Abstract
To provide non-destructive testing in laying, servicing and repair of large diameter pipeline, a digital radiography system on the basis of an X-ray machine and linear detectors has been developed. While developing a set of instruments, theoretical calculations to determine the optimal parameters of the radiation source and the detector were carried out. In the process of X-ray beam formation, a pulse-frequency technique was used to obtain anode voltage in the range of 220-300 kV and anode current of at least 5 mA. The detector provides the inspection area of 20 cm wide and orientation of the scintillation detectors allow a 3-4 line pairs/mm resolution. The capabilities of the developed system were estimated in the studies, the sensitivity dependence of the method was obtained when changing the X-ray tube voltage. The results of the study are shown in Fig. 2.

Keywords: Scanning digital radiography system, Linear Diode Array, X-ray source, resolution, scintillation detectors, sensitivity control, nondestructive testing, large diameter pipeline.

1. Introduction

The intensive development of oil and gas industry, as well as transporting the obtained products to great distances advance high demands to reliability and performance of non-destructive methods of inspection.

A special emphasis should be made on the inspection sensitivity as emergency situations result in a significant environmental damage.

Based on this situation, our Institute conducted an extensive research to determine the optimum performance, and development of X-ray units that solve this problem. As shown in [1], the use of linear detectors consisting of scintillators CsI (TI) and a photodiode matching a luminous flux emitted by the scintillator in the max sensitivity is the most efficient for X-ray registration. This choice is determined, above all, by the high detection efficiency of X-ray radiation, which is defined by the high atomic number, high density and the maximum conversion efficiency of these luminescent materials [2].

Currently, digital radiography systems (DRS) are widely used in industry because of the possibility to receive information on a real-time basis, visualize the obtained results, having made a computer pre-processing to improve the accuracy of inspection and parameters of the detected defects [5, 6, 7].
The world leading companies are developing both individual components of the system and the complete system. The best known companies are Siemens, Institute of Non-Destructive Testing, National Research Tomsk Polytechnic University (NR TPU); they have developed several X-ray machines that generate X-rays in the range from 50 kV to 300 kV [8]. The products of Hamamatsu manufacturer are well-known in the area of scintillator arrays (Linear Diode Array) [10]. The most adequate software for digital signal processing from the Linear Diode Array was developed by the report authors.

The principle of operation of these systems is based on theoretical calculations to determine the optimum parameters of the radiation source and detector [5], namely, a narrow fan beam passing through a tested weld, getting on the Linear Diode Array, which sends signals to the system of test results processing where they are converted to grayscale images of the object internal structure.

These complexes are made and applied by such companies as Heimann, VJ Technologies, Varian, INDT NR TPU, Moscow Institute of Radio Electronics and Automation [12, 13, 9]. These systems have several advantages, the main of which is to monitor in real time mode without affecting the sensitivity of control.

2. **Method and apparatus**

Designed and manufactured, the installation passed laboratory and field trials successfully. The main elements of the installation are:

- X-ray source;
- X-ray sensitive array (Linear Diode Array);
- system of information registration and its processing;
- unit of information display and documentation;
- mechanism of positioning;
- defect marker.

Portable pulsed X-ray units such as RAP-220, RAP-300 or other are used as an X-ray source in the installation. These X-ray units generate an X-ray pulse flux of up to 220 kV or 300 kV and enable quality control of pipelines with a total wall thickness of up to 60 mm of steel. In order to ensure quality control of welds and safety of the operator in the field, a car with a self-contained power supply and a unit of data display and documentation is located at the distance of 20-30 meters from the site of pipeline inspection.

Digital radiography systems (DRS) on the basis of linear detectors are the most promising for technical diagnostics of industrial objects. A photodiode line combined with a line of scintillators convert the radiation in these devices. A two-dimensional X-ray image is formed by moving the line or a test object within the X-ray field. Image processing is provided by algorithms based on the principles of digital and analog filtering, and analyzing the results to
improve the reliability of parameters such as length, shape, and volume of the defect. The inspection pattern using digital radiography based on the linear detectors is shown in Fig. 1.

![Diagram of inspection using digital radiography](image)

**Fig. 1. Inspection using digital radiography [3]**

Currently, the INDT NR TPU is developing a DRS on the basis of linear detectors for welded joint inspection of pipelines of up to 1220 mm diameter, with a total wall thickness of steel up to 24 mm. This direction of DRS development allows avoiding geometric distortion on X-ray images obtained by the DRS on the basis of flat screens and photodiode arrays.

The LDA-based DRS of the developed NDT system provides the width of the inspection area of 20 cm, at the scanning speed of 10-50 mm/sec and inspection of the long weld in a real time mode. The spatial resolution of the linear detector is determined by the number of channels in the line and it is 1024 in our system, which provides a resolution of the whole system of 3-4 line pairs/mm.

This system allows inspection of defects and inhomogeneities with the sensitivity according to the thickness-sensitivity dependence chart, at a speed control of $v = 3$ m/min, at the X-ray energy of 220 kV and 300 kV. The dependence of 10 measurements is shown in Fig. 2.
Fig. 2. System sensitivity vs. thickness of the test object, at the X-ray energy of 220 kV (curve 1) and 300 kV (curve 2)

The NDT system for digital X-ray inspection of pipelines provides continuous scanning with the help of a positioning mechanism in the longitudinal direction and around the pipe within 360°, and forms a continuous digital X-ray image of the weld 3-4 m long, depending on the pipe diameter. It also allows scanning the longitudinal and spiral welded joints of pipelines. The spot of defect location is marked on the test object by a special marker. The system is shown in Fig. 3.

![Fig. 3. Flaw-detection system on a pipeline of 1020 mm diameter](image)

1 – X-ray source; 2 – Linear Diode Array; 3 – pipeline; 4 – positioning mechanism; 5 – marker.

The system includes: an X-ray unit in a protective waterproof housing, and an X-ray sensitive unit in a protective housing mounted on a fixing assembly for pipes with the outer diameter of 1020 mm, with a traveling mechanism and a marker.

The test object is X-rayed as follows. The system is mounted on a pipeline. To ensure the safety of the operator in the field, a car with a unit of data display and documentation and independent power supply is located 20-30 meters away from the pipeline. The obtained image of the inspected object is displayed on the monitor. The X-ray image is analyzed by the operator who locates the defects, abnormal areas, and estimates the weld quality. After 3-minute scanning of 3 meter circumference, the system puts marks on the defective and abnormal areas of the pipeline using the positioning mechanism and the marker, for repairing in field conditions. Then, the positioning mechanism moves the system to the next leg of the inspected weld.
Fig. 4 shows a weld X-ray of the main pipeline 1020 mm in diameter obtained with the LDA-based DRS.

Fig. 4. X-ray image of a weld of a pipe 1020 mm in diameter, with a total thickness of steel 24 mm

INDT NR TPU conducted comparative trials of DRS and X-ray imaging technique, which resulted in detectability of defects in the pipe weld of 1020 mm diameter and 24 mm thickness, being 93%. Here it took 36 minutes to obtain radiographs of the weld 3 meters long using X-ray imaging technique, with sufficient optical density of the D7 film, without taking into account time and expendables for processing. In its turn, the LDA-based DRS method allowed a digital X-ray image of 3 meters over just 3 minutes.

3. Conclusions

Application of DRS instead of the X-ray imaging technique can significantly improve performance without detriment to defect detectability, which in turn increases the productivity of welding during installation and repair of pipelines. It also reduces costs, both material and human resources. It also allows processing of digital radiographs and identifying weld defects without geometric distortion and high contrast.

In the course of work a hardware and software system was realized for digital radiography of welded joints of pipelines, which were tested in the laboratory and field conditions and have demonstrated the technical capabilities of the system corresponding to similar foreign models, such as VJT Alaska Crawler [4, 13]. Further studies on expanding the possibilities of the digital radiography method have been conducted at the Institute extending the X-ray receiver spectrum from 50 keV to 10 MeV for the purpose of inspecting materials and products in a wide range of thicknesses and densities, as well as increasing sensitivity to detection of local inhomogeneities up to 0.7 - 1%.

References:


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