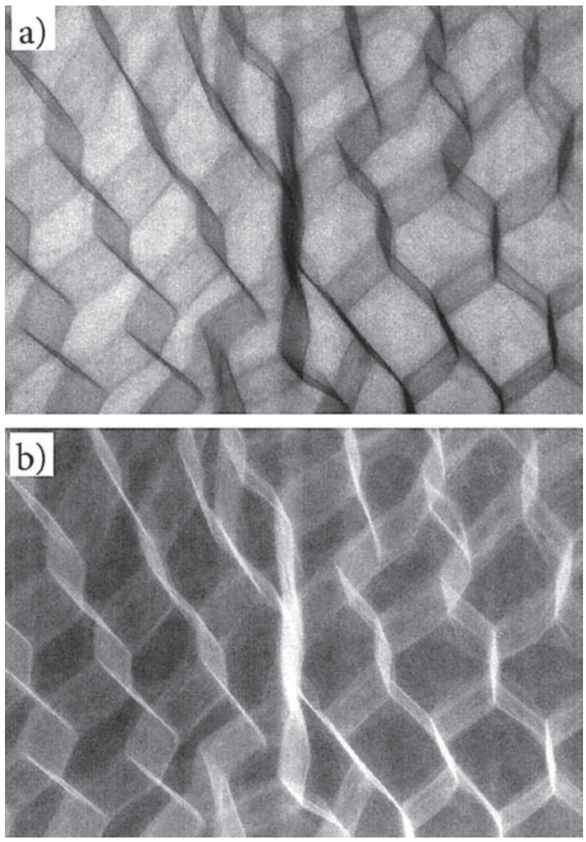

Fig. 9. Digital image of honeycomb structure airplane wing fragment get with digital solid-state transducer S10811-11: a – positive; b – negative
Rys. 9. Obraz cyfrowy fragmentu skrzydła samolotu o strukturze plastra miodu otrzymany cyfrowym przetwornikiem półprzewodnikowym S10811-11: a - pozytyw; b - negatyw

Thus, a success of X-ray mini technology is in its software. Each object has robotics-realized individual programs. It is performed on the customer’s request depending on technological processes using X-ray mini technology. The E. O.

Paton Electric Welding Institute manufactures scanners for X-ray mini and releases corresponding software. X-ray mini testing can have complete or partial automation.

There is an opportunity to create highly effective X-ray technologies combining common X-ray testing and X-ray mini technology. As an example, Figure 8 shows honeycomb structure airplane wing fragment testing. At first the airplane wing was tested by common X-ray (160x120mm working area), then it was selected defective rectangle zone having imperfections, then it has been tested by digital solid-state transducer S10811-11 of Hamamatsu Company (Japan) having 34x24 mm working area. Figure 9 shows 7 times increased digital image of defective zone get with such compact solid-state transducer S10811-11.

4. Conclusions

1) Flash-radiography with digital solid transducers is the most perspective technology. It can provide sensitivity up to 0,1% thickness of inspected metal at resolution, exceeding 10 lp/mm. Besides, this technology is compatible film radiography, i.e. can be carried on the same X-ray equipment. All branches of industry need a quick and cheap FR.
2) Application of small-size movable solid transducers opens new technological capabilities. Solid transducers can be set and moved in the zones where positioning of cartridges with films and storage plate is virtually impossible. Digital solid transducer reveals new process capabilities for non-destructive testing, being not available for other physical methods. X-ray mini technology is an expanding application of NDT in industry.
3) The R-transducer and R-emitter in X-ray mini technology should move on agreed trajectories with recording at each exposure: time, coordinates, energy, and distance to object, orientation in relation to each other.
4) Current equipment allows producing the R-detectors and R-emitters of very small size, therefore, X-ray mini technology expands the capabilities of NDT for inspection of the objects of any complex geometry, and require automation of radiation testing process.

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