Features of tank car testing for dangerous cargoes transportation

M Kelrykh1, O Fomin1, J Gerlici2, P Prokopenko3, K Kravchenko2 and T Lack2

1State University of Infrastructure and Technology, Faculty of Infrastructure and Railway Rolling Stock, St. Kyrylivska, 9, 040071, Kyiv, Ukraine
2University of Zilina, Faculty of Mechanical Engineering, St. Univerzitná 8215/1, 010 26, Zilina, Slovak Republic
3Branch "Research and design and technological Institute of Railway Transport “PJSC”Ukrzaliznytsya”, St. Ivana Fedorova, 39, 030 38 Kyiv, Ukraine

E-mail: kkatherina@ukr.net

Abstract. The experience of the operation of rail transport shows that a significant part of emergency situations with significant negative environmental consequences are related to tank cars carrying liquid goods of a wide range, including liquefied gas, petroleum products, concentrated acids, toxic and explosive products of chemical origin. The article presents the peculiarities and result of carrying out of the corresponding tests. In order to address the question of the possibility of further safe operation of tank cars in the over-term period, their technical diagnostics and control tests are carried out. In this case, the control of the technical condition includes visual inspection of the tank wagon, measurements of the thickness of the metal at the control points of the boiler and the frame of the car, conducting of the magnetopowder, ultrasonic and acoustic emission control of the bearing metal constructions. Control tests include static vertical load tests, test for a low cyclic load by boiler pressure, typical, resource shock tests, and possible emergencies testing.

1. Introduction
In recent years, there has been a significant aging of the Ukrainian fleet of freight cars, including tank wagons for dangerous cargoes transportation. In conditions of Latvian railway the main damages of the barrels of oil tank wagons and their quantity are: cracks of welding seams of shaped pads – 50%, barrel damages in area of supports – 30%, damages of welding seams of the barrel – 15%, unfastening of shaped pads – 5% [1].

Currently, on the Ukrainian railways network, tank wagons with a service life that exceeds the deadline set by the manufacturer and even extended service life are in operation. Therefore, the urgent issue is either the replacement of rolling stock or the extension of the service life of the operated rolling stock.

For example, new railway tank wagon type Zans, which was developed by University of Žilina and Tatravagónka Inc. Poprad Results of calculations and prototype tests prove, that new designed construction of the tank wagon satisfies strength conditions [2].

Analysis of the technical condition of tank cars after the planned repairs shows that a significant part of them is in a satisfactory condition. Due to lack of financing, the purchase of new cars, to ensure the uninterrupted performance of freight transports by rail, remains the task of conducting research work on determining the residual resource and the possibility of continuing the safe operation of tank-wagons for particularly dangerous cargoes transportation.
In order to address the question of the possibility of further safe operation of tank cars in the over-term period, their technical diagnostics and control tests are carried out [3, 4]. In this case, the control of the technical condition includes visual inspection of the tank wagon, measurements of the thickness of the metal at the control points of the boiler and the frame of the car, conducting of the magnetopowder, ultrasonic and acoustic emission control of the bearing metal constructions. Control tests include static vertical load tests, test for a low cyclic load by boiler pressure, typical, resource shock tests, and possible emergencies testing.

In research of Voropai V [5] proposed the procedure of valuation of tank-cars' residual operation time for liquid gas transportation. The calculation allows to calculate equivalent stress using test results that rely on a change of internal pressure activity during drainage and filling operations, and the most unfavorable combination of simulation of active loads on a tank-wagon.

In the paper [6] presents numerically predict the number of cycles (or kilometers) to fracture of tank wagon railway axles in various theoretical conditions. It presented mechanism of railway axles due to the fatigue of material.

2. Formulation of the problem
It is necessary to form the necessity of conducting data of controlling tests of flat wagons.

After analyzing the park and the technical condition of tank cars for the particularly dangerous goods transportation, it was established that the main part of the park consists of tank cars of model 15-1407 - for transportation of propane (Fig. 1), 15-1408, 15-1408-01, 15-1408-02, 15 -1440, 15-1597, 15-1619 - for transportation of ammonia, 15-1409, 15-1556 - for transportation of chloride, 15-1519, 15-1780 - for transportation of propane-butane, and they are in good technical condition.

The above-mentioned tank cars are structurally different from each other by the following features: the material from which the tank boiler is made, the diameter of the boiler, the number of shells in the boiler, the protective equipment of the bottom of the boiler from damage during accidents and protection of the boiler armature.

The purpose of the article. Illustration of theoretical and practical features of conducting technical diagnostics, control tests and tests with simulation of emergency situations of tank cars for the carriage of especially dangerous cargoes.

3. Analysis of literary data
Modern studies devoted to the reduction of the viability of freight wagons, and in particular, article [7-9] is devoted to the coverage of the proposed innovations for the construction of open wagon "railroad space 1520 mm" and the peculiarities of their design, but it limited the possibilities of applying such innovations for cars. The authors [10] reflect certain perspective directions of construction of railroad car bodies in order to improve the techno-economic indicators, but do not reveal the economic potential of the business use of special expensive carriage rolling of unlimited length. Thus, in [11] the characteristic features and results of dynamic characteristics of platform cars are described. And work [12] is devoted to the presentation of the proposed methods for determining the dynamic characteristics for different performances of bearing car designs. In paper [13] presents some of the options Ansys contact setting defines the real tank wagon contact.

The paper [14] presents a theoretical and experimental study on the resistance of the tank-chassis connection (seat) to the dynamical strains caused by the shock due to collision. The theoretical resistance computations using the Finite Element Method, for the compression on the buffers constituted fundamental information for the choice of the verified dangerous sections. The paper presents the collision testing conducted for this purpose with the conclusions imposed by the experimental study.

A number of modern publications are devoted to the new generation freight wagon designs, which are designed with the use of advanced materials and technologies. For example, in [15] the authors reflect the results of computer modeling of the prototype of the freight wagon with the main carrier elements, executed without excessive connections. In [16] the features of the innovations proposed by the authors in the module of the chassis are presented, and their influence on the body module is also reflected, but without taking into account the variation of its performances. In the article [11]
published results of work on the generation of perspective configuration profiles, which can be used in the production of various types of rolling stock. But the authors do not offer data on the possibility of creating promising profiles in tight-fitted designs. Work [17, 18] highlights the proposed methods of analyzing railway structures of the future and ways to expand their functionality, but in it, as well as in article [15], there are no data on increasing the business functionality of intangible special profiles. Also, an important role in modern car-building is played by appropriate approaches in designing, for example, the article [2, 19] presents the developed methodological apparatus for the adoption of optimal solutions. But it also does not provide exhaustive opportunities for the formation of optimal length and configuration of articulated beams. In the works [7, 8, 20-23] features and results of conducted researches on definition of constructive components of freight wagons for creation of directional stress-strain state (based on the principle of previous stresses) were presented. The works [24] reflect the results of the production of round pipes in the construction of a freight wagon and the study of the strength of the carriage structure of the gondola body during transportation on the railway ferry. Taking into account the foregoing, it can be concluded that the results of the analysis of information sources on the issue under investigation indicate lack of sufficient methodological and practical materials on testing and technical diagnostics of tank cars for the transportation of dangerous goods, especially in emergency situations.

Emergency situation (special situation) - a situation that arises in the process of transportation due to a technical malfunction (failure) of parts of the railway transport system or the emergence of extreme external factors or their combinations and which is characterized by a violation of the system capacity, or the creation of hazardous operating conditions. Examples of emergency situations include: impact of a car in the bottom of the tank of the boiler, self-lifting of the wagons, increase of pressure in the boiler of the tank above the working and other.

4. Research results

Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. The main part of the fleet of tank cars for the carriage of particularly dangerous cargoes is made up of tank cars of model 15-1407 - for transportation of propane, 15-1408, 15-1408-01, 15-1408-02, 15-1440, 15-1597 - for carriage Ammonia, 15-1409, 15-1556 - for the re-introduction of chlorine, 15-1519, 15-1780 - for the transportation of propane-butane, their technical characteristics are given in Table 1. The experience of the operation of rail transport shows that a significant part of the emergency situations on the railways is connected with tank cars carrying liquid goods of a wide range, including liquefied gas, petroleum products, concentrated acids, toxic and explosive products of chemical origin. Most often such accidents are accompanied by the arrival of the carriage on the carriage and the transfer of tanks, which may result in a breach of the integrity of the boiler (breakdown of the bottom, damage to the neck for loading of the cargo, breaking the shell in the zone of connection of the boiler with a frame, etc.) and the outflow of environmentally hazardous cargo. For most emergencies, which arise when the carriages off the rails, hitting a car on a car or an obstacle, characteristic is the self- separating of cars and a clutch hit by a nearby wagon or its long load at the bottom of the boiler (Fig. 3).

At present, as additional means of protecting the bottom of tank-wagons in emergency situations, additional metal pads on the bottom (false bottom) or end shields are used. Overhead metal elements, reinforcing the lower part of the bottom and repeating its shape, are used on tanks of models 15-1619, 15-1408. These protective elements have low energy intensity, as they adhere tightly to the bottom of the tank. Taking into account the operational experience and the results of the inspection of the technical condition, it is possible to determine the probability of failure of the elements of the frame of the tank car, \( P_i \) (i = 1, 2, 3 ... N, where N is the number of elements) by the formula:

\[
P_i = \frac{\sum_{i=1}^{k} R_{if}}{k},
\]

where \( k \) - the number of surveyed wagons;
$R_H$ - number of defective elements of the same type in the wagon.

For tank cars carrying ammonia, include: the zone of welding of the hatch, the shaped paws of a boiler, the zone of boiler obstruction on wooden bars, centre sill and a bolster beam of a frame.

Tests were carried out on the four-axle carriage of the model 15-1408 (Fig. 4) for transportation of ammonia, with the expired service life (20 years) and a prototype tank model 15-1619 (Fig. 5) with a boiler diameter of 3200 mm.

![Figure 1. Tank wagon model 15-1407.](image1)

![Figure 2. Tank wagon model 15-1556.](image2)

The platform consists of a frame of welded construction, which is mounted on two-axle bogies model 18-100. The frame is a welded system of beams of a box-shaped section: centre sill and two bolster. A boiler of the welded construction consisting of a cylinder and two elliptic bottoms.

Before the start of the tests, the technical diagnosis of the prototype, the gluing of the strain gauges on the frame of the tank wagon and the boiler, measurements of the thickness of the boiler and frame sheets, and the installation of measuring equipment were carried out.

The inspection of the technical condition included a visual inspection of the tank wagon, measurements of the thickness of the metal at the control points of the boiler and the frame of the wagon, conducting of the magnetopowder, ultrasonic and acoustic emission control of the bearing metal constructions.

The control tests included static vertical loading tests, low-cycle load tests with boiler pressure, typical and resource shock tests, and possible emergency situations testing.
Table 1. The main technical characteristics of the tank wagons.

| Model      | 15-1407 | 15-1408 | 15-1408-02 | 15-1440 | 15-1597 | 15-1409 | 15-1556 | 15-1519 |
|------------|---------|---------|------------|---------|---------|---------|---------|---------|
| Function   | For Propane | For Ammonia | For Ammonia | For Ammonia | For Chlorine | For Chlorine | For Propane |
| Body material | 09G2C, 09G2D, 09G2, 09G2CD-12 | 09G2C, 09G2D, 09G2, 09G2CD-12 | 09G2C, 09G2D, 09G2, 09G2CD-12 | 09G2C, 09G2D, 09G2, 09G2CD-12 | 09G2C, 09G2D, 09G2, 09G2CD-12 | 09G2C, 09G2D, 09G2, 09G2CD-12 | 09G2C, 09G2D, 09G2, 09G2CD-12 |
| Tare, t, min | 34.6 | 36.7 | 32.3 | 32.4 | 32.0 | 35.7 | 28.9 | 27.2 | 34.8 |
| max | 36.7 | 36.7 | 32.4 | 33.5 | 38.8 | 30.7 | 30.0 | 38.8 |
| Cargo capacity, t | 22.9 | 30.7 | 31.2 | 30.7 | 43.0 | 47.6 | 57.5 | 46.0 |
| Volume, m³ | 54.0 | 54.0 | 54.8 | 54.0 | 76.0 | 38.7 | 46.0 | 75.7 |
| Diameter of boiler inside, mm | 2600 | 2600 | 2600 | 2600 | 3000 | 2200 | 2400 | 3000 |
| Production year | 1962 | 1963 | 1995 | 1978 | 1989 | 1964 | 1974 | 1990 |
| Service life | 40 | 20 | 40 | 20 | 40 | 24 | 24 | 40 |

Figure 3. Damage to the boiler of the tank.

Vertical static tests were performed by filling the boiler of the tank wagon with water to full filling with the subsequent drain, with the registration of the experimental data.

The test for a low cycle load of the boiler with excess pressure was performed by filling the boiler with water to full filling, followed by the supply of water to the boiler by the pumping station, to create an excess pressure of 2 MPa. After every 75 cycles of loading by working pressure, a load of test pressure of 3 MPa was performed.

The impact tests were carried out with the speed of rolling a percussive wagon (102 t. mass) on the experimental wagon tank from 1 to 12 km / h, while the wagon tank was in a stalled condition, and was supported by the retarded 4 wagons with a total mass of about 300 t. Longitudinal forces that acted on the tank-car through an auto-coupling device up to 3.0 MN and with several beats up to 4.2 MN. In the case of shock tests deformations were recorded in the design elements of the experimental wagon-tank in the most stressed places obtained during static tests.
Figure 4. Wagon tank 15-1408 for ammonia.

Figure 5. Wagon tank model 15-1619.

5. Simulation of emergency situations
Before and after the end of the test the boiler's tightness was checked by creating an excess pressure of 0.5 to 3 MPa. Pressure lasted for 5 minutes.
The boiler was tested for the following excessive loads:
- creation of excess pressure until the boiler is destroyed or its tightness is lost;
- a one-time stroke of a wagon with a weight of 90 t in an automatic coupler of a tank wagon at a speed of 22 km/h (fig. 6).
- strikes by the head of the automatic coupler of the shock wagon weighing 102 t in the bottom of the tank at a speed of 10,2 km / h (Fig. 7, 8).

Figure 6. Tank wagon after impact.
Estimation of the tensile condition and durability of the design of the boiler by the results of static tests was performed according to the calculated modes by comparing the total stresses from the action of the test loads with allowable stresses.

Mode I:

\[ \sigma_{ver} + \sigma_{pl} \leq [\sigma]_I, \]

Mode III:

\[ \sigma_{ver} + \sigma_{plII} + \sigma_{dyn} + \sigma_{lat} \leq [\sigma]_{III}, \]

Test mode:

\[ \sigma_{ver, test} + \sigma_{p, test} \leq [\sigma]_{test}, \]

where: \( \sigma_{ver} \) – stress from the vertical load, gross; \( \sigma_{pl} \), \( \sigma_{plII} \) – stress from the action of the calculated pressure, equal to the sum of working pressure and pressure from the hydraulic shock, respectively, for the I and III modes; \( \sigma_{dyn} \) – stress from the action of a dynamic additive; \( \sigma_{lat} \) – stress from the effect of lateral force; \( \sigma_{ver, test} \) – stress from the vertical gross load when the boiler is fully filled with water in the tank; \( \sigma_{p, test} \) – stress from the test pressure of 0.6 MPa.

Figure 7. Experimental sample after impact on the boiler by automatic coupler.

Figure 8. Test sample after emergency tests.

In the course of resource tests an analysis of the stressed state at the control points of the boiler of the tank-car was conducted. As can be seen in Fig. 9 the stresses at the control points did not exceed the permissible.
The criterion for assessing the strength of the tank against the effects of unusual loads is the preservation of the load and tightness of the boiler after the test, by controlling the pressure in the boiler.

![Figure 9. Test sample after emergency tests.](image)

### 6. Conclusion

On the basis of technical diagnostics and control tests of the tank-wagon it was established that the tank-wagon is technically a typical representative of the operational fleet of Ukrainian railways, which have completed their intended service life. The tensile condition of the boiler of the tank-wagon from the action of normative static and shock loads did not exceed the permissible 236 MPa. When testing on a low-cycle load on a boiler with pressure from 0 to 2 MPa, 225 cycles were carried out, which corresponds to 5 years of operation. In tests with simulation of emergency situations: the impact on the bottom of the tank, the creation of a limit pressure in the tank, up to 6 MPa, an impact on the auto-coupling device of a tank carriage at a speed of 22 km/h, damage and depressurization of the boiler tank-tank was not detected.

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