



Validation of Results of Automatic Ultrasonic Inspection of Pipeline Welds by Manual Ultrasonic Inspection

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Abstract

Gas consumption has increased in recent years, which has led to the need for more pipelines. Gas pipeline construction in Europe and the world has increased significantly. This led to the need to shorten the gas pipeline production, installation and inspection time. Solution of this task is possible using the automation of welding and inspection processes at the pipeline installation stage. The European Union finances a number of inspection automation projects through Industry 4.0. The implementation of automation in the inspection of welded joints in gas pipelines using phased array testing technology is not validated by European or International Standard. With this work, a pipe welded joint testing was performed by OLYMPUS automated ultrasonic testing system. The test results are compared and analysed with the results of manual ultrasonic testing of the same sample. The influence of the automated system on the repeatability of results of the ultrasound testing was studied.

Keywords: automatic ultrasonic inspection, validation of results, scanning systems, welding pipeline.

Introduction

In some of the most responsible industries, such as the military, aviation, power and others, it is essential to reduce inspection time, increase inspection efficiency, and ensure result reliability [1÷5].

The subject of this work is to validate the results of automated ultrasonic inspection by manual ultrasonic inspection in the advancing energy industry. As of 2019, construction of gas pipelines with a length of over 1000 km is planned in Bulgaria [6, 7]. The deadlines set for construction of the gas pipelines require reducing installation and inspection time, which is achieved through the use of automated welding and inspection systems. There are many automation systems around the world and in Europe for the inspection of gas pipelines developed by leading companies manufacturing equipment and inspection service suppliers [8÷11]. In order to be competitive and meet the requirements of the developing inspection services market in the world and in Europe, part of the Bulgarian inspection companies have implemented commercial automated inspection systems applying ultrasonic and radiographic methods.

One of the leading non-destructive testing companies, Multitest Ltd., has carried out tests of welded joints from a gas pipeline using an OLYMPUS automated ultrasonic system. Scientific personnel from the Institute of Mechanics at BAS participated in the tests. The automated system uses OMNISCAN ultrasonic unit and phased array probes by OLYMPUS. The contact medium is water fed under pressure.

An open test was carried out using the automated system to check the reliability of detecting and sizing the imperfections in the welded joints tested. The imperfections detected and sized

by the automated system are compared with the results of a manual ultrasound testing. The repeatability of results of two consecutive automated scans was also checked.

The purpose of the tests performed is to verify the reliability of the results of the tests carried out on a welded joint of a specimen simulating a pipeline with several imperfections in the weld, and to determine the effect of the automated system on result repeatability.

1. Preliminary preparation to perform the open test

1.1. General information of its performance

The testings of the open test were carried out on February 18, 2019 at Multitest premises using the automated ultrasonic system of OLYMPUS. The testing was performed on a fabricated pipeline specimen with one transverse butt welded joint containing imperfections.

1.2. Information about the inspection object

The specimen is a section of a pipeline with outside diameter of 500 mm and wall thickness of 9mm made of steel with a single transverse butt weld. The surface roughness is ground to the required level less than 6.3 μm .

1.3. Information about the automated system modules

The automated system consists of: an automatic motion mechanism, a head with probe gripping devices, an encoder for probe location and a contact medium feeder – water.

1.4. Information for providing the system with valid regulatory documents and standards

The following standards have been used for testing by the automated ultrasonic system for the implementation of multi-element phased array technology:

- **EN ISO 13588:2012.** Non-destructive test of welded joints. Ultrasound testing. Use of automated phase array technology.
- **EN ISO 19285:2018.** Non-destructive test of welded joints. Phased Array Ultrasonic Testing (PAUT). Acceptance levels.
- **EN ISO 18563-1:2015.** Non-destructive testing (inspection). Characterization and verification of phased array ultrasonic testing equipment. Part 1: Tools
- **EN ISO 18563-2:2017.** Non-destructive testing (inspection). Characterization and verification of phased array ultrasonic testing equipment. Part 2: Probes.
- **EN ISO 18563-3:2016.** Non-destructive testing (inspection). Characterization and verification of phased array ultrasonic testing equipment. Part 3: Combined systems.
- **EN 12732:2013.** Gas infrastructure – Welding steel pipework – Functional requirements.

1.5. Information of using a scanning plan, specialized probes and checking them in accordance with standards.

Phased array technology was used with a sectorial scanning pattern with a front probe position 20mm from the centreline of the weld to cover the entire volume of the weld.

To carry out the open test the following were used: multi-element phased array probe 5L64-A2 with wedge N55S-IHC – 2 pieces; the OMNISCAN SX ultrasonic unit; encoder QUED-12 step / mm.

The probes are checked according to BDS EN ISO 18563-3: 2017. The contact medium is pressurized by a dedicated device.

1.6. Information of reference samples used

The following standard reference blocks were used for the test:

- Reference block for setting time of flight – 1 unit block V1;
- Reference block with side drilled holes (reflectors), for setting the amplitude of the reflected signal – 1 piece.

1.7. Test mode setup information.

The depth gauge is adjusted on the time scale X (velocity and delay in the wedge) with reference block V1. The timeline is adjusted so that the entire test volume of the weld is displayed on the screen.

The amplitude of the reflected signal of the ultrasonic system is adjusted by a reference block with side drilled holes (reflectors). In using the phased-array technology, the amplitude reflected by the same reflector at different angles of transmission is aligned. The amplitude obtained from the reflector is set to 80% FSH (full screen height) of the instrument screen.

1.8. Information of the imperfections to be detected.

During welding of the pipes, 5 imperfections were introduced. They are numbered from 1 to 5 and are located from the index (zero) point of the pipe circumference at a distance as follows: No.1 – 0mm, No.2 – 550mm, No.3 – 820mm, No.4 – 1000mm and No.5 – 1360mm. The imperfections No.1 to No.4 are in the weld root, and No.5 is in the weld middle.

Conducting the open test meets the requirements of the IAEA regulatory documents and ENIQ materials [12].

1.9. Scope and procedure for carrying out the open test.

- Functionality check of the probes, ultrasonic flaw detector, mechanical part of the system and system for supplying contact medium used.
- Measurement of roughness of the weld surrounding area and making adjustments if necessary.
- Provision of ultrasonic inspection data for the absence of discontinuity at the ends of the welded pipes before welding and in the surrounding area after welding.
- Setting up ultrasonic systems by reference blocks.
- Getting familiar with flaws present in weld inspected, before test.
- Scanning of welded joint.
- Analysis of scanning data and preparation of initial report.
- Assessment of the measured characteristics of imperfections detected.
- Evaluation of the repeatability of results by double scanning.
- Verification of results by comparing manual (previous inspection) and automated inspection data.
- Preparation of the final report and conclusions.

2. Testing results of the open test

Scheme of the weld and coordinate system for determining the location (X, Y, Z) of the detected indications, as well as their conditional dimensions (L_x – in length, L_y – in width and h – height) is given in Fig.1. The zero (index) point “O” and the direction of the coordinate axis X are marked on the weld of the tube sample.

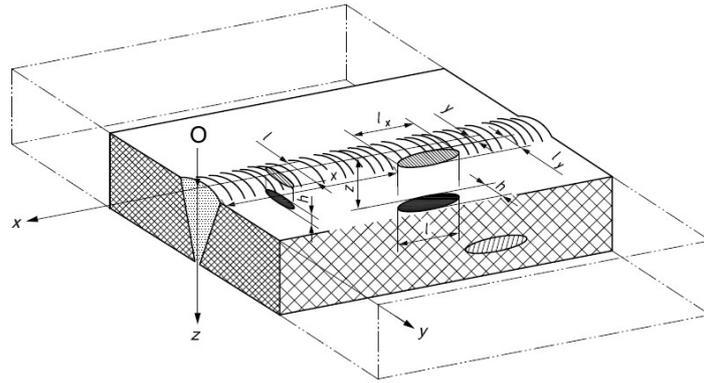


Figure 1. Scheme of weld with coordinate system for determining location and conditional size of detected indications.

2.1. Results of manual ultrasonic inspection of the test object with weld from a gas pipeline

The test was performed with an angled probe and (working) frequency of 4MHz. Machine oil contact medium was used. The pulsing scheme is given in Fig.2. The scanning area marked with *b*, when manually moving the probe on the surface of the weld is 60mm.

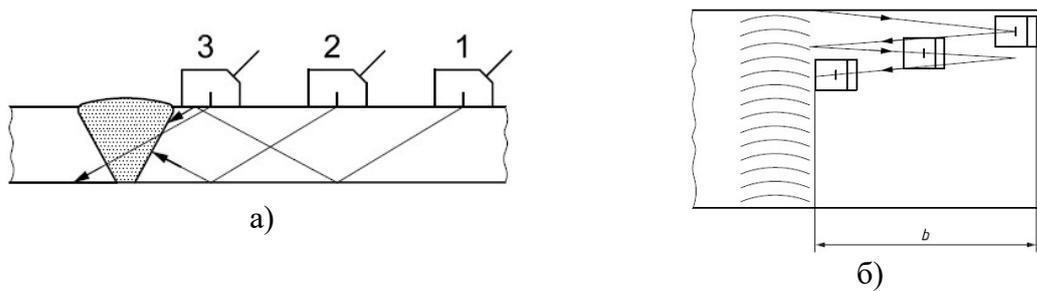


Fig.2. Sound (pulsing) scheme for manual ultrasonic inspection, side view (a) and top view (b) of the weld.

The test and evaluation results are given in Table. 1. The assessment was made for compliance of the weld with the requirements of BDS EN ISO 11666, level 3.

In the column with serial number the detected indications of imperfections in the weld are given. They are marked on the weld by a metal marker. X, Y, and Z indicate the location of the maximum amplitude indication in the weld from the index point “0” marked on the test object – tube with a butt weld. The conditional dimensions in mm given in the table with *L_x*, *L_y* and *h* are determined by 6 dB method. FSH indicates the height of the reflected echo on the instrument screen in %.

Table 1. Results and evaluation of manual ultrasonic test with 70° probe.

№	X, mm	Y, mm	Z, mm	L_x, mm	L_y, mm	h, mm	Max. ampl. dB	Evaluation
1	0	-1.4	8.2	46	3.2	4	over 80%FSH	Non-conforming
2	557	-5.5	7	10	3.9	3.8	over 80%FSH	Non-conforming
3	816	-5.1	6	13	3	3.4	over 80%FSH	Non-conforming
4	1025	-6.4	7	15	3.2	3.9	over 80%FSH	Non-conforming
5	1365	-4.5	4.8	55	4.1	3.2	over 80%FSH	Non-conforming

2.2. Results of automated ultrasound inspection of the test object with weld from a gas pipeline

The test was carried out in the following conditions:

- Used phased array probes
- Inspection plan – sectorial scanning with a constant distance of 20mm, between the center of the weld and the of the probe front (see Figure 3a)
- Probe travel speed 100mm / sec, on pipe circumference
- Contact medium – water
- Reporting location of flaws – using a scanner encoder with the recorded images.
- Set mode – 35dB gain, 5MHz frequency, scan resolution – 1mm, pulsing at angles 45° to 70° (1°step), A, S (sector) and C (top view) scan image recording

The results are recorded in the memory of the unit and can be evaluated both on the ultrasonic device during the test and later by TOMOVIEWER software or other software for reading and evaluating the images of the automated scanning.

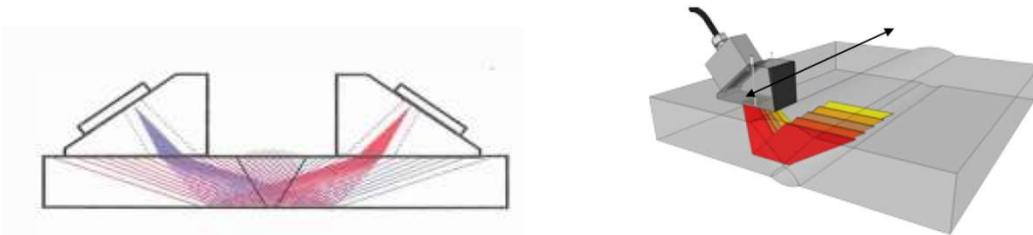


Figure 3. Scheme of scanning using phased array probes of the automated ultrasonic system, side view (left) and top view (right) of the weld.

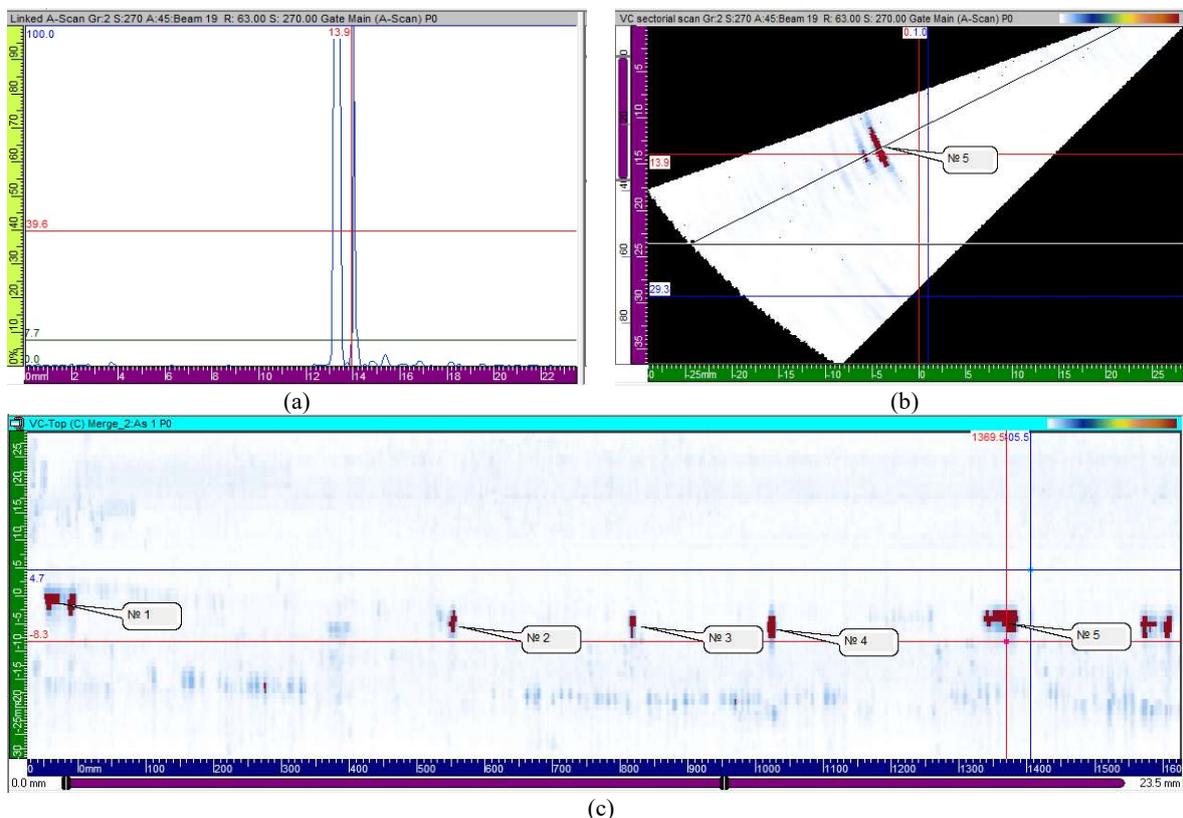


Fig.4. Test results using the automated ultrasonic system in the form of: A-scan image (a), S-scan image (sectoral, side view of weld) (b) and C-scan image (top view of weld) (c).

The results of a single scan are given in Figure 4. Numbers 1 to 5 indicate the imperfections found in the test.

The purple color represents the coordinate Z – in the depth of weld (zero is from the surface of weld). Green is the coordinate Y – in the width of the weld (zero is at the center of the weld). Fig. 4b shows the X coordinate – in the length (circumference of the tube) of weld in dark blue. The start of the scan is from zero (index point "0") marked on the weld by a metal marker. These coordinates correspond to the scheme in Figure 1.

Indication No. 5 of the scan is given in A – and S – scan images.

The numerical values of the test results are taken from the images recorded during the scanning. The results and evaluation of the inspection using the automated ultrasonic system are presented in Table 2. The indications in Table 2 correspond to those given in Figure 1 and Table 1.

Table 2. Results and evaluation of the inspection by the automated ultrasonic system

N ₂	X, mm	Y, mm	Z, mm	Lx, mm	Ly, mm	h, mm	max ampl. dB	Evaluation
1	0	-1.3	8.5	42	3	4	over 80%FSH	Non-conforming
2	553	-5.3	7	8.5	3.5	3.7	over 80%FSH	Non-conforming
3	820	-5.3	6	10	2.5	3	over 80%FSH	Non-conforming
4	1023	-6.3	7	12	3	3.6	over 80%FSH	Non-conforming
5	1368	-4.3	4.5	50	4	3	over 80%FSH	Non-conforming

2.3. Analysis and verification of results

There are two types of result validation carried out:

- comparing the results of one scanning by the automated ultrasound system with those of scanning by manual ultrasonic inspection given in Table 3;
- comparison of the results of two consecutive scanings by the automated system to confirm the repeatability of the test result with the system given in Table 4.

Table 3. Differences in the results of manual and automated ultrasonic testings for the tube sample with butt welds

N ₂	X, mm	Y, mm	Z, mm	Lx, mm	Ly, mm	h, mm
1	0	-0.1	-0.3	+4	+0.2	0
2	+4	-0.2	0	+1.5	+0.4	+0.1
3	-4	+0.2	0	+3	+0.5	+0.4
4	+2	-0.1	0	+2	+0.2	+0.3
5	+3	-0.2	+0.3	+5	+0.1	+0.2

Table 4. Differences in the results of two consecutive scanings using the automated ultrasound system, when testing the tube sample with butt weld

N ₂	X, mm	Y, mm	Z, mm	Lx, mm	Ly, mm	h, mm
1	0	0	0	2	1	0.5
2	2	3	0	1	0.5	0.5
3	3	4	0	1	1	0.3
4	1	4	0	0	1.5	1.2
5	3	4	0	1.7	0	0

Conclusions

- The results of determining the dimensions of the imperfections of the detected indications by the automated test are comparable to those of the manual ultrasonic test. The differences in positioning the imperfections on the X-axis in some cases reach up to $\pm 4\text{mm}$, and in determining the conditional size – up to $\pm 5\text{mm}$.
- The smaller values of the conditional size of the automated ultrasonic system compared to the manually determined ones are due to the possibility of presenting a huge amount of information collected (32 A-images on an area of $1\text{mm}\times 0.6\text{mm}$) through the additional S -scan and C -scan images.
- The results for localization and sizing the discontinuities of two consecutive scanings by the automated ultrasonic system differ by no more than 4mm for positioning and 2mm for conditional size. The precision is sufficient for the repeatability of the results for the purpose of practical testings of the pipeline welds.

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