

DOI: 10.32703/2617-9059-2023-41-15

UDC 629.463.66

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Improvements to the procedure for determination of the residual lifetime of railway vehicles

Existing research concerning the extension of the service life of various types of railway vehicles and assessing its remaining lifetime has been reviewed and analyzed. It has been established that the vast majority of studies relate to the assessment of the residual lifetime of various types of railway rolling stock based on the results of technical diagnostics and routine tests, as well as the assessment of corrosion wear of supporting elements and vehicles bodies. At the same time, little attention has been paid to the issue of improving existing programs and procedures of complex technical diagnostics.

It was determined that the set of diagnostics operations for the extension of the service life includes routine tests of a test sample and examination of the technical condition of the metal structure of each railway vehicle for mechanical and corrosive damage. It is proposed to make changes to the existing current programs and procedures in such key sections as: terminology, objects of technical diagnostics and tests, selection of a test sample for routine tests, execution order and methods of technical diagnostics and routine tests, data processing and evaluation of results. A comprehensive approach for assessing the residual lifetime of railway vehicles is also proposed.

Keywords: *railway vehicles, residual lifetime, routine tests, rolling stock, technical diagnostics.*

Introduction. In recent years, the operating fleet of railway rolling stock has aged significantly. The operation of life-expired railway vehicles involves an increased risk related to ensuring the necessary level of safety in railway traffic. At the same time, decommissioning of railway rolling stock that has served out its lifetime will lead to a sharp decrease in the operating fleet that result into significant problems in railway traffic. Therefore, one of the possible ways to ensure a stable high level of railway traffic safety and prevent a sharp reduction of the operating fleet is to extend the service life of railway vehicles that have served the designated service life guaranteed by the manufacturer.

In this work, it is proposed to continue research in such an important and relevant focus area as the extension of the service life (life cycle) of various types of railway vehicles.

Analysis of recent research and problem statement. The issues of extending the service life of various types of railway vehicles and assessing its residual lifetime have been constantly discussed recently, which indicates their importance and relevance.

Publications [1-8] deal with the extension of the service life and assessment of the residual lifetime of passenger cars. Thus, in paper [1], the residual lifetime of the passenger car body structure was evaluated under operating loads corresponding to 10-year operation. Based on the results of static tests and impact endurance tests with a high degree of reliability, the new service lifetime of the passenger car was confirmed. In work [2], the residual lifetime of a passenger car body structure with corrosion centers of the center sill was assessed. In work [3], the strength of load-bearing structures of passenger cars was studied based on experimental static and shock strength tests, endurance tests under action of longitudinal forces. The assessment and forecasting of the compliance of the wagon bodies for the specified next period have been performed. During scheduled repairs, special attention should be paid to the condition of the side sill and supports. In the study [4], an analysis of the residual lifetime of passenger compartment and open seating cars was performed. In the publication [5] technical condition of passenger cars bodies was considered and their wear was analyzed. Research [6] is aimed at improving the technical diagnostics technique of passenger cars taking into account the features of structural elements damage during operation. In article [7], it is proposed to improve the existing methodology based on the results of scientific and experimental research on determining the maximum service life of passenger cars and bogies. In the article [8], an analysis of the technical condition of the frame elements of passenger cars was performed and the dependence of corrosion wear was obtained.

Works [9-16] focus on research of the service life extension and assessment of the residual lifetime of mainline freight cars. Corrosion wear of load-bearing metal structures of freight cars was studied in [9]. Damage to the load-bearing metal structures of open wagons taking into account corrosive wear is considered. The rate of corrosion wear of elements of load-bearing metal structures and bodies of open wagons models 12-532 and 12-757 was determined. The work [10] deals with the determination of the remaining lifetime of 12-532 model open wagons and the possibility of continuing their operation within Ukraine for more than one and a half years. The article [11] describes the process of carrying out routine type and life tests of the model 19-752 grain wagon. Based on the results of the tests, the residual lifetime of the load-bearing metal structure of the grain wagon was estimated. In work [12], an assessment of the residual lifetime of the load-bearing metal structures of reference wagons and the UVZ-9M bogie operated on the railways of Ukraine, was performed. It has been found that during the technical diagnosis of railcar calibration wagons, it is necessary to pay special attention to the places where the design modifications of the base car were performed. The article [13] addresses the research on corrosion damage of structural elements of open wagons and the effect of cargoes transported in wagons on the speed of corrosion processes. The average speed of corrosion processes of structural elements of open wagons was determined. The publication [14] deals with a study of the residual lifetime of the load-bearing metal structures of hopper-dozer wagons and dump cars (dumpers) based on the results of technical diagnostics and typical tests. Articles [15] give the results of a technical inspection and routine life tests on the cyclic durability of the structural elements of hopper wagons for pellets transportation.

Papers [16-20] address the research on the service life extension and the assessment of the residual lifetime of traction and multiple unit railway vehicles. In article [16] durability and extension of the service life of load-bearing structures of traction and multiple unit rolling stock of railways of Ukraine are considered. The article [17] focuses on the study of the lifetime of the load-bearing structures of the 2TE10 series diesel locomotive, which are under operation at JSC "Ukrzaliznytsia", regarding the possibility of their further safe operation within an extended service lifetime of at least 20 years, including integrated retrofitting. In the article [18], an assessment of the possibility of further safe operation of ChME3 shunting diesel locomotives was performed. The possibility of extending the service life of diesel locomotives of the CHME3 series for at least 6 years has been determined. Article [19] deals with the assessment of the technical condition of the load-bearing structures of VL60 electric locomotives and the expediency of their future operation. The articles [20] give the results of scientific

and experimental studies of the technical condition and residual lifetime of the metal structures of the bodies of metro cars of the model 81-717/714, which served out the designated service life.

The analysis of existing studies [1-20] made it possible to establish that the vast majority of them relate to the assessment of the residual lifetime of various types of railway rolling stock based on the results of technical diagnostics and typical routine tests [1-5, 10-12, 14-20] and research corrosion wear of elements of supporting metal structures and bodies of railway vehicles [8-10, 13]. At the same time, insufficient attention has been paid to the issue of improving existing programs and methods of a complex of diagnostic operations. This issue is considered in works [6, 7] and relate only to passenger cars.

Taking into account the above-mentioned, this article proposes to improve the existing procedure for determining the residual lifetime of railway vehicles by developing appropriate changes to the current programs and methods on the basis of the experience of extending their service life.

The purpose of the study is to improve the procedure for determining the residual lifetime of railway vehicles based on the accumulated experience of carrying out its technical diagnostics and the results of typical routine tests.

Material and methods of research. Currently, the extension of the service life of various types of railway vehicles is carried out on the basis of current programs and methods developed by specialized organizations and agreed with the relevant departments of JSC "Ukrzaliznytsia" in accordance with the established procedure. At the same time, a specialized institution is an institution that has been granted the right to carry out technical diagnostics work for the extension of the service life of railway vehicles by the Wagon Management Commission of the Council on Railway Transport of the Commonwealth Member States. The current programs and methods of conducting a complex of diagnostic operations in order to extend the service life of railway rolling stock must be constantly reviewed and supplemented by making appropriate changes. To begin with, one should describe the point of the existing procedure for extending the service life of railway rolling stock in a simplified form.

The main criterion for the possibility of extending the service life of railway rolling stock is its residual lifetime (or the possibility of its renovation), which is assessed by carrying out a set of diagnostic operations by a specialized institution in accordance with approved programs and methods. Based on the results of the complex diagnostic operations of the railway rolling stock, the specialized institution issues a technical decision regarding the possibility of extending the service life.

Comprehensive diagnostics operations to extend the service life of freight cars intended for operation on main railway lines are performed in accordance with the requirements of the current Order [21]; passenger cars - in accordance with the requirements of the methodology [22]; locomotives, multiple unit and special purpose railway vehicles - in accordance with the requirements [23-25] or other valid regulatory documents.

The set of diagnostic operations to extend the service life includes:

- examination of the technical condition of the metal structure body, bogie frames and beam bolsters (for freight cars, running gear diagnosis is not performed) of each railway vehicle using methods and means of non-destructive testing;
- carrying out routine strength and life tests of bodies samples of various types of railway rolling stock, fatigue bench tests of frames and beam bolster samples (diagnostics of the running gears is not performed for freight cars).

Interchangeable units and elements of bodies and bogies are subject to maintenance and repair in the prescribed manner for these units within the terms, according to the technical documentation for their operation, and are not included in the list of technical diagnostics works.

The task of inspecting the technical condition of railway vehicle is to identify damage and malfunctions of their metal structures, as well as to determine the actual thicknesses of the main load-bearing elements of the bodies, frames and bolster beams of the bogies. Inspection of the

technical condition of metal structures of each railway vehicle is carried out in the following sequence:

- receiving an application for diagnostics;
- studying the operating conditions of the rolling stock by analyzing the design and technical and operational documentation (passport, repair logs), the nature, scope, term and quality of repairs, obtaining data on average daily mileage, transported cargo (for freight rolling stock) using the databases of the Main information and computing center (GIOC) of JSC "Ukrzaliznytsia";
- identification of the railway vehicle model and the year of its manufacture;
- examination of the technical condition of metal structures by the visual-optical method in order to determine the places of mechanical damage and deformations, their nature and geometric parameters;
- detection of defects in the elements of vehicle metal structures that cannot be detected by the visual-optical method or other methods of non-destructive testing;
- determination of the degree of corrosion damage to the main bearing elements of vehicle metal structures;
- photo/video recording of malfunctions and non-compliance with technical requirements;
- filling in the "Sheet of the technical condition of the railway vehicle";
- comparative analysis of the results of the actual measured thicknesses of metal construction elements;
- preparation of a technical decision according to the established procedure and form.

The process of measuring the thickness of elements of the load-bearing structure of freight and passenger cars by the specialists of SE "UkrNDIV" is shown in fig. 1.

According to the results of technical diagnostics, railway vehicles may be excluded from the inventory park if there is significant mechanical and (or) corrosion damage. Freight wagons are excluded from the inventory fleet in the presence of at least one of the malfunctions of the load-bearing structure, which are listed in clause 6.2 of the rules [26]. Passenger cars are excluded from the inventory if there is one of the malfunctions of a mechanical or corrosion nature, which are listed in Appendix D of the methodology [22] and rules [27]. Motorcars and other traction rolling stock are excluded from the inventory park according to the instructions [28, 29] or other valid regulatory and technical documents.

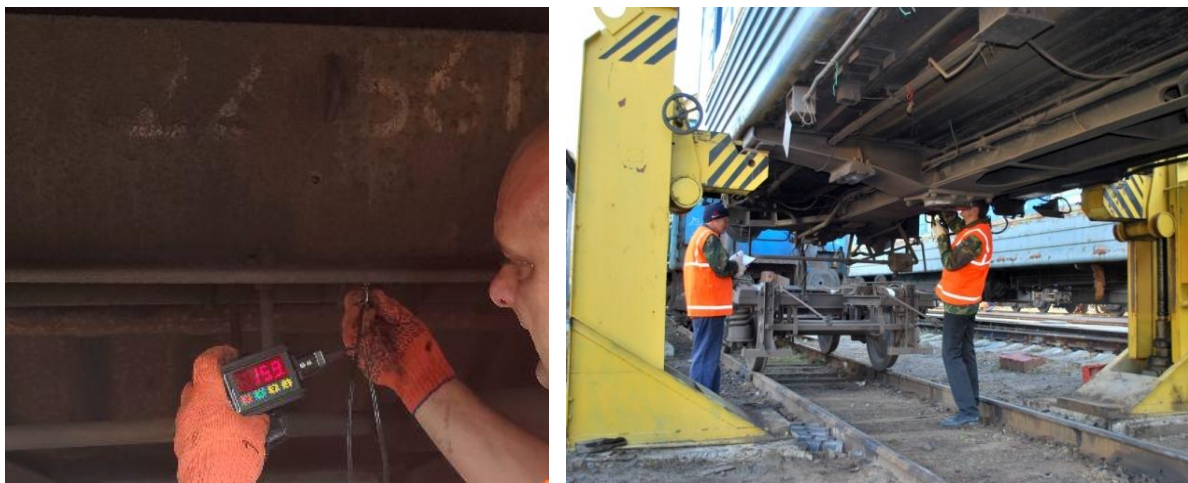


Fig. 1. Measurement of the thickness of the frame elements of the supporting structure of the freight (a) and passenger (b) cars

The criteria for evaluating the possibility of extending the service life of wagons based on the results of the technical condition inspection are established based on the following basic prerequisites:

- mechanical and corrosion damage at the time of the inspection is not extreme and during the period for which the operation of the wagon continues, it should not reach the limit values and go beyond the

limits at which the wagon is subject to exclusion from the inventory. At the same time, the assessment of the degree of further damage development is considered for the most affecting unfavorable coincidence of factors during the new designated operating period;

- mechanical and corrosive damage at the time of inspection, which are eliminated during the repair process, are qualified depending on their type, location, nature of development, size and other factors, as well as the possibility of their elimination during this or that type of repair. At the same time, mechanical and corrosion damage must be eliminated in accordance with the current rules for the repair of railway rolling stock, welding and surfacing instructions, and the established repair technology. For the main load-bearing elements of metal structures of the bogie body, frames and bolster beams, repeated repair of fatigue cracks is not allowed;

- the reasonability of repairing damaged wagons is determined depending on the technical possibility of recovering the necessary load-bearing capacity of the metal structures of the bogie body, frames and bolster beams, as well as the scope of necessary repair work.

The task of the routine tests is to study the strength of a sample of the body of a specific type of railway vehicles, samples of bogie frames and bolster beams (running gear diagnostics for freight cars is not carried out) and to determine the maximum period of continued operation of rolling stock of this type. At the same time, the following types of tests are included in the scope of routine tests: static strength tests under the action of vertical loads; impact tests; impact endurance tests; fatigue bench tests (not for freight cars).

Samples of bodies for routine tests are taken from the batch of railway vehicles, which are subject to diagnostics in the current year (rolling stock that has served the appointed term), in the process of examining their technical condition. Sampling is carried out by experts who perform an examination of the technical condition of rolling stock, in the presence of a representative of its owner. Samples should have the greatest service life (service life, mileage), the most characteristic maximum allowable damage, including repaired, minimum thicknesses of the main bearing elements (if possible).

The main task of static strength tests is to study the stressed state of the metal structure of a car body sample of a specific type that has served the specified term, with the actual thicknesses of elements under calculated static load, as well as to establish the fact that its metal structure has lost its resistance to such loads. During static load tests, the stresses and deformations that occur at the check points of the load-bearing elements of the body structure under the given load modes are determined. Check points are selected in the most heavily loaded areas of the metal structure, which are expertly established on the basis of preliminary calculations, the results of previously performed experimental studies, and the accumulated experience of inspecting wagons.

Static strength tests from vertical load are performed in the following sequence:

- preparation of vehicles for testing (selection of strain gauges, preparation of places for installation of strain gauges on metal construction elements of a vehicle; gluing of strain gauges; installation of connecting cables);

- weighing of railway vehicles containers;

- registration of deformations (stresses) in selected locations of metal construction elements of railway vehicles in empty mode using measuring equipment;

- loading to the nominal carrying capacity (for freight cars); loading to the maximum passenger capacity and equipping with water and coal (for passenger cars); complete locomotive servicing;

- weighing of loaded/equipped vehicles;

- registration of deformations (stresses) in selected locations of metal construction elements of railway vehicles in a loaded state and (or) fully equipped with measuring equipment;

- inspection of railway vehicle metal construction.

The conditioned railway vehicles with selected and glued strain gauges on the elements of its metal structure for static tests is shown in fig. 2.

The purpose of the shock load tests is to study the stress state and strength of the metal structure of a sample of a vehicle body of a specific type with the actual thicknesses of the elements when impacting the vehicle auto-coupling with a given force and speed.



Fig. 2. Railway vehicles conditioned for static tests

The purpose of the impact endurance tests is to experimentally check the durability of the metal structure of a sample of a specific type vehicle body with actual (after the intended period of operation) thicknesses of elements under specified shock load modes, which are equivalent in terms of destructive effect to the loading of the car by operational longitudinal dynamic forces. When carrying out impact endurance tests the following indicators are determined: impact force on the coupling; number of impacts; the presence of permanent deformations, damage from impact loads in the inspected elements of the body. At the same time, it is allowed to assess the durability of the load-bearing elements of the body structure of the passenger car and the locomotive by the fatigue resistance factor, which is calculated based on the results of dynamic and strength tests in accordance with the requirements of the "Standard for the calculation and design of new and modernized railway cars of MPS gauge 1520 mm (non-self-propelled) » [30] and RD 24.050.37 [31]. During dynamic strength tests, dynamic stresses in the main load-bearing elements of the body structure which occur during the movement of wagons at different speeds, up to the design one, on specific sections of the railway track of the corresponding design and current condition are determined and evaluated. During dynamic strength tests, in accordance with the requirements [31], such indicators as the natural frequency of the main vertical bending oscillations of the body and the fatigue resistance factor of the main bearing elements of the body are determined.

Impact endurance tests are carried out in the following sequence:

- a vehicle is equipped with a special auto-coupling dynamometer, static load pre-graded up to 400 tons;
- loading to the nominal carrying capacity (for freight cars); loading to the maximum passenger capacity and provision with water and coal (for passenger cars); complete servicing (for locomotives);
- weighing of loaded/equipped vehicles;
- location of railway vehicles on the test site with a shunting hump test stand with a buffer stop, equipped with a self-coupling device, and preparation of a striker, the weight of which must be no less than the weight of the test car. At the same time, it is allowed to use a railway locomotive instead of a shunting hump test stand, and instead of a railway stop - a formation of several wagons, the total weight of which is at least 300 tons;
- direct impact test;
- measurement of stresses, rolling speed of the tank car with the aid of measuring equipment;
- inspection of the metal structure of the rolling stock is performed after every 3-5 impacts.

The process of carrying out shock endurance tests using a locomotive and an experimental coupling as a railway stop is shown in Fig. 3.

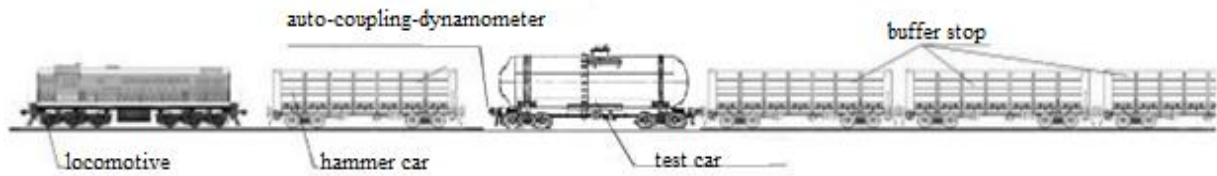


Fig. 3. Scheme of impact endurance tests

The purpose of fatigue bench tests is to experimentally assess the fatigue strength of bogie frames and bolster beams. The following indicators are determined and monitored during the fatigue tests of bogie frames and bolster beams:

- the number of load cycles before the appearance of macrocracks of a 10 mm to 50 mm length, which are detected visually, as well as the number of cycles before destruction;
- the nature of fatigue cracks development when testing and the type of fatigue failure.

Specific test equipment, i.e., test stands, hydraulic pulsator machines, etc. is used to carry out routine fatigue tests. During routine fatigue tests of bogie frames and bolster beams of passenger cars and locomotives, it is possible to use a specialized test stand of type 2CO (Fig. 4).

Therefore, the possibility of extending the service life of each railway vehicle is based on the results of its technical diagnostics and routine tests in order to determine its residual lifetime. At the same time, the main criterion for assessing corrosion wear is the minimum thickness of the elements, which must be at least the minimum set value; mechanical damage, that is deformations, fractures, cracks of the load-bearing elements of the metal structure, which can be eliminated during the prescribed type of repair, are minimally determined by size.



Fig. 4. Appearance of the 2CO test stand

In order to improve the procedure for determining the residual lifetime of railway rolling stock, it is proposed to make the following changes to the existing current programs and methods.

First, it is proposed to make changes in the wording of the term specialized institution. The need to make changes to this term is due to the armed aggression of the Russian Federation and, accordingly, the actual impossibility of Ukrainian institutions to obtain the right to carry out work on technical

diagnostics of railway rolling stock from the Council of Railway Transport of the Commonwealth Member States. The following wording of the term specialized institution is proposed - an institution that has a scientific and technical base and is accredited by the National Accreditation Agency of Ukraine for the right to perform work on technical diagnostics of railway rolling stock.

Secondly, in the near future, it is necessary to supplement the existing methods and provisions with new models of railway rolling stock, whose designated service life guaranteed by the manufacturer ends, taking into account their design features and the results of routine tests.

Thirdly, during routine tests, one should consider the possibility of replacing impact endurance tests with wedge tests and dynamic-strength tests provided that there is a satisfactory convergence of the tests results.

Fourth, review the approach to recording corrosion damage. At present, corrosion damage to load-bearing structures and bodies is recorded during technical diagnostics of railway rolling stock that has served the appointed term. At the same time, under the existing approach, it is assumed that the rate of corrosion of the main load-bearing elements is uniform. In fact, the results of many existing studies show that corrosion processes have a non-linear nature. Therefore, to increase the accuracy of determining the residual lifetime of railway rolling stock, it is necessary to monitor corrosion processes during its life cycle.

In the future, it is proposed to monitor the corrosion processes of load-bearing elements and bogies (with the exception of freight cars) during their operation within the time limits guaranteed by the manufacturer during scheduled repairs of railway rolling stock, with the entry of the check results into the database of the Main information computational center. It is suggested to record the thicknesses of load-bearing elements and bogies (with the exception of freight cars) before and after scheduled repairs of railway vehicles.

According to this approach, the value of the residual lifetime is proposed to be determined through the thinning coefficient according to formula (1):

$$T_{res.} = T_{des.} \cdot \lambda_{\Delta t}(t), \quad (1)$$

where - $T_{des.}$ is the designated service life of the railway vehicle, years;

$\lambda_{\Delta t}(t)$ is the dependence of the thinning coefficient on the time of operation of the car.

The thinning coefficient at a specified time period is determined by formula (2):

$$\lambda_{\Delta t} = \frac{t_{act.}}{t_{nom.}}, \quad (2)$$

where $t_{nom.}$ is the nominal thickness of the element, mm, is determined by the results of measuring the element in places not affected by corrosion, or by horizontal dimensions. Horizontal dimensions, as a safety margin, are taken with a positive tolerance;

$t_{act.}$ is the actual thickness of the structural element according to the measurement results, mm;

At the same time, the actual fatigue limit value, taking into account the service life, can be determined by expression (3):

$$\sigma_{a,N}^{act.} = \frac{\sigma_{a,N}}{\lambda_{\Delta h}}, \quad (3)$$

where $\sigma_{a,N}$ is the calculated limit of endurance under a symmetrical stress cycle, brought to the test base, obtained on the basis of bench vibration tests of supporting elements.

It is proposed to explain the determination of the value of the residual lifetime due to the thinning factor according to the dependence shown in Fig. 5.

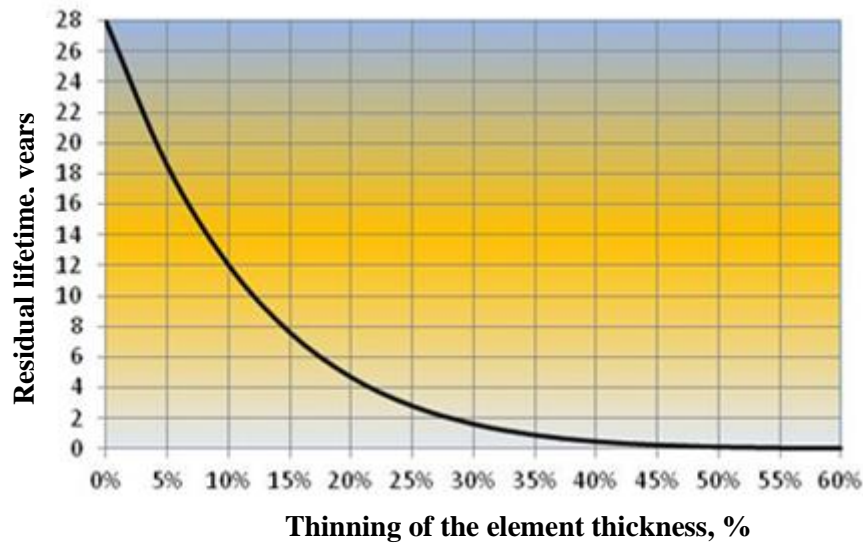


Fig. 5. Dependence of the residual lifetime on the amount of corrosion wear

So, for example, with a 30-year service life and 15% thinning of the supporting element at the time of diagnostics, the residual lifetime of the structure will be 8 years.

The dependence $\lambda_{\Delta t}(t)$ can be exponential, power, polynomial and is determined experimentally on the basis of a significant amount of accumulated research data based on the results of technical diagnostics of railway rolling stock.

Fifth, one should review the procedure for selecting a test sample for routine tests. It should be taken into account that routine tests results will be distributed to the entire batch of railway vehicles of this type, subject to diagnostics. So correctly selected samples for routine tests directly depend on the validity of their results and, accordingly, the term of service extension.

It is suggested that the content of the section "Sample selection for routine tests" should be reworded, taking into account the gained experience, experimental studies, as well as the recommendations formulated in the work [32]. This paper proposes its own algorithm for selecting samples of passenger cars and bogies for routine tests, which is based on the most characteristic mechanical and corrosive damage identified based on the results of an examination of the technical condition of all vehicles that underwent technical diagnostics during the year preceding the year in which the routine tests are scheduled.

This section is proposed in the following wording:

Body samples for routine tests are selected from the batch of railway vehicles, which are subject to diagnosis in the current year (rolling stock that has served the appointed term), in the process of examining their technical condition. The selection of samples is carried out by specialists who carry out an examination of the technical condition of rolling stock, in the presence of a representative of its owner. Samples should have the greatest performance (service life, mileage), the most characteristic maximum allowable damage, including repaired, minimum thickness of the main bearing elements. Samples for routine tests are selected by specialists based on a comprehensive analysis using the GIOC database of mechanical and corrosion damage, calculations of the reliability indicators of load-bearing structures, as well as a result of direct technical diagnostics of the selected vehicles with the longest operating time, maximum, but permissible damage of a mechanical and corrosion nature.

Sixth, in the programs and methods, it is proposed to determine the reliability indicators for each object of diagnostics using the GIOTS database, which will allow to take into account the structural and

technological features of each rolling stock, to expand the possibilities for a comprehensive analysis of the feasibility of extending its service life beyond that set by the manufacturer.

At the same time, as part of the work on technical diagnostics of railway rolling stock, it is proposed to determine the reliability indicators using the database of the Main information computational Center upon request, taking into account the KZhA classification of the railway vehicles. In this case, unplanned uncoupling of rolling stock is analyzed depending on the fault code. The analysis period is from the moment the railway vehicle is put into operation until its technical diagnosis. Malfunctions (failures) are formed and subsequently analyzed for separate time periods (intervals). Time periods are established on the basis of planned maintenance intervals according to the consideration of technical documentation for a specific type of rolling stock.

The processing of the results of the determination of reliability indicators can be presented in the form of a computational process, the input of which is the following data: the period of operation of the vehicle (T , years), the number of the same type of inspected (N_i , pcs) and damaged (n_i , pcs) elements in the i -th interval. The main reliability indicators that are determined are the following:

- the frequency of occurrence of a malfunction in the i -th interval

$$q_i = \frac{n_i}{N_i} \quad (4)$$

- the accumulated interval frequency of malfunction in the i -th interval

$$r_i = \sum_{k=1}^i q_k = \sum_{k=1}^i \frac{n_k}{N_k} \quad (5)$$

- the empirical probability of element failure during the i -th service life

$$R_i^* = \exp\left(-\sum_{k=1}^i \frac{n_k}{N_k}\right) \quad (6)$$

- the empirical probability of the element working in good condition during the i -th service life:

$$Q_i^* = 1 - \exp(-r_i) = 1 - \exp\left(-\sum_{k=1}^i \frac{n_k}{N_k}\right) \quad (7)$$

- density of damages (failures)

$$f(t) = \lambda \exp\left(-\sum_{k=1}^i \frac{n_k}{N_k}\right) \quad (8)$$

- average working time before failure

$$T_{cp} = \frac{1}{\lambda}; \quad (9)$$

- gamma percentage resource

$$T_\gamma = \frac{1}{\lambda} \left(-\ln \frac{\gamma}{100} \right); \quad (10)$$

- failure flow parameter

$$\omega = \frac{\Omega(t_p)}{t_p}, \quad (11)$$

where $\Omega(t_p)$ is the average specific number of failures of rolling stock, its nodes or systems during the estimated period of operation;

t_p is the average mileage of the car during the estimated period of operation before the first depot repair (in years, thousand km of mileage, etc.).

It should be noted that formulas (4)-(11) are given for the exponential distribution law. This distribution is uniparametric and is a partial case of the Weibull distribution, in which the failure rate is a constant value. Under conditions of subordination to another theoretical law of failure distribution (Rayleigh distribution, Weibull distribution, gamma distribution, etc.), formulas are used to determine reliability indicators, which are considered in detail in papers [33, 34].

Seventh, the approach to the criteria for evaluating the residual lifetime should be reviewed. Currently, the residual lifetime of railway rolling stock is determined based on the results of routine tests and technical diagnostics. At the same time, the new service life is based on the expert assessment of specialists of a specialized institution, which cannot exceed the limit established by the results of routine tests.

The authors suggest evaluating the residual lifetime of railway vehicles based on its complex minimum value. This comprehensive indicator of residual lifetime assessment will take into account the results of routine tests, expert assessment of specialists based on the results of technical diagnostics, research of corrosion processes due to the thinning factor, calculated reliability indicators. In a simplified mathematical form, the complex criterion for evaluating the residual lifetime can be presented in the following form:

$$T_{res.} = \left(\begin{array}{c} T_{res.}(\lambda_{\Delta t}(t)) \\ T_{res.}(n) \\ T_{res.}(Q_i^*) \end{array} \right) \rightarrow \min \quad (12)$$

where $T_{res.}(\lambda_{\Delta t}(t))$ is the residual lifetime determined by the results of technical diagnostics of corrosion processes due to the thinning factor;

$T_{res.}(n)$ is estimate of the residual lifetime based on the results of data processing of routine tests;

$T_{res.}(Q_i^*)$ is the residual lifetime determined based on the results of calculations of reliability indicators.

The proposed comprehensive approach to the assessment of the residual lifetime of the railway rolling stock will allow to increase the descriptiveness and accuracy of the results of such an assessment, to determine this indicator more reasonably, which will generally increase the safety of railway transportation.

Thus, this article proposes seven key directions for improving the procedure for determining the residual lifetime of railway rolling stock, which are aimed mainly at improving the safety of railway transportation and preventing a sharp reduction in the operating fleet.

Conclusions.

1 The whole point of current programs and methods of extending the service life of railway rolling stock is given. It was determined that the complex of diagnostic operations for the extension of the service life and the assessment of the residual lifetime includes routine tests on the experimental sample and the examination of the technical condition of the metal structure of each vehicle for mechanical and corrosion damage. At the same time, the experimental sample for routine tests must have the longest operating time, the greatest characteristic maximum permissible damage, including those removed,

minimum thickness of the main supporting elements (if possible). The limit period of continued operation is determined by the results of routine tests. The possibility of extending the service life of each railway vehicle is determined based on the results of its technical diagnostics, taking into account the marginal residual lifetime of the metal structure.

2. It is proposed to make seven key changes and additions to existing current programs and methods of extending the service life of railway rolling stock. These changes and additions primarily relate to terminology, sample selection for control tests, processes and methods of technical diagnostics and control tests, data processing and evaluation of results. The main differences concern the control of corrosion processes, the additional determination of the reliability indicators of the load-bearing elements of metal structures, the application of a comprehensive approach to the assessment of the residual resource of railway rolling stock.

Further efforts should be directed to the introduction of proposed changes and additions to the current programs and methods of extending the service life of railway rolling stock in order to further coordinate them with the relevant structures in the established order.

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Удосконалення процедури визначення залишкового ресурсу залізничного рухомого складу

Обґрунтовано необхідність продовження строку експлуатації залізничного рухомого складу, що виступив призначений термін служби гарантований заводом-виробником, з метою запобігання різкому скороченню експлуатаційного парку. Розглянуто та проаналізовано існуючі дослідження в напрямку продовження строку служби різного типу залізничного рухомого складу та оцінки його залишкового ресурсу. Встановлено, що переважна більшість досліджень стосується оцінки залишкового ресурсу різного типу залізничного рухомого складу на підставі результатів технічного діагностування та типових контрольних випробувань, а також оцінці корозійного зносу елементів несучої конструкції та кузовів залізничного рухомого складу. При цьому питанню удосконалення існуючих програм та методик комплексу діагностичних операцій приділено недостатньо уваги. Наведено основну сутність чинних програм та методик продовження строку експлуатації залізничного рухомого складу різного типу. Визначено, що комплекс діагностичних операцій з продовження строку експлуатації включає проведення контрольних випробувань на дослідному зразку та обстеження технічного стану металоконструкції кожного рухомого складу на наявність пошкоджень механічного та корозійного характеру. Запропоновано в існуючі чинні програми та методики внести зміни за такими ключовими розділами як: термінологія, об'єкти технічного діагностування та випробувань, відбір дослідного зразка для контрольних випробувань, порядок та методи технічного діагностування та контрольних випробувань, обробка даних та оцінка результатів. Також запропоновано комплексний підхід для оцінки залишкового ресурсу залізничного рухомого складу, який дозволить підвищити інформативність та точність результатів такої оцінки, а також більш обґрунтовано визначати цей показник.

Ключові слова: залізничний транспорт, залишковий ресурс, контрольні випробування, рухомий склад, технічне діагностування.