Experience of Integrated NDT of Large-Volume Welded Tanks for Storage of Liquid Ammonia, Petroleum Products and Alcohols

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Abstract. Performance of periodical integrated technical inspections of steel cylindrical welded tanks of a large volume is a mandatory condition of their safe service.

The main purpose of integrated technical inspection of tanks is determination of their technical condition, possibility of further safe operation, dates of subsequent inspections, need for repair or removing the tanks from service.

Introduction

The basis for integrated technical inspection of tanks are procedures of non-destructive testing of the quality of metal and welded joints:

- visual-optical testing of the tank surface, detection and evaluation of unevenness (camber, dents, delaminations, etc.) on the wall and bottom inside and outside the tank, more precise determination of the scope of application of other testing techniques;
- NDT of welded joints and metal of tank wall: ultrasonic testing (UT), magnetic testing (MT), penetrant testing (PT), acoustic emission (AE);
- NDT of welded joints and tank bottom metal: UT, MI, leakage testing (LT);
- Determination of mechanical characteristics of the metal and welds on samples made from reference-samples cut out from the wall and bottom;
- Metallographic analysis of welded joints on samples made from reference-samples cut out from the wall and bottom;
- Metallographic analysis of the metal of the wall and bottom by the replica method;
- Chemical analysis of the metal, including quantitative analysis of the content of hydrogen in the metal.

The code base of the integrated technical examination of the tanks are documents [1 – 8], as well as standards and technical schedules for individual kinds of testing [9 – 14, 16 – 18, 20, 21].

1. Description of the Objects of Testing

For many years the E.O.Paton Electric Welding Institute performed dozens of operations on integrated technical examination and non-destructive testing of various welded tanks of a large volume. The objects of our research most often were tanks of surface, casemate and underground location:

- horizontal cylindrical welded tanks of 10 – 200 m^3 volume;
- vertical cylindrical welded tanks of 100 – 50000 m^3 volume;
- entrenched welded tanks of 1000 – 5000 m^3 volume;

- vertical isothermal welded tanks of 10000–16000 m^3 volume for storing liquid ammonia.

Integrated technical examination and non-destructive testing of welded joints and metal of a tank for liquid ammonia storage of 16000 m^3 capacity has become the most interesting work over the last years.

This isothermal storage of liquid ammonia is designed as a double-wall vertical cylindrical tank, located in a concrete casemate and enclosed by a guard wall.

Inner tank, in which the liquid ammonia is actually stored, is concentrically located inside the outer tank. Outer tank preserves the lagging from damage and moisture penetration. Wall thickness of the outer tank is 7 mm (1 – 6 tiers) and 6 mm (6 – 15 tiers).

Thickness of the inner tank wall is equal to (by tiers): 16–14–13–12-10-10-10-10-12-12 mm – 10 tiers altogether, each of 2000 – 2050 mm height.

The inner tank wall is assembled from large-sized sheets (about 2.0 x 6.0 m). All the joints are butt-welded. The following steels are used in the tank: N-TVF33 (Japan) – wall and N-TVF30N (Japan) – bottom and roofing. Interwall space between the inner and outer tanks is filled with lagging from Circulite sand.

Gaseous sand is continuously fed into the interwall space for drying of the lagging during operation. Nitrogen flow is also used as the carrier for recording the possible appearance of ammonia in the interwall space.

Access doors are provided in the lower part of the wall and on the roof for work performance.

The storage is fitted with pipelines for input and output of the liquefied and gaseous product, devices for protection from excess pressure and vacuum formation, control and measuring instruments and other equipment.

Technical characteristics of the inner tank are as follows: bottom diameter – 30050 mm; wall height – 21000 mm; amount of stored product - 10000 tons; temperature of stored product – minus 33 C; pressure in the tank – 3 – 7 kPa;

Isothermal storage of liquid ammonia was made element-by-element and supplied by TEC Kawasaki, Japan. It is mounted on ammonia producing site 1-A of SGPP "Objedinenie Azot" in 1973 – 74.

Fig. 1. General view of welded tanks for liquid ammonia storage.

2. Visual Testing

Visual testing of tank metal structures was conducted for detection and sizing of the defects or damage in the base metal and welded joints, formed in operation.

The purpose of visual inspection, according to DSTU 4046-2001 [6], is detection of the following defects:

- in the base metal: cracks, tears, wall corrosion, bulges, corrugations, blowholes, crevices, mechanical surface damage, delaminations and other surface defects, formed or developing in service;
- in welds: welding defects such as cracks of all kinds and directions, blowholes and porosity of the weld outer surface, undercuts, rolls, burns-through, unfilled craters, corrosion, non-conformance of weld shape and dimensions to the specification requirements;
- visible deformation of structural elements (buckling, sagging, deviation from the initial position).

Geometrical dimensions of welds are checked for compliance to the requirements of GOST 5264-80 and GOST 8713-79 [9 – 10].

Before performance of testing, the weld surface and the HAZ up to 100 mm wide on each side of the weld are scraped using soft flap emery wheels. Roughness of the surfaces scraped for testing should be not more than R_a 12.5 (R_z80) to GOST 2789-73.

Visual inspection is performed according to the technical requirements set forth in DSTU EN 13018-2006 and DSTU ISO 17637-2003 [11 – 12].

The following auxiliary equipment is used at visual inspection: viewing magnifiers (2-3 fold magnification); measuring magnifiers to GOST 25706-83; measuring scales to GOST 427-75; calipers to GOST 166-89; welder's versatile gauges UShS-3; metal and hair brushes for scraping; portable lights; markers; binoculars (for examination of metal structures of the wall and roof).

3. Ultrasonic Testing

Ultrasonic testing is performed in keeping with the requirements of GOST 14782-86 [13], DSTU EN 583-1-2001 [14] and "Technological instructions on ultrasonic testing of overlap and fillet welded joints of an isothermal tank bottom" to reveal internal plane and volume defects. When developing the procedure, the many years of experience of the E.O.Paton Electric Welding Institute in the field of ultrasonic testing [15] were used in addition to the standards and codes.

The following is subjected to 100% ultrasonic testing:

- vertical and horizontal butt welded joints of sheets of the first, second and third tiers of the wall;
- overlap welded joints in the central part of the bottom;
- butt welded joints of sheets of the bottom rim and overlap welded joints of the sheets of the rim and bottom central part;
- chime fillet weld.

Ultrasonic testing is performed using flaw detectors USN-52 (Krautkramer, Germany) UD2-70 (NPF "Ultracon-Service", Ukraine), UD2-12 (NPO "Volna", Moldova) and others.

Testing is performed using direct and inclined TR transducers with the working frequency in the range of 2.5 – 5.0 MHz and angle of incidence of 45 degr. Inclined transducers were specially manufactured at the E.O.Paton Electric Welding Institute.

The main testing parameters are checked on reference blocks from KOU-2 set. Setting up of the flaw detectors and testing parameters is performed on test samples with artificial reflectors of specified dimensions and location.

The following methods of testing with the inclined transducer are mainly used:

- by a direct beam – to reveal defects in the weld root;
- by a once-reflected beam – to reveal defects in the weld middle and upper part.

Acoustic coupling of the transducer with the metal surface was provided using special gel lubrication of MR-Chemi, Germany.

Flaw detector setting-up includes:

- setting up the scanning rate and depth meter;
- setting the controlled zone;
- setting up the sensitivity.

Norms of quality evaluation (SNiP 3.03.01-87) are given in Table 1.

Table 1. Norms of evaluation of welded joint quality by ultrasonic testing results

Welded joints	Element thickness, mm	Length of evaluated region	Fixed equivalent area of individual defect, mm^2		Admissible number of individual defects in the evaluated area, pcs.
			acceptance level	registration level	
Butt, fillet, tee, overlap joints	6…10	20	5	7	1
	10…20	25	5	7	2
	20…30	30	5	7	3
	30…60	30	7	10	3

Measurement of the thickness of tank structural elements is performed using a number of ultrasonic thickness gauges. The most convenient for this purpose is thickness meter UT-04 EMA Delta (NPF “S.N.P.”, Ukraine) with a contactless electromagnetoacoustic transducer.

If required, we apply the technologies of **acoustic-emission testing**, as well as computerized ultrasonic flaw detectors, allowing use of **TOFD, SAFT** and other technologies.

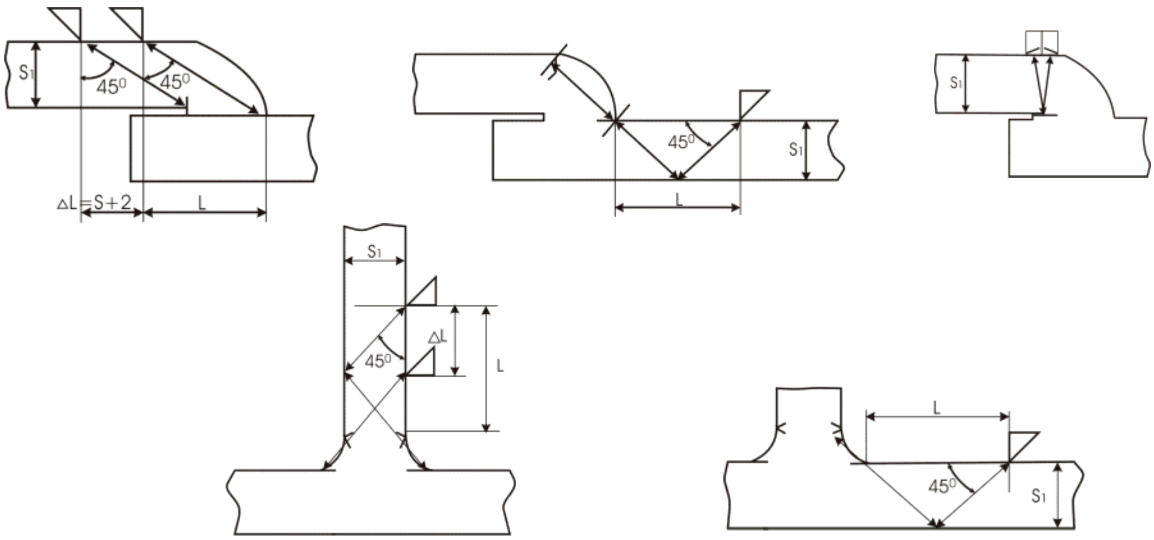

Fig. 2. Main schematics of ultrasonic testing of overlap and tee welded joints.

4. Magnetic Testing

Magnetic particle testing is conducted in keeping with the requirements of GOST 21105-87 [16], DSTU 2954-94 [17], DSTU EN 1290-2002 [18], and “Technological instructions on magnetic powder inspection of welded joints of an isothermal tank bottom” to reveal surface and subsurface cracks of different origin, hair lines, tears, folds, lacks-of-penetration and other defects of welded joints and HAZ. When developing the procedure, the many years of experience of the E.O.Paton Electric Welding Institute in the field of magnetic inspection [19] were used in addition to the standards and codes.

The following is subjected to magnetic particle inspection:

- vertical butt welded joints of the first and second tiers of the wall;
- horizontal butt welded joint of the first and second tiers of the wall;
- overlap welded joints of the bottom central part;
- butt welded joints of sheets of the bottom rim and overlap welded joints of the sheets of the rim and bottom central part;
- fillet chime weld.

Magnetic particle testing is performed using magnetizers of flaw detectors Parker, USA and PMD-70, NPO “Volna”, Moldova.

Testing method is testing in the applied field. Method of welded joint magnetizing is longitudinal (pole), using an attached electric magnet. Magnetic intensity between the poles is not less than 80 A/cm. Magnetic powder was applied on the controlled surface by the “dry” method. Magnetic powder Ferromor of Fly Chemical Company, Great Britain, was used.

Chalk suspension in aerosol form made by NPF “IFKh-COLOR”, Kiev, is used to create a white background in contrast with the magnetic powder.

To check the operability of the entire system of magnetic particle testing, the following reference blocks are used every hour: Berthold sample and factory reference sample (from the set of PMD-70 flaw detector).

Testing using “magnetic scanners” is performed to study the corrosion condition of sheet structures of the tanks.

Testing by “magnetic memory” technique is conducted to reveal sections of welded joints with a non-uniform inherent magnetic field for their further more detailed study.

Eddy current testing is performed to reveal surface and subsurface cracks of different origin and other defects of welded joints and hear-weld zone.

5. Penetrant Testing

Penetrant testing is conducted in keeping with technical requirements of GOST 18442-80 [20] and DSTU EN 571-1-2004 [21] to reveal the visible or hardly visible for a naked eye defects of the type of materials discontinuities, coming to the surface (cracks, blowholes, lacks-of-penetration, etc.).

The following is subjected to penetrant testing:

- welded joints made for cutting-in the branchpipes or manholes;
- overlap welded joints of the bottom – selectively;
- butt welded joints of the wall – selectively;
- surface of the manhole ring, on which the plug is installed.

Penetrant testing is performed with flaw detection materials of MR-Chemie, Germany in aerosol form; MR-68C penetrant; MR-85 cleaner; MR-70 developer.

Testing method is luminescent-colour. KD-33L luminescent lamp (NPO “Volna”, Moldova) is used. Material sensitivity is checked on a reference block, made in keeping with the requirements of GOST 23349-84 (Appendix 3, sample #2).

Penetrant testing includes the following technological operations:

- cleaning of the controlled section;
- application of MR-68C penetrant on the controlled section. Penetrant holding on the section for not less than 20 min.;

- penetrant removal from the controlled section with rags soaked in MR-85 cleaner. Natural drying of the section for 10 - 20 min.;
- application of MR-70 developer on the controlled section. Observation of the controlled section during developer drying for the first 5 min. Second examination of the controlled section 20 min after the developer application.

6. Leakage Testing

Leakage testing of welded joints of tank bottoms and walls is performed by the vacuum chamber method (bubble testing) or capillary penetration method (liquid penetrant inspection). In rare case we are using gas-analytical leak detectors.

7. Mechanical Testing

The purpose of mechanical testing is determination of mechanical properties of the base metal and welded joints at room and working temperature, without which it is impossible to correctly assess the condition of the metal in operation. The main kinds of mechanical testing are tensile, impact toughness, bending, hardness tests, etc.

Mechanical characteristics of the metal are measured under laboratory conditions on samples, made from sheets, cut out of the bottom and wall.

Tensile testing of the metal, allowing determination of the characteristics of strength and ductility of the metals under static uniaxial loading, is performed on various samples to GOST 6996-66, using an electromechanical testing machine.

Impact toughness testing of the metal is performed on samples with V- or U-shaped notch to GOST 6996-66 using a pendulum hammer.

Testing allows determination of the yield point, ultimate strength, relative elongation, impact toughness and hardness of the metal.

8. Metallographic Analysis

Metallographic analysis is conducted to study the macro- and microstructure of the deposited weld and base metal.

Metallographic analysis of the deposited weld metal and base metal of the **bottom** is conducted, as a rule, under laboratory conditions, on samples made from plates cut out of the tank bottom. Samples are prepared by grinding. Finish treatment of the surface is performed with diamond pastes and subsequent etching of the sections by alcohol solution of nitric acid.

Macroanalysis of the deposited weld metal reveals cracks, tears and other defects in welded joints, distance between the plates of the overlap welded joint, and metal susceptibility to corrosion.

When studying the microsections of welded joints and base metal, their microstructure, for instance, ferrite-pearlite, fine-grained; crystal structure, for instance columnar, acicular; grain size to GOST 6539-82, and striation of structural components to GOST 6540-68 are determined on samples.

Metallographic analysis of the deposited weld and base metal of the tank **wall** is conducted, as a rule, by the method of “impression” from the surface, using polystyrol replicas and a portable microscope (without cutting samples out of the wall). Several zones (sections) are prepared for investigations in the places of crossing of vertical welds of the wall with the horizontal welds.

Section surface finish treatment is performed with diamond pastes. “Neophot-21” microscope is used, providing a magnification of x100 and x250.

Macroanalysis of sections of 200x200 mm size also reveals shallow undercuts, located on the fusion line of the weld and base metal, as well as micropore clusters. Such minor defects form during the tank manufacture. In a number of cases metal microtears and chains of corrosion pits are found in the welded joint HAZ.

Microanalysis of the wall metal sections also determines their structure, crystalline structure, grain size and striation of the structural components.

Metallographic examination allows establishing the microstructure, grain size, condition of intergranular boundaries of the deposited weld and base metal of the bottom and wall, typical for the particular steel grades and their welded joints or differing from the norm, with the traces of ageing, etc.

9. Chemical and Spectral Analysis

Chemical analysis of samples cut out of the tank bottom shows the content of carbon, alloying elements and impurities in the metal, and confirms that the steel belongs to a certain class and grade. Methods of chemical analysis are usually based on transferring the analyzed element into a certain chemical compound by its dissolution, fusion or combustion.

Chemical analysis of samples of the bottom metal also shows hydrogen content and yields its numerical values.

Methods of spectral analysis are often used in practical analysis of metals, both together with the chemical methods and independently. Spectral analysis is based on studying metal vapours radiation. Transfer of the analyzed metal into the vaporous state is achieved under the action of an arc or spark discharge between the metal and special electrode. The spectrum is excited using spark and arc generators, included into the steeloscope units.

10. Conclusions

1. Non-destructive testing of welded joints and base metal of the tank results in revealing sections with inadmissible defects for their repair. Such sections are then repaired and re-tested.
2. Mechanical testing and metallographic analysis of samples, chemical and spectral analysis of the metal reveal deviations from the requirements to steel of certain type.
3. The tank is cleared for operation for the next period.

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