Complex method of railway tanks and reservoirs tightness control

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Abstract. This article presents the development of a complex method of tank impermeability control by the example of rail tank cars. Application of methods of acoustic emission and thermal control makes it possible to detect defects on the surface of tanks in two stages - localization of the through defect is carried out by the acoustic method, and the determination of geometrical size of the defect by the analysis of temperature anomalies of the outer surface of the tank. Application of such method in practice increases reliability of nondestructive control of railway tanks and reservoirs.

1. Introduction and problem statement

One of the important tasks for the development of the Russian railway transportation system is to increase the speed and volume of freight transported [1]. In this connection, we are seeing a sharp increase in the need for serviceable rolling stock for the transportation of extracted raw materials to processing plants, as well as the transportation of the finished product across the country and beyond. So maintaining a high level to reliability of the rolling stock is an integral task for the research. Tank wagons are widely used to transport liquid and gaseous substances, which ensure easy filling and emptying of the tank and safe transportation of the cargo. Due to the difficulty of tank car design, different diagnostic methods are used in wagon depot conditions during repair and control [2].

Analysis of existing methods for diagnosing the boiler of railway tank wagons and reservoirs allows to distinguish the following methods of control: mass spectrometry, halogen, bubble, chemical, manometric, luminescent-hydraulic, hydraulic with luminescent coating, acoustic, thermal. In the railway sector, the most widely used methods are acoustic emission and thermal inspection [3-6]. These methods have a number of significant drawbacks, which affects the accuracy of diagnostics. The disadvantages of thermal control are mainly associated with environmental conditions and the reflection of sunlight from the surface under study, which causes its heating. The method of acoustic emission (AE) makes it possible to localise the place of the defect accompanied by discharges, and this method significantly increases the reliability of diagnosing the condition of railway tanks and reservoirs. Acoustic flaw detectors can check an object in whole or in part. The disadvantages of the AE method is sensitive to the material structure, the high cost of equipment, and the fact that it does not detect the "geometry” of defects, so other inspection methods have to be applied to determine the shape of the defect. In this regard, it can be argued that the diagnosis of railway tanks and reservoirs can be carried out with the use of integrated methods which allow to eliminate the drawbacks of existing methods and improve the diagnostic accuracy.

The purpose of this work is to develop a complex method to control air tightness of railway tanks and reservoirs based on joint application of acoustic emission and thermal control methods.
2. Acoustic emission method

As the implementation of the proposed method of control, consider a scheme for monitoring the integrity of the tank using AE sensors [5] and thermal imager [7]. In the body of the considered tank there is a crack [fig. 1].

![Figure 1. Appearance of the tank and location of the AE sensors.](image)

The tank body integrity inspection is proposed to be carried out in two stages: the first stage is an acoustic-emission inspection and the second stage is a thermal inspection using a thermal imager. This approach is related to the previously mentioned disadvantage of thermal imaging inspection related to heating of the tank from external sources and the need to perform multiple inspections to locate the crack.

Due to the fact that the methods used are passive non-destructive testing, it is necessary to load the surface of the tank under examination in order to locate the defects. For loading of the tank walls in the search for through defects the overpressure of air, which is fed into the tank by means of nozzles through the universal drainage device, is well suited. The loading function diagram is shown in figure 2.

![Figure 2. Functional pneumatic diagram of unit for research:](image)

- 1 – vacuum compressor; 2 – check valve; 3 – receiver; 4 – manometer; 5 – filter with condensate discharge; 6 – vacuum switch; 7 – pressure regulator; 8 – regulating valve; 9 – reservoir; 10 – thermal

Diagnostics by AE method is carried out by installing sensors on the surface of the tank using magnets. Analysis of recorded acoustic pulses is performed by SCAD 16 system designed to determine [5, 7]:
- coordinates of defects (cracks, corrosion);
- coordinates of internal and through integrity defects;
- degree of danger in the process of strength tests of mechanical engineering structures.

The operating principle of SCAD 16 is based on zone location and method of detecting various defects and their distances by means of elastic waves. The emission elastic waves occur during the process of rearrangement of the internal structure of solids due to changes in stresses. The calculation
of defect coordinates is based on determining the difference in time of arrival for AE signals to acoustic emission transducers installed at the corners of the rectangular zone on the inspection object. The acoustic signals generated by the simulator transducers are proportional to the distance from the sensor location to the fracture (fig. 1, \(L_0-L_3\)) and are converted into electrical signals by the piezo plate transducers, which are then amplified and digitised in the AE system channel [10].

The SCAD 16 system is designed using a parallel-serial construction structure and contains from 1 to 5 piezo plates. Each piezo plate is connected to a board which is plugged into a PCI socket in the PC. The signals are recorded as follows. The electrical oscillations from the transducer come to the preamplifier (PA), where they are amplified. A bandpass filter is installed in the same housing as the preamplifier to allow signals of a given frequency to pass through. The filtered signal from each channel is then sent to the detection board and detector, where it is measured. The measured amplitude value is compared with the comparator selection threshold set, and if the amplitude exceeds the set threshold on at least one channel, the timer counter automatically marks the arrival time of the signal. In Figure 3 shown the acoustic emission recorded signal display panel. The first channel that registered the signal is assigned an arrival time difference equal to \(T_0\). This time is the time of position 1 from the moment of switched the AE system. At the same time, the switch is directed to activate the signal recording mode for all the channels of the board. There will be recorded signals that have at least one threshold exceeded, otherwise there will be many unnecessary random bursts of amplitude on the oscillogram.

![Figure 3. Generation of a pulse and the difference in arrival times of the four acoustic emission transducers.](image)

In this way we can see that the AE method makes it possible to quickly localise the area in which the crack is located. Further determination of the geometric dimensions of the crack is carried out using thermal imaging [8, 9].
3. **Thermal imaging control method.**

Methods of thermal control are based on interaction between the object thermal field and a thermometric sensing element and conversion of field parameters into parameters of electrical or other signal and its transmission to the recording device. During technical diagnostics most often non-contact methods are used. Thermal imagers are used as basic devices, recording radiation at control of insulation condition of tanks and cisterns, which allow:

- get local and overview thermal images of the object;
- detect areas with different surface temperatures and defects;
- determine stress concentration in capacitive technological equipment of large dimensions.

The location of stress concentrators in the tank is identified by increased infra-red radiation arising from elastoplastic deformation of tank metal structures by load tests. The existence of defective areas is determined by an increase in heat loss through the insulation, which allows identifying the cause and carrying out timely repair or replacement of the insulation. For this purpose, the tank is inflated with air through a pipe of a universal drainage device with a special device for air supply. After that the outer surface of the tank is scanned with an acoustic antenna.

The thermal control used the Joule-Thomson effect, which is based on the change in temperature of a gas during adiabatic expansion (throttling), i.e. the slow flow of gas under a constant pressure drop through a local obstacle to the gas flow. If gas under pressure is forced to flow into a space with a low pressure (on the order of atmospheric pressure), e.g. through a valve or a narrow opening, a temperature difference also occurs. This process is analogous to the flow of pressurised gas from a vessel with a narrow opening (leakage) into the environment, which expands infinitely. As a result of this temperature difference, on the surface of the vessel in the area of through defects a temperature gradient is formed, which is registered by thermal imaging equipment (fig. 4) [6].

Figure 4 shows a thermogram and a photograph of the tank in the leaking area at the initial point in time, without throttling, as an example of the use of the thermal imager.

![Figure 4. Thermogram of the tank area with the defect at the initial point in time](image)

Figure 4 shows that the thermogram clearly shows a tank main surface temperature averaging 21°C, there are surface defects in the tank, characterised by changes in surface temperature, in the form of slag inclusions, weld irregularities, weld spatter and metal spatter. There are no traces of temperature changes in the areas where the defects are supposed to be located. At the moment of compressed air supply into the tank at a pressure of 0,1 MPa no changes are observed in the thermogram, and in its turn the pressure drop is recorded on the tank pressure gauge, which indicates air leakage from the tank. Upon expiration of 10 minutes, while keeping in a vessel constant pressure equal to 0,1 MPa, on the thermogram there is a change of temperature, fixed by a thermographic instrument in the area of the supposed leak (fig. 5). The thermograms shown in fig. 4, 5 were obtained using a Testo 882 thermal imager, the technical specifications of which are given in Table 1.
Table 1. Technical specifications of the TESTO 882 thermal imaging camera.

| Specification                                      | Details                                      |
|---------------------------------------------------|----------------------------------------------|
| Temperature measuring range, °C                   | from -20°C to +350°C (from +350°C to +550°C as option) |
| Detector                                          | Uncooled microbolometer array 320x240 elements With Superresolution function – 640x480 elements |
| Temperature sensitivity threshold                 | < 0,06°C                                     |
| Temperature measurement uncertainty               | ±2°C, no less than ±2%                      |
| Optical field of view, horizontal x vertical     | 32° x 23° (standart), 1,7 mrad              |
| Spatial resolution IFOV                          | 8-14 mkm                                    |
| Spectral range                                    | 8-14 mkm                                    |
| Scan rate, frames/s                               | 9 Hz (33 Hz for EU)                         |
| Guidance system                                   | Laser class 2                               |
| Secondary Functions                               | Built-in colour digital video camera. Photo overlay function on thermogram. LED illumination. Recording of voice commentary. |
| Focusing                                          | Manual + motorised, minimum distance 20 cm   |
| Adjustable emissivity                             | from 0,10 to 1,00 (step 0,01)               |
| Display                                           | 3,5” Led Color LCD                          |
| Data transmission                                 | USB 2.0 (Transmission of images only) and thermovideo in real time |
| Battery life                                      | 4 hours                                      |
| Operating conditions:                             | -15 - +40 °C                                 |
| Ambient temperature, relative humidity            | 20 - 80%                                     |

4. Conclusions.
A complex method of tank inspection is proposed to increase the efficiency of detection of through defects. In the case if during acoustic control the areas of excitation of ultrasonic waves corresponding to the presence of a defect are registered, it is necessary to make an additional scanning of the surface of the studied tank with thermal imaging equipment.

In this work the authors proposed the implementation of a complex method for detecting defects in the integrity of tanks, based on a combination of AE and thermal control methods, which has high expressiveness and informativeness. In further works regarding improvement of the method it is
necessary to realize experimental researches directed to determination of geometrical sizes and shape of defects, comparison with output signals of measuring equipment, directed to increase effectiveness for integrity control of railway transport tanks and cisterns.

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