Functional Materials 18, No.3 (2011)

The looking for new possibilities of improvement of receiving-detecting circuit for digital radiographic systems with advanced spatial resolution

V.D.Ryzhikov, O.D.Opolonin, B.Grynyov, V.G.Volkov, O.K.Lysetska, S.M.Galkin, Y.F.Voronkin, V.L.Perevertaylo*[*]

Institute for Scintillation Materials, STC "Institute for Single Crystals",
National Academy of Sciences of Ukraine, 60 Lenin Ave., 61001 Kharkiv, Ukraine
[*]Research Institute for Micro Instrument, 3 Street Severo-Siretskaya,
04136 Kyiv, Ukraine

Received March 22, 2011

For obtaining shadow X-ray images, a receiving-detecting circuit with the 32-channel detector array "scintillator-photodiode" of new design was developed for $200\cdot10^{-3}$ m scanning field. Using model digital radiographic systems and standard testing we have evaluated spatial resolution (not worse than 1.25 line pairs/mm) and detecting ability (better than $0.2\cdot10^{-3}$ m steel wire behind $6\cdot10^{-3}$ m steel). The use of a 16-channel analog to digit converter as part of receiving-detecting circuit allowed broadening the dynamic range and improving, as compared with previous results, resolution of the model system over thickness from ≈0.9 % to ≈0.4 % (behind $6\cdot10^{-3}$ m steel).

Для получения теневых рентгеновских изображений проведена разработка приемно-детектирующего тракта с линейкой детекторов для поля сканирования $200\cdot10^{-3}$ м. С помощью макетов цифровой радиографической системы и стандартных тестовых объектов определены пространственное разрешение (не хуже 1.25 пар линий/мм) и обнаружительная способность (лучше, чем $0.2\cdot10^{-3}$ м стального провода за 6 мм стали). Использование 16-разрядного аналого-цифрового преобразователя в составе приемно-детектирующего тракта позволило увеличить динамический диапазон и улучшить, по сравнению с предыдущими результатами, пространственное разрешение по толщине от ≈0.9 % до ≈0.4 % (за $6\cdot10^{-3}$ м стали).

1. Introduction

The film radiographic inspection (FRI) shows that this method does not always guarantee exact evaluation of damages [1–6]. Also, carrying out of FRI requires expensive materials and is time-consuming. Materials of the 9th European Conference on non-destructive testing show that the main direction of digital radiography systems (DRS) development is improvement of spatial resolution (SR) [6]. DRS are inferior to film as for its resolution, however, its contrast sensitivity is much higher – (0.8–1) % and (1–2) %, respectively.

This work was aimed at looking for new possibilities of improvement of SR, resolution over thickness and detection ability of DRS based on X-ray radiation detectors of "scintillator-photodiode" (S-PD) type.

Preliminary studies indicated two main technological problems hindering creation of S-PD detectors with improved SR [1–3, 7]. One of them is preparation of scintillator arrays (assemblies) with small aperture of

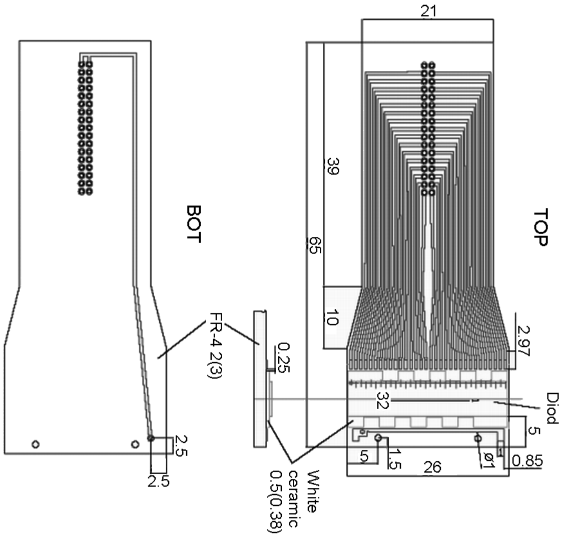

Fig. 1. 32-Channel photodiode of new design.

each scintillation element. The other is compact arrangement of pre-amplifiers (PA).

We have proposed technical solutions for production and improvement of PD and scintillation arrays with number of channels from 32 on each PD, as well as detector design as a whole.

2. Design development of a detector with improved SR

The X-ray radiation detector of S-PD type comprises two main elements — a multi-channel PD and a scintillator array (assembly). Previously used design of 16- and 32-channel PD imposes limitations on the directions of PD irradiation. These detectors can be used correctly only if irradiation is normal to the plane of photosensitive elements [2, 3]. In collaboration with Research Institute for Micro Instrument, Kyiv, Ukraine we have developed a new design of the 32-channel PD (Fig. 1). Its advantages are [4, 7, 8]:

1) all contacts of photosensitive elements are from one side of the silicon board;

2) the presence and location of a connector allows any desired position of the board with respect to the irradiation direction;

3) 2 adjustment openings are envisaged on the face side of the housing (the side without contacts).

The first and the third feature allow reaching the identity of characteristics of detector couples (high-energy and low-energy detectors, HED and LED).

The second feature allows easy attachment of detectors with minimum gap between them, which is important for preserving the channel step in $0.8 \cdot 10^{-3}$ m arrays.

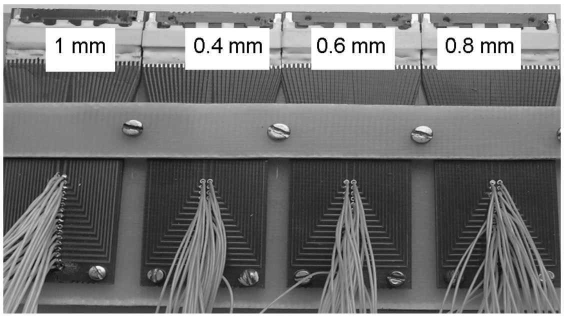

Fig. 2. 32-channel detectors with scintillation elements of different thickness.

Also, the PD design ensures sufficiently large distance between the detector and the PA board, which protects the element base from effects of direct and scattered ionizing radiation. Protection of the elements of electronics is especially important when, e.g., high-energy X-ray sources (XRS) with anode voltage up to 450 keV are used [9].

Experimental samples of 1D-arrays were prepared using monolithic scintillator pieces. 32-Channel scintillator assemblies made from plates had dimensions $(25.4 \times 4 \times 0.6) \cdot 10^{-3}$ m, showed good uniformity of scintillation characteristics and could be precisely placed on photosensitive elements of multi-channel PD [9].

3. Preparation of model detectors and studies of their characteristics

Model samples of 32-channel X-ray radiation detectors were made. Requirements to parameters of the 32-channel detector were formulated at the level of foreign analogs. The parameters of detectors are shown in the Table 1. External appearance of the 32-channel detectors with scintillation elements of different thickness are shown in Fig. 2. Topology of the detector module should allow sequential attachment of modules into a line preserving the detector step at the module junction.

4. Testing of 32-channel detector array as part of model sample of DRS on the basis of receiving-detecting circuit

A model sample was assembled of DRS based on receiving-detecting circuit (RDC) with an array of 32-channel detectors. For obtaining shadow X-ray images, a RDC with

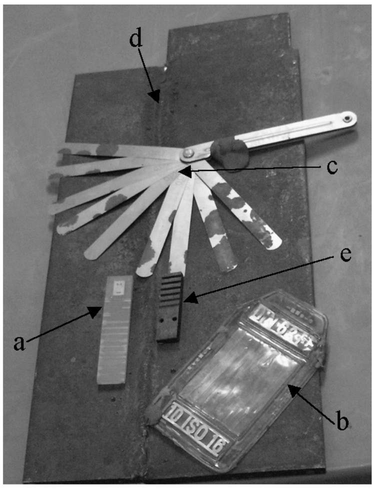

Fig. 3. External appearance of standard testing objects: EN 462-5 — set of wire pairs (a), set of iron wires DIN 62 Fe (10 ISO 16) (b), set of car dipsticks (c) and welded joining the steel plates by thickness $6 \cdot 10^{-3}$ m (d), grooving sensitivity reference No.2 (GOST 7512-82) (e).

Table 1. The parameters of the 32-channel detector

Parameters	Data
Detector output window area	$(0.6 \times 0.6) \cdot 10^{-3}$ m^2
Detector step	$0.8 \cdot 10^{-3}$ m
Static detector current without irradiation (T = 293 K, Ubias = $10 \cdot 10^{-3}$ V)	$<20 \cdot 10^{-12}$A
Detector signal decay after $10 \cdot 10^{-3}$ s	
CsI(Tl)	to 2 % level
ZnSe(Te)	to 0.2 % level
$CdWO_4$	to 0.1 % level
Detector capacitance (T = 293 K, Ubias = $100 \cdot 10^{-3}$ V)	$<50 \cdot 10^{-12}$F

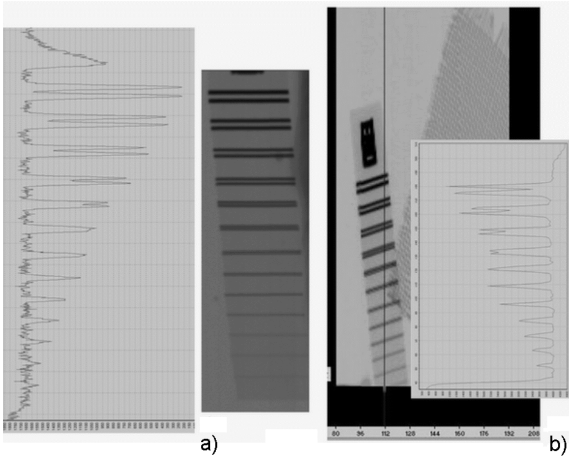

Fig. 4. Evaluation of spatial resolution DRS a) first model DRS-1, testing objects — EN 462-5 is located behind 6 mm steel, increase ≈2; b) second model DRS-2 testing objects EN 462-5 is located without obstacle, increase ≈1.3.

Table 2. The sizes of the wires pairs of testing objects — EN 462-5

Pair	Diameter, mm
1D	1.60
2D	1.26
3D	1.00
4D	0.80
5D	0.64
6D	0.50
7D	0.40
8D	0.32
9D	0.26
10D	0.20
11D	0.16
12D	0.13
13D	0.10

a detector array of new design was developed for $200 \cdot 10^{-3}$ m scanning field. The RDC was integrated consecutively into two DRS models.

The first model DRS-1 consisted of RDC, linear motor (minimum movement step less than 1 μ, length more than $1.6 \cdot 10^{-6}$ m) and X-ray radiation source of Isovolt Titan E type ($U_{a\ max}$ = 160 kV, $I_{a\ max}$ = 45 mA, maximum power 4.5 kW). The second model DRS-2 consisted of RDC, mechanism for movement and rotation of the inspected object, RAPAN 140/140 type source ($U_{a\ max}$ = 140 kV, $I_{a\ max}$ = 1 mA). The presence of the rotation mechanism allowed realization of multi-view scanning mode (60 views), resulting in substantially higher informativity of non-destructive testing and technical diagnostics.

Using these DRS models and standard testing objects — EN 462-5 (set of wire pairs), grooving sensitivity reference No.2 (GOST 7512-82), set of iron wires DIN 62 Fe (10 ISO 16), kit of car dipsticks of different thickness (from $0.1 \cdot 10^{-3}$ m to $0.02 \cdot 10^{-3}$ m) and welded joining the steel plates by thickness $6 \cdot 10^{-3}$ m we have evaluated SR. External appearance of standard testing objects are shown in Fig. 3. The

Table 3. The sizes of the wires of testing objects — DIN 62 Fe (10 ISO 16).

No. of wire	Diameter, mm
W10	0.40
W11	0.32±0.01
W12	0.25
W13	0.20
W14	0.16
W15	0.125
W16	0.100
W17	0.080±0.05

sizes of the wires, which be included in set of standard testing objects EN 462-5 and DIN 62 Fe (10 ISO 16) are shown in the Tables 2 and 3, respectively.

Tests of detector arrays with different thickness of scintillation elements as part of models DRS, with obtaining images of tested objects (calibrated wire pairs), have shown that, depending upon thickness of the scintillation assembly, the spatial resolution is 1÷1.25 line pairs/mm, and detecting ability is better than $0.2 \cdot 10^{-3}$ m steel wire (Fig. 4).

The use of a 16-channel analog to digit converter as part of RDC allowed broadening the dynamic range and improving, as compared with previous results [9], resolution of the model system over thickness from ≈0.9 % to ≈0.4 % behind $6 \cdot 10^{-3}$ m steel (Fig. 5).

Thus, our studies have shown that the developed detector array for obtaining shadow X-ray images with high SR can be successfully used with X-ray sources of up to 160 kV anode voltage.

5. Conclusions

It can be concluded that X-ray detectors reported in this work can be successfully used for creation of fast DRS with improved SR. Their applications include welded joints, pipelines, fabricated metals and metalworks. Also it can be used in inspection systems, including anti-terrorist activities, technical diagnostics and medicine [1, 4, 7, 9].

Acknowledgments. This work was supported in part by NATO project SfP-982823.

Fig. 5. Evaluation of spatial resolution DRS over thickness (behind $6 \cdot 10^{-3}$ m steel).

References

1. V.D.Ryzhikov, O.D.Opolonin, S.M.Galkin et al., in: Proc. SPIE Optics + Photonics (Optical Engineering + Application), San Diego, USA (2009), v.7450, p.0J1.
2. V.D.Ryzhikov, O.D.Opolonin, D.N.Kozin et al., *Nucl.Instr.Meth. Phys. Res.A*, **505**, 192 (2003).
3. V.Ryzhikov, D.Kozin, B.Grynyov, *Nucl.Instr. Meth.Phys. Res. A*, **505**, 181 (2003).
4. S.V.Naydenov, V.D.Ryzhikov, C.F.Smith et al., in: Proc. SPIE Optics + Photonics (Optical Engineering + Application), San Diego, USA (2006), v.6319, p.A1.
5. V.P.Seminozhenko, V.D.Ryzhikov, A.D.Opolonin et al., in: Proc. SPIE Optics + Photonics (Optical Engineering + Application), San Diego, USA (2006), v.6319, p.B1.
6. K.Bavendiek, U.Ewert, Zscherpel, U.Meade, in: Proc.9-th Europ. Conf.NDT, Berlin, Germany (2006), v.2, p.44.
7. B.V.Grinyov, V.D.Ryzhikov, V.P.Seminozhenko, Scintillatsionnie Detectori i Systemi Radiatsionnogo Monitoringa na ih Osnove, Naukova Dumka, Kyiv, Ukraine (2007) [in Russian].
8. V.Ryzhikov, B.Grynyov, A.Opolonin et al., *Radiat.Meas.*, **42**, 915 (2007).
9. V.D.Ryzhikov, O.D.Opolonin, S.M.Galkin et al., in: Proc. SPIE Optics + Photonics (Optical Engineering + Application), San Diego, USA (2010), v.7805, p.P1.

Пошук нових можливостей вдосконалення приймально-детектуючого тракту для цифрових радіографічних систем з покращеним просторовим розділенням

В.Д.Рижиков, О.Д.Ополонін, Б.В.Гриньов, В.Г.Волков, О.К.Лисецька, С.М.Галкін, Є.Ф.Воронкін, В.Л.Перевертайло

Для отримання тіньових рентгенівських зображень проведено розробку приймально-детектучого тракту з лінійкою 32-канальних детекторів "сцинтилятор-фотодіод" нового дізайну для поля сканування $200{\cdot}10^{-3}$ м. За допомогою макетів цифрової радіографічної системи та стандартних тестових об’єктів визначено просторову роздільну здатність (не гірше 1,25 пар ліній/мм) та виявну здатність (краща ніж $0.2{\cdot}10^{-3}$ м стального дроту за $6{\cdot}10^{-3}$ м сталі). Використання 16-розрядного аналого-цифрового перетворювача у складі приймально-детектучого тракту дозволило збільшити динамічний діапазон та підвищити, порівняно з попередніми результатами, роздільну здатність за товщиною з ≈ 0.9 % до ≈ 0.4 % (за $6{\cdot}10^{-3}$ м сталі).