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Increasing the service life of tank car boilers for the transportation of chemical cargoes by using the method of tread protection

The article is devoted to the search for a comprehensive technical solution to increase the service life of tank car boilers by introducing an effective protection method. A significant problem of increasing the service life of tank cars for the transportation of chemicals is the high level of boiler wear, which is associated with corrosion phenomena that arise as a result of the interaction of the inner surface of the boiler with chemical corrosive cargoes. To solve the problem of the possibility of operating tank cars in terms of determining the service life due to corrosion damage, it is necessary to develop and implement comprehensive measures to assess the final service life of tank cars. At the same time, specialists, researchers and scientists face a special task - to maximize the boiler life using a progressive protection method. One of the most promising methods that can reduce the negative impact of corrosion and be applied in practice is the tread protection method. The article presents an algorithm for calculating the tread protection, which makes it possible to determine the required number of surface protection elements. The effectiveness of protection when changing the cathodic polarization is evaluated. The requirements that should determine the principles of construction of the protection system design and its functioning are considered, and a set of technical solutions and measures aimed at ensuring the protection of metal surfaces of the object of study: a tank car boiler.

Keywords: *boiler, tank car, cylindrical part, shell, method of tread protection, calculation algorithm.*

Introduction. One of the significant factors affecting the integrity of the tank car boiler shell is internal corrosion. This phenomenon is the process of spontaneous destruction of metal as a result of its interaction with an aggressive environment. In most cases, corrosion occurs according to the electrochemical principle when the metal comes into contact with an aqueous medium.

Corrosion of the boiler's inner surface is one of the main reasons for the inability to perform operational functions and is associated with the influence of many factors - high water content of the transported product, high acidity, the content of impurities that increase the rate of corrosion processes, transportation modes, temperature, the condition of the boiler metal surface, etc. These factors can affect the corrosion rate: in some cases, they can reduce it, and in others, they can increase it. Regardless of this, the fundamental danger of corrosion is determined by the presence of the aqueous phase in the transported media.

The process of corrosion causes a decrease in the technical life of the railroad car, partial or complete disruption of the system's functioning, and the inability to participate in the transportation process.

Tank car boilers are vulnerable to corrosion caused by physical processes of contact between different media and chemical reactions that occur as a result of their interaction. Over time, corrosion reduces the integrity of the boiler and eventually penetrates its structure, causing changes in thickness and leading to perforation of the shell, which can lead to the leakage of chemical cargo into the environment and the occurrence of a further man-made disaster.

Since most corrosion occurs inside the boiler, the extent of the danger is usually unknown and hidden until external signs appear, which is often too late to eliminate. The timely detection of such “dangerous” areas is a priority task when conducting technical diagnostics of the boiler surface, and therefore the development of forecasting methods to detect them at an early stage is of particular importance when assessing the technical condition of the railcar structure.

The most typical types of corrosion observed during the operation of tank cars include:

- general corrosion - occurs over the entire surface of the boiler;
- local corrosion - occurs in certain places where the liquid phase of a chemical substance accumulates or is located
- pitting corrosion - occurs on horizontal surfaces, at the bottom of the boiler and in places where the liquid phase accumulates (bottom sheets).
- weld metal corrosion - occurs when the weld metal interacts with the boiler metal, causing an electrolytic reaction.

In order to detect corrosion, the boiler must first be emptied of the chemical load, and then a complete internal cleaning using pressure jetting is performed. Next, non-destructive testing is performed to check the metal thickness at various points in the boiler, depending on the selected measurement location. The respective measurements are made for the bottom, middle and top of the boiler shell. If corrosion is detected, measures are taken to eliminate it, in accordance with the restoration technology approved by the repair company.

Among the existing best-known methods of protection (anodic and cathodic methods) against corrosion of metal surfaces, the simplest and most effective in the study of corrosion control and reduction of its consequences is the protector method of corrosion protection, as a type of cathodic method, therefore, it is advisable to use it for the inner surface of tank car boilers used for the transportation of chemicals.

Analysis of recent research and problem statement. The use of the most effective methods of protecting metal surfaces of various parts of railcars from corrosion is currently one of the most important tasks that needs to be addressed to increase the service life of rolling stock. One of the most effective methods of metal corrosion protection is the tread protection method. It is widely used in the civil engineering industry to protect metal pipelines and structures that are located underground and have direct contact with the ground. In addition, the idea of using a tread protection system was implemented for oil storage tanks. In general, a significant number of publications have been devoted to the design of cathodic protection systems in recent years. The authors of various articles have conducted electrochemical tests of metals [1], modeled the distribution of the electric field of cathodic protection systems located in the ground [2], and developed the design and location of anode grounding in corrosive environments. Article [3] analyzes the mechanisms of external corrosion and the causes of destruction of underground gas and oil pipelines, presents existing monitoring tools for assessing external corrosion and models for preventing corrosion and predicting its occurrence. The authors note that to ensure proper corrosion protection of underground metal structures, it is necessary to design and use cathodic protection systems. Work [4] is devoted to the development of an algorithm for optimizing the system of the auxiliary anode of the grounding grid based on an improved method of simulated annealing. The boundary element method is widely used to model cathodic protection systems for underground and offshore structures. Thus, in [5], the authors used the boundary element analysis to study the effect of the horizontal distance between parallel pipelines, the rate of damage to the insulating coating, the electrical conductivity of the soil, and the anode output current on the interference of parallel pipelines. At the stage of designing a protection system, by changing the layout elements, it is necessary to ensure the overlap of the protection zones of neighboring cathodic stations and thereby reduce the output currents of cathodic protection stations in the system. The vast majority of works are devoted to various methods for calculating the main parameters of protection systems for different facilities and conditions of placement and operation of pipeline systems. The authors of [6] performed numerical modeling by the boundary element method of anode grounding of deep well casing. In [7], the authors of numerical modeling by the boundary element method determined the distribution of the electric field of the cathodic protection system for structures of complex geometry. An optimization scheme of the corrosion protection system was developed by adjusting the amplitude of the current supplied to the anode, as well as the location and size of the anode layer area. Studies [8-10] propose a new distributed model for the development of a cathodic protection system for oil and gas pipelines. The main difference between the proposed model and the traditional approach is the use of measured soil resistance throughout the structure instead of a fixed average value. However, the complexity of practical implementation and its cost slow down the possibility of application.

Creation of tread protection systems for railway transport requires the development and implementation of design solutions similar to those in related industries where similar solutions have already been implemented, but with a number of features. This is primarily due to the type of chemical cargo, its acidity (pH), temperature and humidity conditions of transportation, the concentration of the liquid phase, which determines the rate of corrosion, etc. An equally challenging task is to develop an algorithm for calculating the required number of anode elements to be used during redox processes and to create a set of measures for timely maintenance of protection systems.

The purpose and tasks of the study. Determining the effect of corrosion of the metal shell of a tank car boiler on its structural strength remains an urgent scientific and technical problem that needs to be solved using methods and implementing a number of measures both during operation and in determining the possibility of further extending the service life of railcars. In accordance with the current regulatory documentation [11], according to the established design load modes, the strength of individual parts of railcars is determined by the permissible stress values. The assessment of strength indicators can be carried out using standard calculation methods or during various types of field tests using measuring equipment. However, the need to assess the service life of the boiler structure of a tank car, which can transport chemical cargoes of various nomenclatures, requires finding the most rational methodology for studying its stress-strain state [12, 13] using adaptive mathematical calculation models. This is especially true for determining the service life of a railroad car based on its technical condition, where a corrosion protection system can be used.

The aim of the presented study is to assess the possibility of extending the service life of tank cars for the transportation of chemicals using the tread method of boiler protection. The tasks are to create a calculation algorithm that can be used to determine the required number of protection elements, determine the strength and density of the protective current on the contact surface of different media, and develop design proposals for further project implementation.

Materials and methods of research. Among the existing best-known methods of corrosion protection of metal surfaces, the simplest and most effective in the study of corrosion control [14] and reduction of its consequences is the tread method of corrosion protection as a type of cathodic method, so it is advisable to use this method for the inner surface of tank car boilers used for the transportation of chemicals.

Due to the fact that an electrolytic bond creates a potential difference between the tread and the metal structure, an electric current flows. This dissolves the active material - the tread (galvanic anode), while the cathode (protective structure) remains inert.

With the help of the projector, the metal structure is polarized, which in turn leads to a shift in the potential of the structure in the negative direction. The metal of the protective structure is shielded on the surface (hydroxide precipitate), which impedes oxygen diffusion and increases the thickness of the protective layer.

This method makes it possible to use electrochemical protection by a galvanic anode against corrosion using the protective properties of the dissolved anode surface deposit formed on the cathodically polarized metal surface.

Use of active corrosion protection by galvanic anodes (protectors) is recommended to be combined with the use of protective paint and varnish coatings, which can significantly reduce current consumption and anode alloy consumption and extend the service life of the protective coating. In the case of using the protective coating without paint and varnish coatings and preliminary surface preparation, cleaning from rust and other surface defects will provide surface protection for approximately 11-14 years (with the application of protective paint and varnish coatings, the service life is almost doubled).

The protective effect is caused by the inhibition of corrosive microelements due to the polarization of the corroded surface. The corrosion system as a binary short-circuited galvanic element (K-A) (Fig. 1), to which a third electrode (Zn) is added, is the most effective protector.

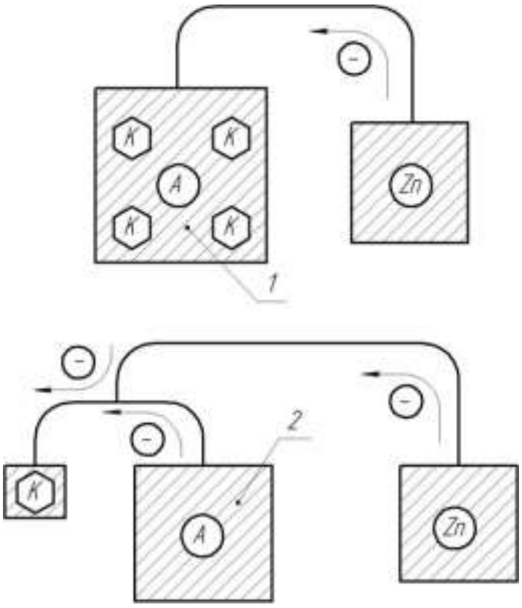

Fig. 1. **Schematic representation of the interaction models of the protective system: 1 - contact of the corroding metal (K-A) with the anode (Zn); 2 - equivalent three-electrode model of the protective system.**

In the polarized corrosion diagram (Fig. 2), the point S defines the corrosion potential V_x and corrosion current without the use of electrochemical cathodic protection (without contact with the anode); V_y it is the total potential of the three-electrode system after the protector is attached.

The diagram shows that the corrosion current is significantly reduced after the protector is attached compared to the initial current (V_xS).Therefore, the more negative the initial tread potential and the flatter the anode polarization curve of the tread, the greater the shift in the potential of the three-electrode system V_y to the negative side and the lower the final corrosion current of the micropairs. If the total system potential is sufficiently shifted in the negative direction (to the potential V_a^0), the corrosion current can be zero - complete protection occurs.

In accordance with the phenomenon of the differential effect, it becomes necessary to introduce a protective effect coefficient $K_{зах.еф.}$ when reducing the operation of corrosion microcouples by increasing the current density of external cathodic polarization by one. At the same time, the dependence of the protective effect constant on the value of the cathodic and anodic polarization of the system when the polarization curves are close to straight lines $K_{зах.еф.}$ will be approximately constant and the overall protective effect is proportional to the cathodic current density.

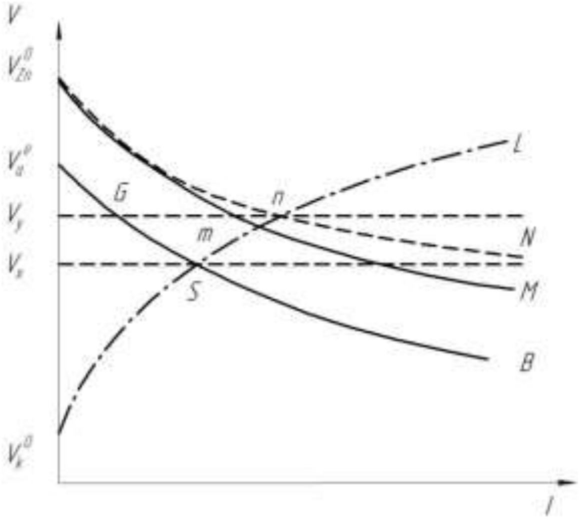

Fig. 2. **Polarization diagram of corrosion:**
$V^e_a B$ **– anode curve of a composite electrode;** $V^0_K L$ **– cathode curve of a compound electrode;**
$V^0_{Zn} M$ **– curve for anode contact;** $V^0_{Zn} N$ **– general anode curve.**

The diagram (Fig. 3) shows the ideal cathode $V^0_K c$ and anode $V^e_a A$ curves for the studied corrosion system under the given conditions, and V_x is the potential of the corrosion system in the absence of electrochemical protection. If electrochemical protection is used by attaching a protector or cathodic polarization from the outside by applying a voltage, then the potential of the corrosive system will be shifted to a more negative value V'_x. In this case, the corrosion current will decrease from the value $V'_x b$ to $V'_x a$ and the external cathode current will be equal to the value ac. Full protection will be provided if, during the cathodic polarization process, the potential of the corroding system becomes more negative than the value of the initial potential of the anodic process V^e_a.

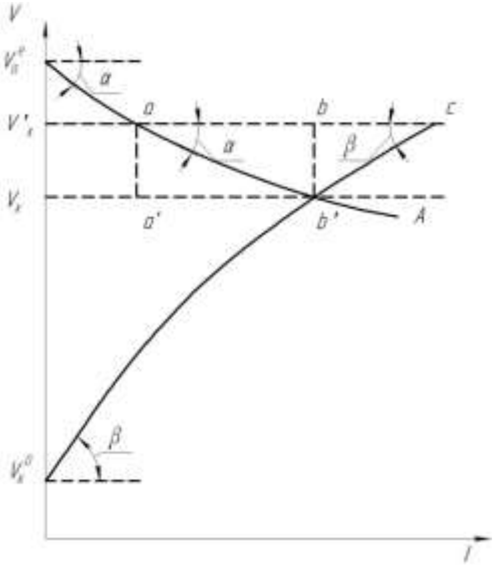

Fig. 3. **Polarization diagram for determining the tread effect coefficient**

If we consider the polarization curves at their intersection as straight lines, we can show that there is a direct proportionality between the protective effect and the density of the applied cathodic current.

This condition is fulfilled with a high degree of probability at a low value of the external cathodic polarization current.

Based on the graphical construction (Fig. 3), the voltage potential can be written using the following expressions:

$$\Delta V = b \cdot c \cdot tg\beta , \tag{1}$$

$$\Delta V = a \cdot b \cdot tg\alpha , \tag{2}$$

Dividing the first expression by the second, we get:

$$\frac{bc}{ab} = \frac{tg\alpha}{tg\beta} , \tag{3}$$

After the conversion, we can write this expression as follows:

$$\frac{bc}{ab} + 1 = \frac{tg\alpha}{tg\beta} + 1 ,$$

Or otherwise:

$$\frac{bc + ab}{ab} = \frac{tg\alpha + tg\beta}{tg\alpha} , \tag{4}$$

The segment aa' is the protective effect of cathodic polarization by an external current I, which is graphically represented by the segment $ac = ab + bc$.

Then we have a ratio for the segment aa':

$$\frac{I}{aa'} = \frac{tg\alpha + tg\beta}{tg\beta} , \tag{5}$$

Where we get it from:

$$aa' = \frac{tg\beta}{tg\alpha + tg\beta} I , \tag{6}$$

Or otherwise:

$$aa' = K_{зах.еф.} \cdot I , \tag{7}$$

At constant values of α and β, the protective effect coefficient will be constant in value. If we assume that the cathodic and anodic polarizations are linearly dependent on the current density, i.e. $tg\alpha = P_a$ and $tg\beta = P_к$, then the protective effect coefficient can be written in the form:

$$K_{зах.еф.} = \frac{P_к}{P_к + P_a} = \frac{1}{1 + \frac{P_a}{P_к}} , \tag{8}$$

Therefore, the protective effect, i.e. the reduction of the local current with an increase in the external cathodically polarized current, will be greater the greater the cathodic polarization of the corrosion protection system.

If the polarization curves are close to straight lines, this rule will be valid over the entire range of polarization currents. If the polarization curves cannot be considered as straight, then this rule will be observed only at relatively small values of the external current compared to the value determined by the abscissa of the intersection point of the polarization curves.

The variant of tread protection for tank car boilers proposed by the authors of the article involves the use of groups of treads that are placed in blocks in the boiler (Fig. 4). Calculation of the parameters of tread protection involves determining the number of parallel extended treads and their total weight, which provide a given degree of protection of tanks according to the method described below.

Calculation of the protective cathodic polarization is carried out by the formula:

$$\Delta\varphi_{П} = 0{,}08\lg\left(1 - P_{з}\right), \tag{9}$$

where $P_{з}$ – degree of protection of the tank car boiler against corrosion.

Minimum required protective current density on the surface of the tank car boiler is defined as:

$$j_3 = \frac{\left|\Delta\varphi_{П}\right|}{P_c}, \tag{10}$$

where P_c – polarization resistance of steel.

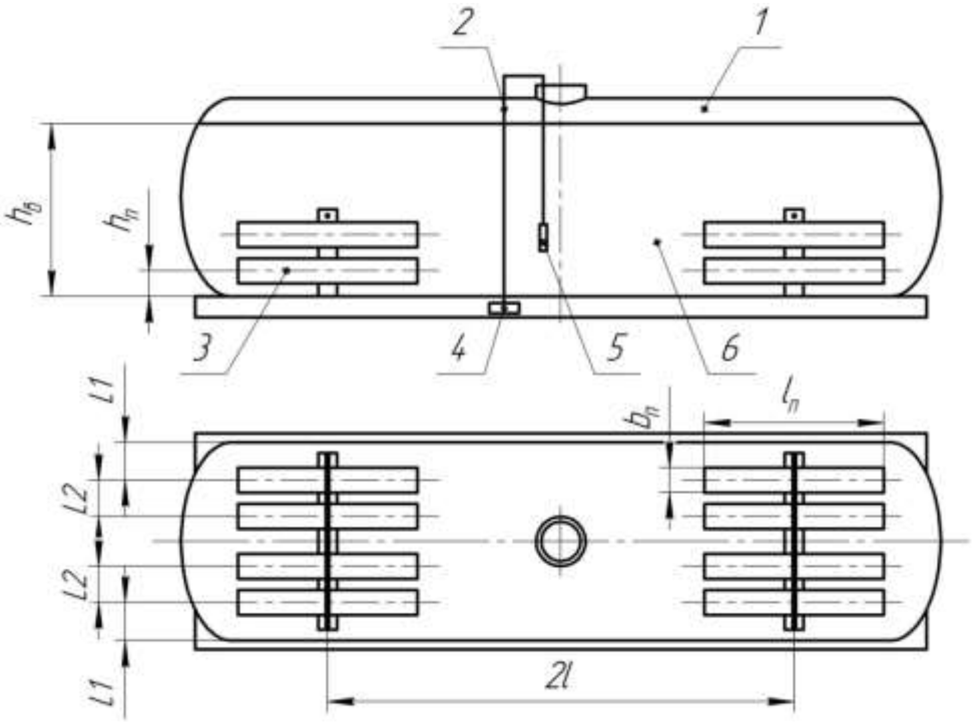

Fig. 4. **Scheme of tread protection of a tank car boiler for chemical cargo transportation:**
1 - tank car boiler; 2 - electric conductor; 3 - tread block; 4 - control and measuring equipment; 5 - electrode; 6 - liquid chemical cargo.

Arc angle of the circumference of the tank car boiler, which is wetted with the liquid phase, is calculated by the formula

$$\psi = 360 - 2\arccos\frac{2h_{в} - D}{D}, \tag{11}$$

where $h_{в}$ – level of the liquid phase in the tank car boiler.

Area of the inner surface of the tank car boiler in contact with the water phase is calculated using the formula

$$S_{ц} = \frac{\psi}{360}\cdot\pi D L_{ц} + 1{,}3\left(\frac{\pi D^2\psi}{2\cdot 360} + \frac{D^2}{2}\cdot\sin\frac{(360-\psi)}{2}\cdot\cos\frac{(360-\psi)}{2}\right), \tag{12}$$

where D – internal diameter of the tank car boiler;
$L_{ц}$ – length of the cylindrical part of the tank car boiler;
ψ – arc angle of the circumference of the tank car boiler wetted with the liquid phase.

Protective surface area of the tank car boiler is calculated by the formula

$$S_{3} = S_{ц}\cdot S_{0}, \tag{13}$$

where S_0 – defect rate of the corrosion protection coating of the tank car boiler.

Current required to protect the inner surface of the tank car boiler is determined by the formula

$$I_{Ц} = j_3\cdot S_{3}, \tag{14}$$

Calculation of the current strength that can be provided by one row of treads is based on the formula

$$I = \frac{m_0\cdot N\cdot L_{ц}\cdot K_{в}}{T_{П}\cdot q}, \tag{15}$$

where m_0 – weight of one running meter of tread rod;
N – number of rows of projectors;
$L_{ц}$ – length of the cylindrical part of the tank car boiler;
$K_{в}$ – tread weight utilization rate;
$T_{П}$ – design service life of the treads;
q – anodic dissolution rate of the tread.

Calculation of the number of rows of treads that provide the required current strength to protect the inner surface of the tank car boiler using the formula

$$N = \frac{I_{Ц}}{I}, \tag{16}$$

Tread utilization rate is determined by the formula:

$$A = \frac{2h_{П}(D - h_{П})}{D\cdot A_{П}}, \tag{17}$$

where $h_{П}$ – height of the tread in the tank car;
$A_{П}$ – cross-sectional area of the tread rod;
D – internal diameter of the tank car boiler.

Calculation of the total resistance between the tread and the tank car, with the calculated number of rows of treads N

$$R=\frac{1}{\psi}\left[\frac{4\left(\rho_{В}\delta_{П}+P_{c}\right)}{\left(2L_{ц}+D\right)DS_{0}}+\frac{\rho_{В}}{\sqrt{N}}\ln\left(A+\sqrt{A^{2}-1}\right)\right], \tag{18}$$

where ψ – arc angle of the circumference of the tank car boiler wetted with the liquid phase;
$\rho_В$ – resistivity of the liquid phase of the chemical mixture in the tank car boiler;
$\delta_П$ – thickness of the anti-corrosion coating of the inner surface of the tank car boiler;
P_c – polarization resistance of the steel from which the boiler is made;
$L_ц$ – length of the cylindrical part of the tank car boiler;
S_0 – defect rate of the anti-corrosion coating;
N – number of rows of treads.

Calculation of the protective current of the tank car boiler

$$I_{Б}'=\frac{\Delta\varphi_{e}+\Delta\varphi_{П}}{R+\dfrac{P_{П}}{\pi A_{П}L_{ц}N}}, \tag{19}$$

where $\Delta\varphi_e$ – difference in the natural potentials of the tread and the boiler;
$\Delta\varphi_П$ – protective cathodic polarization;
$P_П$ – polarization resistance of the steel from which the boiler is made.

Verification of the adequacy of the mass of the calculated number of treads to ensure the protective current $I_Б''$ during the design life of the treads $T_П$ can be performed if $I_Б'' > I_Б'$ the mass of the calculated number of treads is sufficient.

$$I_{Б}''=\frac{m_{0}\cdot N\cdot L_{ц}\cdot K_{в}}{T_{П}\cdot q}, \tag{20}$$

Calculation of the protective current density in the lower part of the tank car boiler

$$j=\frac{4\cdot I_{Б}'\cdot K_{T}}{\left(2L_{ц}+D\right)\cdot D\cdot S_{0}\cdot\psi}, \tag{21}$$

where K_T – coefficient of uneven distribution of current density along the perimeter of the tank car boiler shell.

For example, here is a calculation of tread protection based on the input data (Table 1).

In accordance with the methodology of the above calculation and according to the input data in formula (9), the protective cathode polarization is first determined, the potential of which is equal to $\Delta\varphi_П = –0{,}104\ \text{V}$. The obtained value of the voltage potential corresponds to the value of the minimum required protective current density on the surface of the tank car boiler $0{,}11\ \text{A/m}^2$. Taking into account that the level of the liquid phase in the boiler is assumed to be equal $h_в = 2{,}85\ \text{m}$ to the arc angle of the circumference of the tank car boiler, which is wetted by the liquid phase, will be equal to $\psi = 308°$.

The protective surface area of the tank car boiler is approximately equal $10\ \%$ to the area of the inner surface of the boiler and, in accordance with the accepted geometric dimensions, is determined by formula (12) and is $S_ц = 92{,}94\ \text{m}^2$. The calculated current required to protect the inner surface of the boiler is equal to $I_Ц = 0{,}967\ \text{A}$. Taking into account that the strength of the protective current $I_Б'' = 1{,}01\ \text{A}$

during the design life of the treads $T_П = 5$ years is greater than the minimum required $I_Б' = 0{,}15$ A, i.e., the condition is met $I_Б'' > I_Б'$, the mass of one running meter of the tread rod $m_0 = 8{,}3$ kg/m will be sufficient for use.

Table 1. Input data for the calculation

Parameter, dimensionality	Value
Degree of protection of the tank car boiler against corrosion	0,95
Polarization resistance of steel, Om·m^2	0,1
Liquid phase level in the tank car boiler, m	2,85
Inner diameter of the tank car boiler, m	3,0
Length of the cylindrical part of the tank car boiler, m	9,614
Defectiveness coefficient of the corrosion protective coating of the tank car boiler	0,1
Weight of one running meter of tread rod, kg/m	8,3
Tread weight utilization rate	0,75
Design service life of treads, years	5
Anode dissolution rate of the tread, kg/A·h	11,9
Height of the tread in the tank car, m	0,1
Cross-sectional area of the tread rod, m^2	0,021
Resistivity of the liquid phase of a chemical mixture in a tank car boiler, Om·m	0,15
Thickness of the anti-corrosion coating of the inner surface of the tank car boiler, m	$1{,}5 \cdot 10^{-4}$
Difference in natural potentials of tread and boiler, volts	0,3

The presented dependence (Fig. 5) of the ratio of the current density on the bottom of the boiler to the current density of the entire protective surface on the number of projectors determines the required number of elements of the protection system. As can be seen from the graph, the minimum threshold value of the ratio should be $j / j_з = 1{,}2$.

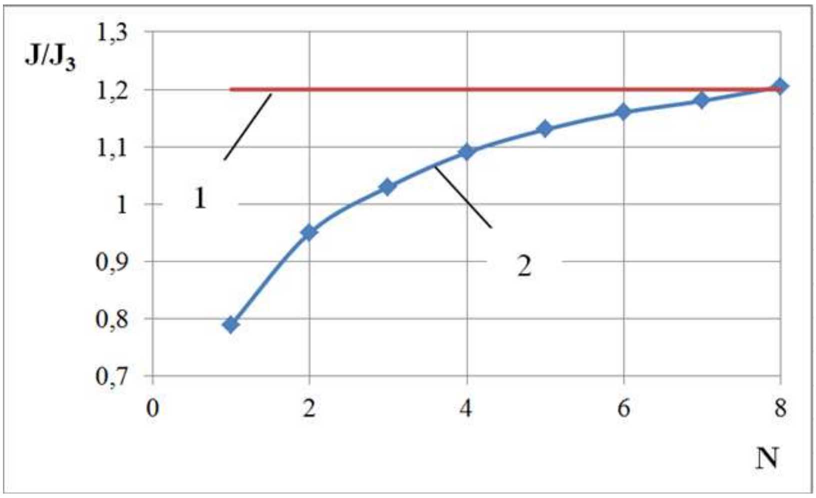

Fig. 5. **Calculated graphical dependence of the protective current density on the number of treads:**
1 – minimum limit value of the protective current density; 2 – calculated value of the protective current density for N protectors.

According to the results of the calculations, it was found that in order to achieve the minimum permissible current density in order to protect the boiler surface, it is necessary to use $N = 8$ units of protectors.

The graphical dependence (Fig. 6) of the protective current strength on the total resistance arising between the tread and the tank car under the action of the protection system with a change in the number of treads $N = 1 \div 8$ can be represented in accordance with the equation of a polynomial curve $y = 0,2268x^2 - 0,7023x + 0,6575$ of degree two.

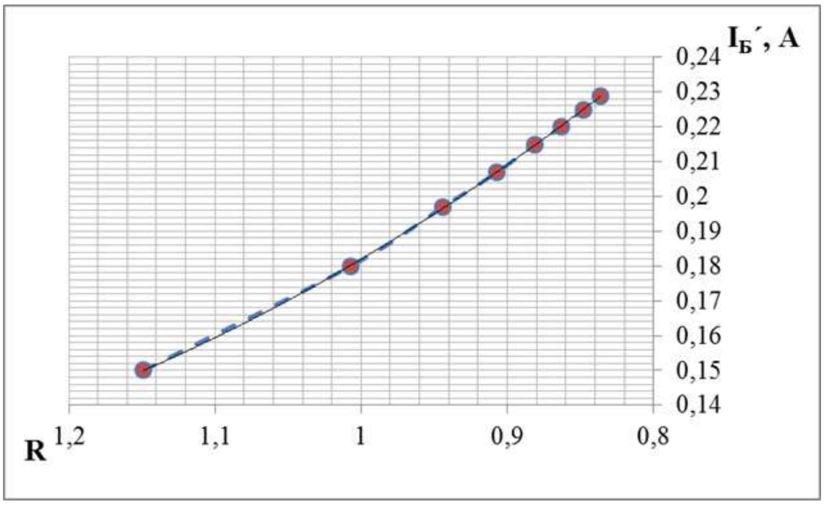

Fig. 6. **Calculated graphical dependence of the protective current on the total resistance for the number of protectors N = 1÷8**

As can be seen from the graph (Fig. 6), a decrease in total resistance leads to an increase in the strength of the protective current. When using the minimum number of protective elements sufficient to protect the boiler surface, the protective current increases by 1,52 times, while the value of the total resistance drops by 27,3 percent.

The protection system is presented in the form of a complex containing two blocks of protectors with galvanic anodes, combined into independent groups located at a certain distance from each other inside the tank car boiler (Fig. 7).

Such groups are stirred in the lower part of the boiler and fixed by the mechanism of fixing the tread block in the selected spatial position. Installation and dismantling of the block part protectors is performed at the place of their installation. The anodes can be connected using a parallel or series connection scheme to the active group.

The protectors are connected to the tank car boiler body by means of resistors, the resistances of which should be calculated depending on the type of chemical cargo in order to limit the maximum current of the protector. A voltage regulator is connected to the resistors according to the scheme to determine the potential difference between the cathode (the inner surface of the boiler body) and the anode (the tread). The effectiveness of the tread protection is determined by the value of cathodic polarization (electrolyte potential shift), which is measured relative to the working electrodes, or by means of a potential measuring unit (control and measuring equipment) brought out and mounted on the tank car boiler frame.

Development of a set of technical solutions for protecting the inner surface of a tank car boiler from corrosion is based on the following requirements:

1) boiler protection can be designed as a built-in block or individual structural design, independent of the boiler size.

2) protection system can be used as a backup system when using cathodic protection schemes.

3) protection with the help of protectors should be used with a certain calculated specific electrical resistance in accordance with the type of protectors, their number, material and electrolytic medium;

4) tread protection installations should be equipped with control and measuring devices and, if necessary, regulating resistors or shunts;

5) protection shall consist of single or group installations, with the choice of the type and arrangement of protectors being made taking into account the specific conditions of installation at the facility;

6) the protective current density on the surface of the tank car boiler from projectors should be taken into account in the design calculation.

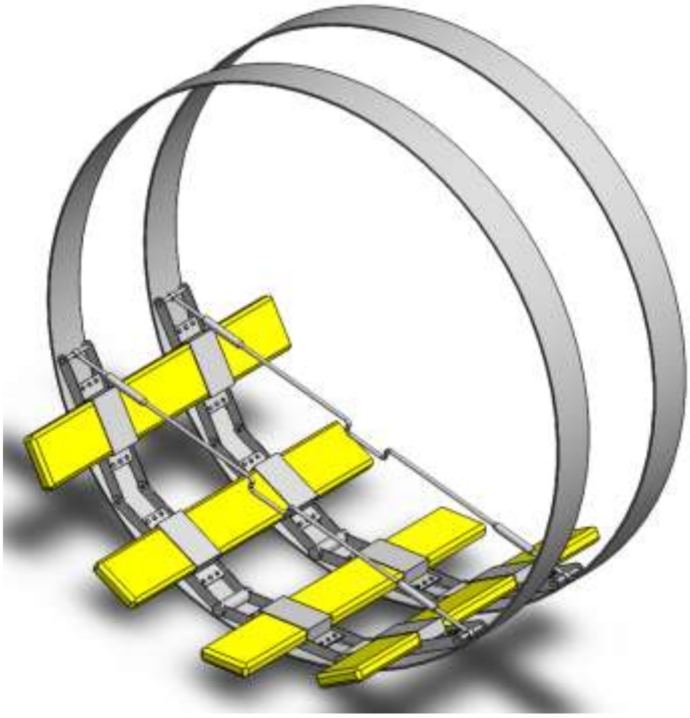

Fig. 7. **Basic unit of the model of the tank car boiler corrosion protection system**

The set of technical solutions includes:

- proposals for the creation of a block protection system for the tank car boiler;
- development of drawings for the protection mechanism;
- creation of a model of the protection system;
- development of a schedule of scheduled diagnostic work to determine the technical condition of the inner surface of the tank car boiler after the introduction of corrosion protection systems;
- application of an ultrasonic method for monitoring the thickness of the boiler shell metal according to the developed measurement scheme.

Conclusions. The decrease in the technical life of a railroad car is associated with corrosion processes. Tank car boilers are one of the most vulnerable parts to corrosion caused by physical processes of contact between different media and chemical reactions that occur in them as a result of their direct interaction. Over time, corrosion reduces the integrity of the boiler by penetrating its structure, causing changes in thickness and leading to a loss of strength properties of the shell metal. The occurrence of corrosion phenomena and their spread is a particularly dangerous factor in the transportation of chemical corrosive cargoes in tank wagon boilers, as it significantly accelerates chemical reactions of oxidation of the boiler shell metal and poses a threat not only of premature repair or even replacement of the boiler, but also of man-made disasters in the event of chemical leakage into the environment.

Introduction of a number of complex measures is aimed at ensuring the required degree of anticorrosion maintenance of the tank car boiler during a long period of use and ensuring an increase in the resource of the tank car in operation. The developed algorithm for calculating the tread protection system involves: determining the cathodic polarization of the metal surface of the boiler; calculating the minimum required protective density and current; providing the required number of rows of treads that determine the level of protection of the structure. In the course of the work, it was found that the protective effect will be greater, the greater the cathodic polarization of the corrosion protection system with a decrease in local current with an increase in external cathodically polarized current.

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Збільшення ресурсу котлів вагонів-цистерн для перевезення хімічних вантажів за рахунок використання методу протекторного захисту

Стаття присвячена питанням пошуку комплексного технічного рішення щодо збільшення ресурсу котлів вагонів-цистерн за рахунок впровадження ефективного методу захисту. Суттєвою проблемою збільшення ресурсу вагонів-цистерн для перевезення хімічних вантажів є високий рівень зносу котла, що пов'язано з корозійними явищами, які виникають внаслідок взаємодії внутрішньої поверхні котла з хімічними корозійно-активними вантажами. Для вирішення задачі з можливості експлуатації вагонів-цистерн в умовах визначення терміну служби внаслідок отримання корозійних пошкоджень є необхідність розробки і проведення комплексних заходів з оцінки остаточного ресурсу вагонів-цистерн. При цьому перед фахівцями, дослідниками та науковцями постає особливе завдання – забезпечити максимальне збільшення ресурсу котла з використанням прогресивного методу захисту. Одним з найбільш перспективних методів, який може зменшувати негативний вплив дії корозії та бути застосований практично є протекторний метод захисту. В статті представлено алгоритм розрахунку протекторного захисту, який надає змогу визначити необхідну кількість елементів захисту поверхні. Надана оцінка ефективності захисту при зміні катодної поляризації. Розглянуто вимоги, які мають визначати принципи побудови конструкції системи захисту та її функціонування, а також запропоновано комплекс технічних рішень та заходів, спрямованих на забезпечення захисту металевих поверхонь об'єкта дослідження: котла вагон-цистерни.

Ключові слова: *котел, вагон-цистерна, циліндрична частина, оболонка, метод протекторного захисту, алгоритм розрахунку.*