UPDATING OF THE DETECTOR SYSTEM TO INCREASE THE RESOLUTION CAPABILITY OF INDUSTRIAL INTROSCOPES AND TOMOGRAPHS BASED ON 6-15 MeV ACCELERATORS

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Abstract

The updating of the detector systems developed at NPKLUTS for application to customs inspection systems based on 6-10 MeV accelerators is considered in the paper. Under the updating the cross section of cadmium tungstate ($CdWO_4$) scintillators was reduced from 3×3 to 2×2 mm, the ADC bit capacity was increased from 16 to 24 and preamplifiers with variable gain factors were installed in the analog part of electron channels of the detector system. As a result, we have obtained higher sensitivity and spatial resolution of the detector system, wider dynamic range of the system. Tests of a new updated detector system applied in an industrial introscope based on a 15 MeV accelerator have demonstrated a wider range of thickness of scanned objects (from 100-360 to 75-410 mm) at a resolution of 1-1T according to the radiographic ASTM standard.

Works on the development and updating of the multi-channel systems for detection of gamma-radiation have been performed in NPK LUTS for more than 10 years. The first such a system to be applied to industrial introscopes and tomographs, as well as to customs inspection systems of large-scale vehicles and cargo containers based on 6-15 MeV linear accelerators, was developed in 1995 and consisted of 768 channels. The primary measuring elements of the system were scintillators used together with photodiodes to transform gamma-radiation into measured analog electric signal. Crystals of cadmium tungstate ($CdWO_4$) 3×3×20 mm in sizes were applied as scintillators. The analog part of the system, modular in structure (64 detectors per each module), was installed in the plane of the fan-shaped beam of X-ray radiation formed by the collimation system.

The main drawbacks of the developed system are: small dynamic range due to low ADC capacity (12 bit) and non-standard interface used for data transfer to the data acquisition and processing computer. The electronic part of the system underwent serious updating, which consisted in the application of a 16 bit ADC and a standard 10 Mbit Ethernet interface for data transfer (TCP/IP protocol). In addition, the analog and digital parts were combined in modules, the number of detectors in each module was increased up to 128, the control of the enhancement factor was introduced and the total number of channels amounted to 1152.

Tests of the developed system performed at the stand of NPK LUTS, NIIEFA and when integrated into the complex for non-destructive radioscopic inspection installed in the People’s Republic of China in 1998 demonstrated a resolution of 1-1T in compliance with the radiographic ASTM standard.

At the accelerator energy of 15 MeV, the said level of resolution is provided for steel thickness ranging from 100 up to 360mm.

Further development will be focused on attaining the higher spatial resolution of the system. With this aim in view, first were updated the primary measuring elements, scintillator-photodiode arrays. To obtain higher spatial resolution, scintillators’s cross-sections were decreased from 3×3 to 2×2 mm without any narrowing of the system dynamic range due to appreciably improved manufacturing technique (the “PULSAR” firm, Moscow), which allowed the reduction of the photodiode dark current to a level lower than 1 nA/cm^2.

Besides, single scintillator-photodiode arrays were replaced with modular ones, each of 8 detectors (Fig. 1), which resulted in a smaller gap between the detectors (0.5 mm instead of previous 0.2 mm) and higher accuracy of detectors’ positioning. The detector pitch in the module is 2.2 mm. The scintillator side facing the radiation is 2×2 mm. The scintillator dimension along the radiation propagation is 20 mm. The module is 32×17.6 mm in sizes. The main point of the electronic part updating was application of a 24 bit sigma-delta ADC, as a consequence of which we had approximately twice the dynamic range and could substitute the 10 Mbit Ethernet interface for a 100 Mbit one.

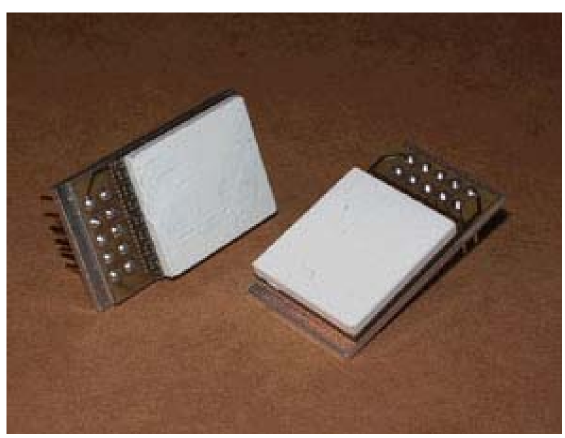

Figure 1: Detector modules (8 detectors each).

In 2002 the system for detection of gamma-radiation integrated into a complex for non-destructive radioscopic inspection based on the 15 MeV linear accelerator was installed and tested in Langfan, the People's Republic of China. Results of the tests are shown in tables 1-2, and figures 2-4 demonstrate typical images obtained.

In the process of the tests steel barriers with a thickness ranging from 75 up to 400 mm were scanned. Plate and wire defectometers were mounted on each of these barriers in such a way as to comply with resolutions of 1-1T, 1-2T and 2-2T (ASTM radiographic and radiological standard) for each barrier thickness. The object transport velocity at scanning was varied from 0.25 up to 2.4 mm/s. Under the tests the accelerator was located at a distance of 4.7 m from the detector line. The pulse repetition rate of the machine was 100-150 Hz. The dose rate 1m from target at a frequency of 150 Hz was 40 Gy/min.

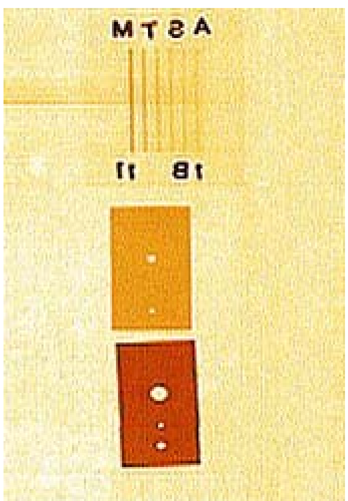

Figure 2: Wire and plate defectometers behind the 75 mm steel barrier.

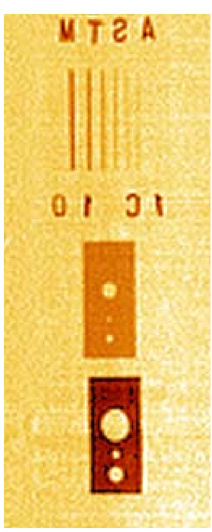

Figure 3: Wire and plate defectometers behind the 200 mm steel barriers

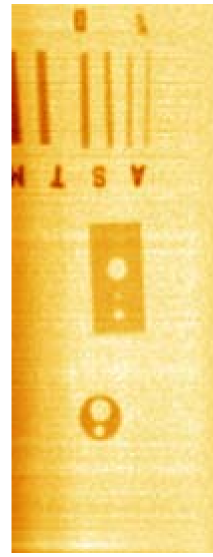

Figure 4: Wire and plate defectometers behind the 300 mm steel barrier

The data presented in the paper demonstrate that the latest updating of the system made possible to obtain higher spatial resolution of the system and, in addition, appreciably wider range of scanned thicknesses.

At present, works on a new updated version of the system with better parameters are underway in NPK LUTS. The scintillator cross-section will be increased from 2 up to 4 mm in the direction transverse to the X-ray fan beam, and in each channel of the system a variable gain amplifier will be installed in front of the integrator instead of scaling amplifier of ADC, as previously.

When detectors are collimated, the first modification makes possible the location of photodiodes outside the area of radiation impact, which improves the stability of detector parameters under long-term radioscopic and tomographic scanning.

As preliminary tests of an experimental module have demonstrated, the second modification provides, with definite limits, constant level of noise produced by the electronics in the channel at higher gain factor.

Table 1: Results of the resolution tests of the radioscopic system using plate defectometers

Thickness of steel barrier, mm	Thickness of plate defectometer, mm	Hole diameter, mm	Discrimination	Resolution (ASTM standard)
75	0,75	0.75	+ +	1-1T 1-2T
100	1.00	1.0 2.0	+ +	1-1T 1-2T
200	2.0	2.0 4.0	+ +	1-1T 1-2T
300	3.0	3.0 2.0	+ +	1-1T 1-2T
375	3.75	3.75 7.0	+ +	1-1T 1-2T
400	4.0	4.0 8.0	+ +	1-1T 1-2T

Table 2: Results of the resolution tests of the radioscopic system using wire defectometers

Thickness of steel barrier, mm	Thickness of wire defectometer, mm	Diameter of wire defectometer, mm	Discrimination	Resolution (ASTM standard)
75	B	0.25	+	
		0.33	+	
		0.4	+	1-1T
		0.51	+	
		0.64	+	1-2T
		0.81	+	
100	B	0.25	-	
		0.33	- +	
		0.4	+	
		0.51	+	
		0.64	+	1-1T
		0.81	+	
200	C	0.81	+	
		1.02	+	
		1.27	+	
		1.6	+	1-1T
		2.03	+	
		2.5	+	1-2T
300	D	2.5	+	1-1T
		3.2	+	
		4.06	+	1-2T
		5.1	+	
		6.4	+	
		8.0	+	
400	D	2.5	-	
		3.2	- +	
		4.06	+	1-1T
		5.1	+	
		6.4	+	1-2T
		8.0	+	