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# Determination of the efficiency of the modernization of passenger car bodies

*The authors determined the intensity of the increase in wear of various elements of the body. It has been established that the lower trim, the roof slope and the lower part of the side wall have the greatest wear. It is proposed to use aluminum alloys for the modernization of passenger car bodies. The advantage of such a technical solution is an increase in the corrosion resistance of the body. The reduction of tare allows to reduce the specific resistance to train movement, reduce fuel and electricity costs for train traction. To reduce operating costs using the basic provisions of the locomotive traction theory, calculations were made to determine the energy consumption for the movement of a passenger train according to the profile conditions of the real section of the regional branch of the Southern Railway by diesel and electric locomotive traction with the base variant and the variant of passenger cars with reduced tare weight) in composition of the train. It has been established that the annual savings in energy costs for the traction of passenger trains when using passenger cars with a reduced tare weight is about 1 million UAH.*

***Key words:*** *passenger car, body, resource, wear, modernization, economic effect.*

**Introduction.** Railways of Ukraine have been the main element in passenger transportation for many years. They own up to 40% from the total passenger traffic.

But the share of passenger transportation by rail is steadily decreasing. One of the reasons is the significant wear and tear of rolling stock. The vast majority of the inventory of passenger cars owned by the "Passenger Company" branch has already exhausted its resource, since these cars were mainly built in the second half of the 20th century. Accordingly, outdated cars do not allow to increase the speed of movement. Not the least role is played by the poor quality of passenger service.

Increasing the efficiency of railways requires the use of new innovative technical solutions in the construction of non-traction rolling stock.

**Analysis of recent research and problem statement.** A number of researches both in our country and abroad are devoted to the issue of increasing the efficiency of the passenger economy. The results of studies [1, 2] indicate that significant capital investments are required to update the passenger fleet with new generation wagons and modernize the infrastructure. Given that passenger transportation for JSC Ukrzaliznytsia is unprofitable, own funds are insufficient. Involvement of third-party investors is necessary.

Articles [3, 4] give the results of the analysis of the technical condition of the fleet of passenger cars owned by Passenger Company JSC. The vast majority of passenger cars were built back in the times of the USSR. Accordingly, their wear is about 90%. The authors come to the conclusion that the state of passenger rolling stock has reached a critical limit and needs immediate updating.

As confirmation of these conclusions, the articles [5, 6] present the results of a statistical analysis of the amount of wear and damage of metal structures of the frame and body of passenger cars of different years of construction that have completed their service life.

The authors of the studies [7, 8] believe that in the conditions of chronic underfunding, the overhaul of passenger cars with the extension of their service life is a completely reasonable alternative to the purchase of newly built cars in order to provide railways of Ukraine with passenger cars of a modern level of safety and comfort.

The articles [9, 10] consider possible options for the organization of repair and maintenance of passenger cars after overhaul.

The structural requirements for the design of passenger cars are set out in the normative document [11]. The issue of the use of composite materials for the manufacture of rolling stock bodies is considered in the article [12].

The article [13] provides an assessment of the technical and economic indicators of the operation of the existing traction rolling stock when moving passenger trains, taking into account the operating conditions.

The authors of study [14] proposed to improve the method of calculating the operating costs of passenger transportation by determining the energy costs of train traction for various types of passenger traction rolling stock, taking into account the indicators that change under the influence of increasing speed, developed an economic-mathematical model that makes it possible to determine the operating costs and profitability of passenger train composition under various operating conditions.

In article [15], the issue of ensuring sustainable socio-economic development of railway transport of Ukraine is considered in particular, and a methodical approach to determining the social effect of maintaining passenger traffic in inactive areas is presented.

Paper [16] presents a methodical approach to determining the optimal running zones of passenger trains of various types, which is based on reducing their operating costs and increasing the speed of movement when changing the organization of traffic according to the new classification of trains, which will allow to increase the economic efficiency or reduce the unprofitability of passenger transportation and increase their competitiveness on the market of passenger transport services.

Article [17] examines ways of increasing the competitiveness of railway passenger transportation in Ukraine. Attention is focused on increasing the efficiency of passenger transport by increasing the speed of trains, increasing the quality of provided transport services and improving the comfort of passenger transportation. A new approach to the evaluation of the efficiency of railway passenger transportation is proposed.

Technical and economic indicators of railway passenger transportation are systematized in [18]. Also, this article provides an analysis of the dynamics of cost indicators and determines their impact on the efficiency of these transportations through the determination of the reasons for the decrease in the efficiency of the passenger complex of railway transport of Ukraine.

**The purpose and tasks of the study.** The purpose of this work is to study the effectiveness of improving the structures of the bodies of passenger cars that have exhausted their resource. To do this, it is necessary to determine which of the elements of the body structure have the greatest effectiveness in operation, to propose technical solutions for the modernization of passenger car bodies and to substantiate their economic feasibility.

**Materials and methods of research.** The diagnosis of wagons that have reached the end of their service life (28 years) was carried out in the scope of an examination of their technical condition and control tests of the metal structures of frames and bodies, over-spring beams and bogie frames of wagon samples in accordance with the "Methodology of technical diagnosis of passenger wagons that have served the specified term, for the purpose of its continuation" ЦЛ-0070, approved by the order of Ukrzaliznytsia No. 304-Ц of June 25, 2008 [19].

Two types of cars were subject to inspection of the technical condition of the bodies of passenger cars that had exhausted their service life: rigid compartment models 47D, 47K, built at the Waggonbau plant Ammendorf (Germany), and non-compartment open-type (place card) models 61-425, 61-821, built at the Kalininsky (now Tver) wagon-building plant. In total, about 540 wagons of various ranges according to the years of construction were inspected.

Determining the technical condition of the cars was carried out by visual inspection followed by thickness measurements. At the same time, attention was paid to the presence of cracks, fractures, breaks, dents, wear, deformations, traces of repairs, corrosion damage, changes in the geometric shapes of the elements of the car body and frame. The results of the inspection and the actual thicknesses of the main load-bearing elements of the car were recorded in the technical condition maps. Measurements were made from both the boiler room and the non-boiler side of the car.

The nominal values of the thicknesses of the elements are determined according to the working drawings of the manufacturing plant. When inspecting the technical condition of the cars, schemes of compartment and open (reserved) passenger cars were used.

During the analysis, the results of inspections of metal structures of cars were divided into five conditional groups: cars with a service life of 29-32 years, 33-36 years, 37-40 years, 41-44 years, and more than 45 years. At the same time, the nominal values of the thickness of the structural elements of the car and the actual values of the thickness, taking into account the amount of wear, were compared. This article deals with damage to the most vulnerable elements of the body.

**The lower harness of the car.** In the cars, measurements of the amount of wear of the lower harness were carried out both on the left side and on the right side of the car (Fig. 1).

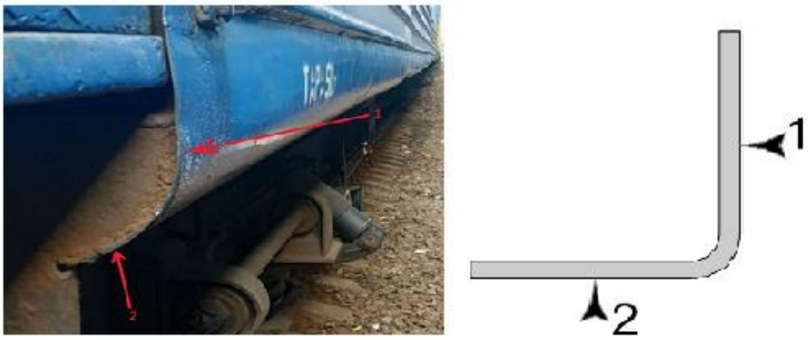

*Fig. 1.* **The scheme of carrying out measurements of the lower binding**

In open-type wagons, the maximum value of the trip was found on the working side of the vestibule at point 2. Its value was equal to 4.5 mm. This is approximately 32% wear from the nominal thickness of the metal. The maximum value of tripping in compartment cars was found, as in open-type cars, at point 2. Its value is equal to 7.1 mm, which is 51% of wear from the nominal size.

As a result of the study, the dependences of the increase in the intensity of activation for compartment cars and open-type cars by year were obtained (Fig. 2).

It is obvious that they have a character close to linear. And the intensity of activation in open-type carriages in all age groups is greater than in compartment carriages. This is especially typical for cars with a service life of more than 45 years (exceeding almost twice).

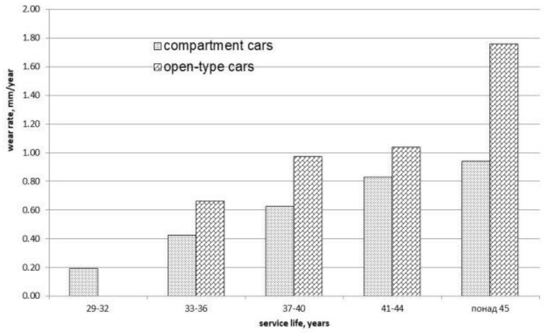

*Fig. 2.* **Intensity of operation of the lower harness in compartment cars and open-type cars**

**Roof covering.** The scheme for measuring the amount of wear of the roof cladding and displaying the node is shown in fig. 3.

*Fig. 3.* **Scheme of roof sheathing measurements**

The maximum value of the opening of the roof covering in non-compartment type cars on the left and right sides of the car was found at points 2 and 02 – 0.7 mm with a nominal thickness of 2 mm.

Accordingly, for compartment cars at these same points, the maximum amount of tripping was 0.6 mm.

The magnificent effect on the slopes of the roof is much greater. It is equal to 2 mm on both types of cars. This is due to the fact that the same factors (weather conditions, constant moisture, etc.) act on the slope of the roof cladding.

In fig. 4 shows the obtained dependences of the increase in the intensity of operation for rigid compartment cars and open-type cars of the service life.

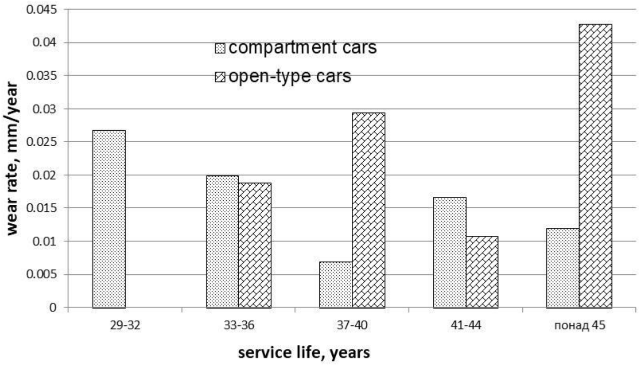

*Fig. 4.* **Intensity of operation of the roof slope in compartment cars and open-type cars**

If in open-type cars with an increase in the service life there is a tendency to increase the tripping, then in compartment cars – the opposite is the case.

**Side wall.** The measurement was made from both the right and the left side of the car in accordance with requirements. The scheme for measuring the wear of the side wall and displaying the node is shown in Fig. 5.

*Fig. 5.* **Scheme of side wall paneling measurements**

For open-type cars, increased corrosive wear of the side wall cladding in the lower part in the window space of the side wall is characteristic (point 4). The reason is the constant ingress of moisture in rainy weather through open windows into the windowsill pockets where the mechanisms for raising and lowering the windows are located. With closed windows in the compartment (or blind windows in the passage), the presence of condensation in the cold season causes the appearance of moisture. The maximum trigger value at point 4 was 1.8 mm.

The maximum value of the trip was detected from the side of the corridor along the car (ie in the area of the location of the side seats for passengers) and at point 2 it was 2.1 mm.

For rigid compartment cars, the maximum actuation value was found at point 4, both on the right side of the car along the side corridor, and on the left side, where the passenger compartments are located. The trigger value is 1.5 mm on the right side and 1.4 mm on the left, respectively.

In fig. 6 shows the obtained dependences of the increase in the intensity of operation for rigid compartment cars and open-type cars by year.

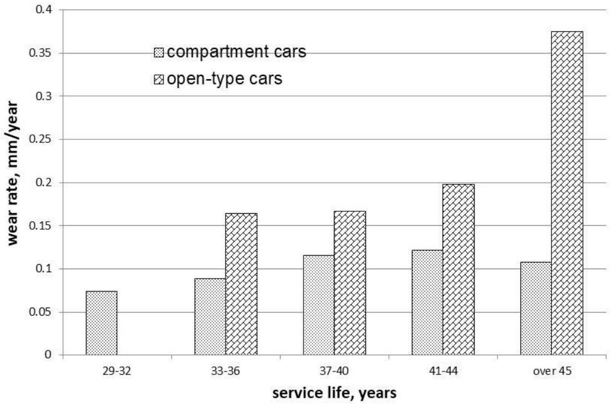

*Fig. 6.* **Intensity of activation of side wall cladding in compartment cars and open-type cars**

In open-type carriages, a sharp increase in the intensity of sidewall activation is observed already after 44 years of operation.

In compartment cars, the maximum intensity of side wall activation is typical for cars aged 41-44 years.

**Spinal beam.** The scheme for measuring the amount of wear of the spinal beam is shown in fig. 7.

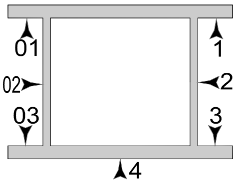

*Fig. 7.* **Scheme of carrying out measurements of the spinal beam**

For open type cars, the maximum trigger value is 6 mm, and for compartment wagons - 4 mm.

In fig. 8 the resulting dependences of the growth intensity of the spinal beam for rigid compartment cars and open-type cars by year are given.

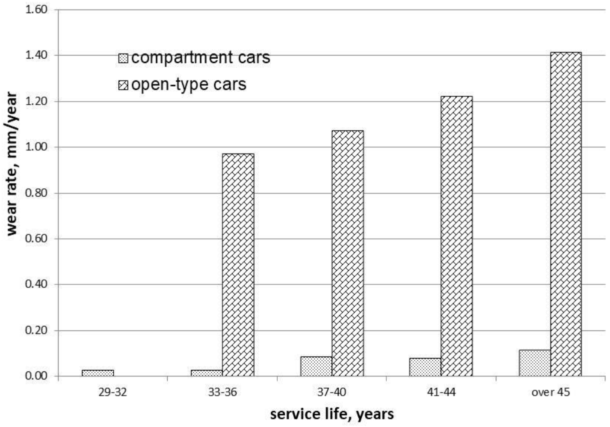

*Fig. 8.* **Intensity of operation of the spinal beam in compartment cars and open-type cars**

The intensity of operation for open-type cars significantly exceeds this indicator for compartment wagons. The nature of the distribution of the activation intensity is also different. If for open-type cars it has a linear nature of growth, then for compartment cars in the period of 28-36 years it practically does not change, and then there is an increase (more than 4 times).

**End wall.** Measurements were made from the working and non-working vestibule of the car. The scheme for measuring the wear of the end wall and displaying the node is shown in Fig. 9.

*Fig. 9.* **Scheme of measurements of the end wall cladding**

In open-type cars, the maximum value of the trip was detected from the boiler side of the car at point 2 and was equal to 0.9 mm at a nominal thickness of 2 mm. In compartment cars, the maximum trigger value was detected from the boiler side of the car at point 1 and was equal to 0.8 mm at a nominal thickness of 2 mm.

In fig. 10 the resulting dependences of the growth intensity of the end wall for rigid compartment cars and open-type cars by year are given.

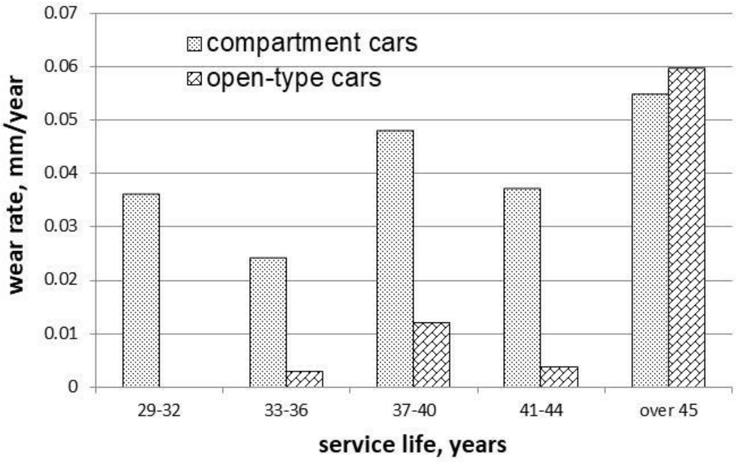

*Fig. 14.* **Intensity of operation of the end wall in compartment cars and open-type cars**

It is obvious that the patterns of operation are fundamentally different in different types of cars. If in compartment cars the intensity tends to a smooth linear increase, then in open cars that have already worked for more than 45 years, there is a six-fold increase in the intensity of operation.

The obtained results indicate that the lower harness, the roof slope and the lower part of the side wall are most often damaged during operation of passenger cars. Therefore, it is expedient to modernize the bodies of passenger cars during major renovations by replacing steel sheet and rolled steel with aluminum alloy [20] in the specified places. Among the advantages of such a technical solution is an increase in the corrosion resistance of the body, which significantly increases the service life of the wagons, and a decrease in the wagon's tare weight.

The latter, in turn, allows to reduce the specific resistance of trains. This circumstance determines the reduction of fuel and electricity costs for train traction, which allows to reduce the operating costs of railway transport for energy consumption.

In the calculations, we assume that for the movement of passenger trains, the TEP70 diesel locomotive is used for diesel traction, and the CHS4 AC electric locomotive is used for electric traction, as those serving the movement of passenger trains in the direction chosen for the calculation study.

We will use the provisions of the theory of locomotive traction [21, 13], as well as some studies of factors that affect the consumption of energy carriers [22, 23].

Determination of savings in yearly energy costs for train traction due to a reduction in the Mass of the passenger car under the conditions of running on a specific route

Decreasing the tare weight of a passenger car makes it possible that reduce the specific resistance of trains. This circumstance determines the reduction of fuel and electricity costs for train traction , which allows that reduce the operating costs of railway transport for energy consumption ..

In the calculations, we assume that for the movement of passenger trains the TEP70 diesel locomotive is used for diesel traction and the CHS4 AC electric locomotive is used for electric traction, as those serving the movement of passenger trains in the direction chosen for the calculation study.

Fuel consumption for train operation of a diesel locomotive $\mathrm{G_d}$ he the site is determined by the fuel consumption in even $\mathrm{G_{e.d}}$ and odd $\mathrm{G_{o.d}}$ directions:

$$\mathrm{G_{e.d}} = \int_{\tau_s}^{\tau_{s+1}} \mathrm{G_{e.d}}(\tau) \times \mathrm{d}\tau, \qquad (1)$$

$$G_{o.d} = \int_{\tau_s}^{\tau_{s+1}} G_{o.d}(\tau) \times d\tau. \tag{2}$$

where $\tau_s$ is passage time of the locomotive with the passenger train of the section profile element.

The specific fuel consumption per meter of operational work (1000 pas-km) is determined by the formula

$$b_p = \frac{\int_{\tau_s}^{\tau_{s+1}} G_{e.d}(\tau) \times d\tau + \int_{\tau_s}^{\tau_{s+1}} G_{o.d}(\tau) \times d\tau}{(P_{e.d} + P_{o.d}) \times l_T} \times 10^3, \tag{3}$$

where $P_{e.d}$, $P_{o.d}$ – the number of passengers following , respectively , in even and department directions , pas .;

$l_T$ – the distance followed by the diesel locomotive at the head of the passenger train in an even or department direction , km .

Electricity consumption for train operation of an electric locomotive $A_e$ he the section is determined by the consumption of electricity in the even $A_{e.d}$ and $A_{o.d}$ odd directions.

Electricity consumption by directions is determined by formulas:

$$A_{e.d} = \int_{\tau_s}^{\tau_{s+1}} A_{e.d}(\tau) \times d\tau, \tag{4}$$

$$A_{o.d} = \int_{\tau_s}^{\tau_{s+1}} A_{o.d}(\tau) \times d\tau. \tag{5}$$

The specific consumption of electricity per meter of operational work (1000 pass-km) is determined by the formula:

$$a_e = \frac{\int_{\tau_s}^{\tau_{s+1}} A_{e.d}(\tau) \times d\tau + \int_{\tau_s}^{\tau_{s+1}} A_{o.d}(\tau) \times d\tau}{(P_{e.d} + P_{o.d}) \times l_e} \times 10^3, \tag{6}$$

where $l_e$ is the distance followed by an electric locomotive at the head of a passenger train in an even or department direction, km.

We will use the main provisions of traction calculations that determine the energy consumption for the movement of a passenger train under the conditions of the profile of the real section of the regional branch "Southern Railway" by thermal and electric locomotive traction with the basic version and the version of passenger cars with reduced tare weight (new version) in the composition train.

Characteristics of the profile of the area of the regional branch "Pivdenna zaleznytsia " are given in table 1 and fig. 15 and 16 [1, 3, 4]. As can be seen from the given data, in the department direction the prevailing profile is with a slope of 0...1‰, in the even direction - 0...1‰. The total length of the freight train rotation section is 344,502 km . The train has 6 stops he the section in both directions .

*Table 1.* **Site profile characteristics**

| Tilt range | Percentage distribution of profile elements, % | Length, km | Percentage distribution of profile elements, % | Length, km |
|---|---|---|---|---|
| | Even direction | | Odd direction | |
| -16...-15 | 0.09 | 0.3 | 0 | 0 |
| -15...-14 | 0 | 0 | 0 | 0 |
| -14...-13 | 0 | 0 | 0.12 | 0.4 |
| -13...-12 | 0.07 | 0.25 | 0.27 | 0.922 |
| -12...-11 | 0.06 | 0.2 | 0.35 | 1,214 |
| -11...-10 | 0.36 | 1.24 | 0.73 | 2,528 |
| -10...-9 | 1.67 | 5.77 | 1.64 | 5,652 |
| -9...-8 | 3.82 | 13,16 | 4.35 | 14,981 |
| -8...-7 | 5.03 | 17,313 | 5.36 | 18,456 |
| -7...-6 | 2.98 | 10.25 | 4.52 | 15,559 |
| -6...-5 | 2.81 | 9,682 | 3.11 | 10,698 |
| -5...-4 | 3.34 | 11,498 | 2.33 | 8,041 |
| -4...-3 | 3.76 | 12.94 | 2.68 | 9,226 |
| -3...-2 | 6.14 | 21,16 | 4.37 | 15,062 |
| -2...-1 | 9.57 | 32,965 | 5.17 | 17,795 |
| -1...0 | 7.03 | 24,207 | 7.40 | 25,495 |
| 0...1 | 17.08 | 58,853 | 16.71 | 57,575 |
| 1...2 | 6.00 | 20,655 | 9.70 | 33,415 |
| 3...4 | 2.56 | 8,826 | 3.93 | 13.55 |
| 4...5 | 2.82 | 9,721 | 3.46 | 11,923 |
| 5...6 | 2.62 | 9,021 | 2.88 | 9,907 |
| 6...7 | 3.89 | 13,403 | 2.52 | 8,695 |
| 7...8 | 6.00 | 20,659 | 4.93 | 16,988 |
| 8...9 | 4.23 | 14,562 | 4.27 | 14.7 |
| 9...10 | 1.90 | 6,551 | 2.03 | 7.01 |
| 10...11 | 0.93 | 3.2 | 0.42 | 1.44 |
| 11...12 | 0.52 | 1,792 | 0.06 | 0.2 |
| 12...13 | 0.35 | 1,222 | 0.07 | 0.25 |
| 13...14 | 0.06 | 0.2 | 0 | 0 |
| 14...15 | 0.06 | 0.2 | 0 | 0 |
| 15...16 | 0 | 0 | 0.09 | 0.3 |
| Together | 100 | 344,502 | 100 | 344,502 |

To carry out traction calculations, in addition to the characteristics of the section profile, it is necessary to specify the following data, both when using diesel locomotive and when using electric locomotive traction:

1. Mass of the train in tons.
2. The number of cars in the train by type.
3. The average population of a car of a passenger train.
4. Technical speed.

To determine these indicators, we will use the reference indicators of the schedule of passenger trains on the section of the regional branch "Yuzhnaya zheleznaya doroga" for the year 2023, which are given in Tables 2, 3 and 4.

*Table 2.* **Output data for the traction calculation in the odd direction**

| Characteristic | Station | | | | | | | Together |
|---|---|---|---|---|---|---|---|---|
| | formation | 1 | 2 | 3 | 4 | 5 | 6 | |
| Distance, km | | 24.2 | 131.4 | 54.91 | 34.6 | 56,56 | 42.84 | 344.51 |
| Arrival, h.:min. | | 23:00 | 0:47 | 1:55 a.m | 2:28 | 3:24 a.m | 4:02 a.m | |
| Departure, h.:min. | 22:30 | 23:02 | 1:07 a.m | 1:57 a.m | 2:30 a.m | 3:26 a.m | | |
| Running time, hours | | 0.50 | 1.75 | 0.80 | 0.52 | 0.90 | 0.60 | 5.07 |
| Time of stops , h. | | 0.03 | 0.33 | 0.03 | 0.03 | 0.03 | | 0.47 |
| Technical speed, km/h. | | 48.4 | 75.1 | 68.6 | 67.0 | 62.8 | 71.4 | 68.0 |
| District speed, km/h. | | 45.4 | 63.1 | 65.9 | 62.9 | 60.6 | | 62.3 |
| Precinct speed coefficient | | 0.94 | 0.84 | 0.96 | 0.94 | 0.96 | | 0.92 |

*Table 3.* **Output data for traction calculation in even direction**

| Characteristic | Station | | | | | | | Together |
|---|---|---|---|---|---|---|---|---|
| | 6 | 5 | 4 | 3 | 2 | 1 | formation | |
| Distance, km | | 42.84 | 56,56 | 34.6 | 54.91 | 131.4 | 24.2 | 344.51 |
| Arrival, h.:min. | | 1:19 a.m | 2:12 | 2:43 a.m | 3:33 | 5:51 a.m | 6:27 a.m | |
| Departure, h.:min. | 0:39 | 1:21 a.m | 2:14 a.m | 2:45 | 3:53 | 5:54 a.m | | |
| Running time, hours | | 0.67 | 0.85 | 0.48 | 0.80 | 1.97 | 0.55 | 5.32 |
| Time of stops , h. | | 0.03 | 0.03 | 0.03 | 0.33 | 0.05 | | 0.48 |
| Technical speed, km/h. | | 64.3 | 66.5 | 71.6 | 68.6 | 66.8 | 44.0 | 64.8 |
| District speed, km/h. | | 61.2 | 64.0 | 67.0 | 48.5 | 65.2 | | 59.4 |
| Precinct speed coefficient | | 0.95 | 0.96 | 0.94 | 0.71 | 0.98 | | 0.92 |

*Table 4.* **Output data for traction calculation**

| Characteristic | Variant of the car | |
|---|---|---|
| | base | modernized |
| Total number of cars in the train | 18 | 18 |
| - compartment | 15 | 15 |
| - bedrooms | 3 | 3 |
| Number of seats in the carriage: | | |
| - compartment | 38 | 38 |
| - bedroom | 19 | 19 |
| Tare mass of the wagon, i.e.: | | |
| - compartment | 56 | 54.5 |
| - bedroom | 56 | 54.5 |
| Mass of the passenger with luggage, kg | 100 | 100 |

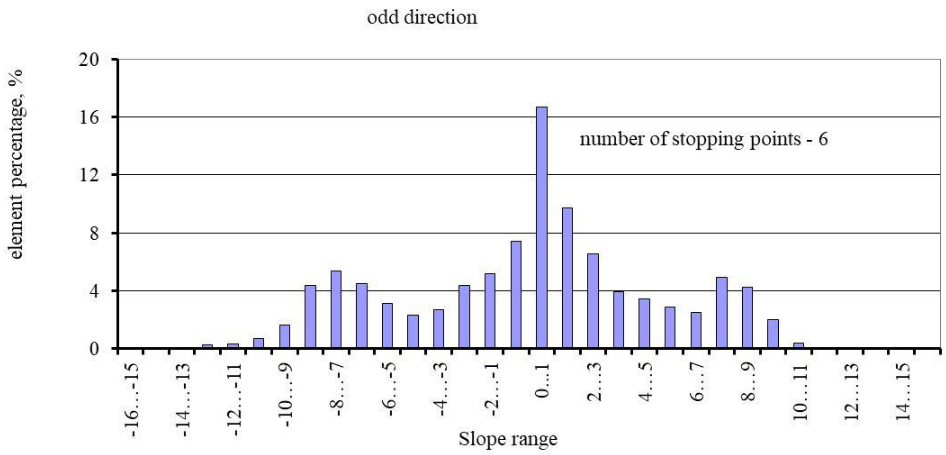

Fig. 15 – Histogram of distribution of site profile elements by slope in an odd direction

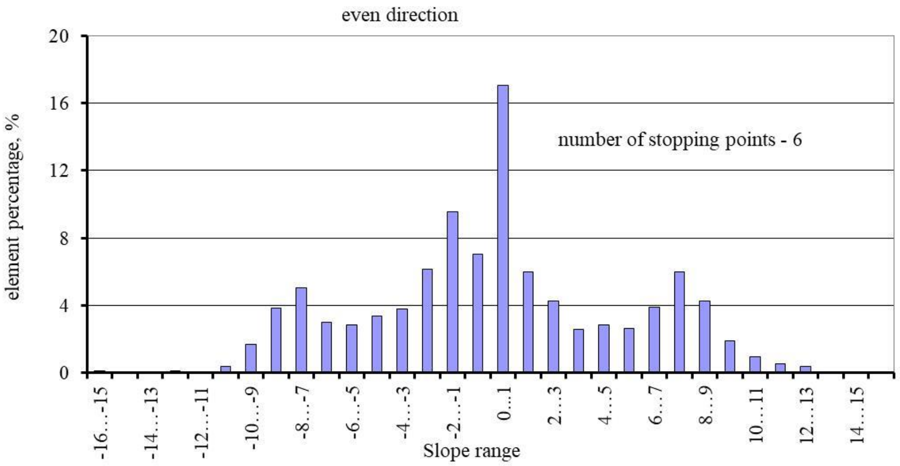

Fig. 16 – Histogram of distribution of site profile elements by slope in even direction

The average population of a car of a passenger train is determined by the formula

$$P_{\text{н}} = \frac{n_{c.c} \times M_{c.c} + n_{s.c} \times M_{s.c}}{n_{c.c} + n_{s.c}} \tag{7}$$

where $n_{c.c}$, $n_{s.c}$ – the number of passenger cars in the train, respectively, compartment and sleeping cars, weight.;
$M_{c.c}$, $M_{s.c}$ – the number of seats in the carriage, respectively, compartment and sleeper seats.

The mass of the passenger train is determined by the formula

$$m_c = q_{c.c} \times n_{c.c} + q_{s.c} \times n_{s.c} + \frac{P_{\text{н}} \times m_p}{1000} \times (n_{c.c} + n_{s.c}), \tag{8}$$

where $q_{c.c}$, $q_{s.c}$ – tare weight of the carriage, respectively, compartment and sleeper, i.e.;
$m_p$ – mass of the passenger with luggage, kg

Tables 5 and 6 show the results of the calculation of the initial data for carrying out traction calculations according to the variants of passenger cars and types of locomotive traction.

*Table 5.* **Results of calculation of raw data for carrying out traction calculations for variants of passenger cars with diesel traction**

| Characteristic | Odd direction | | Even direction | |
|---|---|---|---|---|
| | base car | modernized car | base car | modernized car |
| Mass of the locomotive, i.e. | 130 | 130 | 130 | 130 |
| Number of cars in the train: | 18 | 18 | 18 | 18 |
| - compartment | 15 | 15 | 15 | 15 |
| - bedrooms | 3 | 3 | 3 | 3 |
| Tare mass of the car, i.e.: | | | | |
| - compartment | 56 | 54.5 | 56 | 54.5 |
| - bedroom | 56 | 54.5 | 56 | 54.5 |
| Number of seats in the carriage: | | | | |
| - compartment | 38 | 38 | 38 | 38 |
| - bedroom | 19 | 19 | 19 | 19 |
| Mass of the passenger with luggage, kg | 100 | 100 | 100 | 100 |
| The average population of the car, pas. | 34.8 | 34.8 | 34.8 | 34.8 |
| Mass of the composition, i.e. | 1071 | 1044 | 1071 | 1044 |
| Mass of the train, i.e. | 1197 | 1170 | 1197 | 1170 |
| Technical speed on interstation sections, km/h. | in table 2 | in table 2 | in table 3 | in table 3 |
| Interstation distance, km. | in table 2 | in table 2 | in table 3 | in table 3 |

*Table 6.* **Results of calculation of raw data for carrying out traction calculations for variants of passenger cars with electric locomotive traction**

| Characteristic | Odd direction | | Even direction | |
|---|---|---|---|---|
| | base car | modernized car | base car | modernized car |
| Mass of the locomotive, i.e. | 126 | 126 | 126 | 126 |
| Number of cars in the train: | 18 | 18 | 18 | 18 |
| - compartment | 15 | 15 | 15 | 15 |
| - bedrooms | 3 | 3 | 3 | 3 |
| Tare mass of the wagon, i.e.: | | | | |
| - compartment | 56 | 54.5 | 56 | 54.5 |
| - bedroom | 56 | 54.5 | 56 | 54.5 |
| Number of seats in the carriage: | | | | |
| - compartment | 38 | 38 | 38 | 38 |
| - bedroom | 19 | 19 | 19 | 19 |
| Mass of the passenger with luggage, kg | 100 | 100 | 100 | 100 |
| The average population of the train, pas. | 34.8 | 34.8 | 34.8 | 34.8 |
| Mass of the composition, i.e. | 1071 | 1044 | 1071 | 1044 |
| Mass of the train, i.e. | 1197 | 1170 | 1197 | 1170 |
| Technical speed on interstation sections, km/h. | in table 2 | in table 2 | in table 3 | in table 3 |
| Interstation distance, km. | in table 2 | in table 2 | in table 3 | in table 3 |

The results of the traction calculation according to the variants of passenger cars when moving by locomotive traction are shown in Table 7.

*Table 7*. **Results of traction calculation according to variants of passenger cars when moving by diesel traction**

| Characteristic | Variant of the car | |
|---|---|---|
| | base | modernized |
| **Odd direction** | | |
| Freight turnover, tkm . gross | 368960 | 359659 |
| Fuel consumption for traction, kg | 1067.9 | 1055.6 |
| Time on the route, hours | 5.56 | 5.55 |
| Technical speed km/h. | 68.4 | 68.6 |
| District speed km/h. | 61.9 | 62 |
| Precinct speed coefficient | 0.90 | 0.90 |
| Passenger turnover, pass-km | 216008 | 216007.8 |
| Specific fuel consumption per gauge, kg/1000 pass-km | 4.94 | 4.89 |
| **Even direction** | | |
| Freight turnover, tkm . gross | 368960 | 359659 |
| Fuel consumption for traction, kg | 1090.1 | 1077 |
| Time on the route, hours | 5.84 | 5.84 |
| Specific fuel consumption per meter, kg/10 $^{4}$ tkm _ gross | 29.5 | 29.9 |
| Technical speed km/h. | 64.2 | 64.3 |
| District speed km/h. | 58.9 | 59 |
| Precinct speed coefficient | 0.92 | 0.92 |
| Passenger turnover, pass-km | 216008 | 216007.8 |
| Specific fuel consumption per gauge, kg/1000 pass-km | 5.05 | 4.99 |
| **Average turnover** | | |
| Mass of the composition, t | 1071 | 1044 |
| Freight turnover, tkm . gross | 737920.5 | 719318.0 |
| Mileage of the train, train - km | 689.2 | 689.2 |
| Time on the route, hours | 11.40 | 11.39 |
| Technical speed km/h. | 65.95 | 66.02 |
| District speed km/h. | 60.46 | 60,51 |
| Precinct speed coefficient | 0.917 | 0.917 |
| Fuel consumption for traction, kg | 2158.0 | 2132.6 |
| Passenger turnover, pass-km | 432016 | 432016 |
| Specific fuel consumption per gauge, kg/1000 pass-km | 5.00 | 4.94 |

The results of the traction calculation according to the variants of passenger cars when moved by electric traction are shown in Table 8.

*Table 8.* **Results of traction calculation according to variants of passenger cars when moving by electric traction**

| Characteristic | Variant of the wagon | |
|---|---|---|
| | base | modernized |
| **Odd direction** | | |
| Freight turnover, tkm . gross | 368960 | 359659 |
| Electricity consumption for traction, kWh. | 7898.4 | 7403.4 |
| Time on the route, hours | 5.54 | 5.53 |
| Technical speed km/h. | 67.9 | 68.1 |
| District speed km/h. | 62.2 | 62.3 |
| Precinct speed coefficient | 0.92 | 0.91 |
| Passenger turnover, pass-km | 216008 | 216008 |
| Specific consumption of electrical energy per meter, kWh/1000 pass-km | 36,57 | 34,27 |
| **Even direction** | | |
| Freight turnover, tkm . gross | 368960 | 35965 9 |
| Electricity consumption for traction, kWh. | 8171.3 | 7632.5 |
| Time on the route, hours | 5.76 | 5.76 |
| Technical speed km/h. | 65.3 | 65.3 |
| District speed km/h. | 59.9 | 59.8 |
| Precinct speed coefficient | 0.92 | 0.92 |
| Passenger turnover, pass-km | 216008 | 216008 |
| Specific consumption of electrical energy per meter, kWh/1000 pass-km | 37.83 | 35,33 |
| **Average turnover** | | |
| Mass of the composition, t | 1071 | 1044 |
| Freight turnover, tkm . gross | 737920.5 | 719317.5 |
| Mileage of the train, train - km | 689.2 | 689.2 |
| Time on the route, hours | 11.30 | 11.29 |
| Technical speed km/h. | 66.59 | 66.65 |
| District speed km/h. | 60.99 | 61.05 |
| Precinct speed coefficient | 0.916 | 0.916 |
| Electricity consumption for traction, kWh. | 16069.7 | 15035.9 |
| Passenger turnover, pass-km | 432016 | 432016 |
| Specific consumption of electrical energy per meter, kWh/1000 pass-km | 37.20 | 34.80 |

Using the results of traction calculations, we will determine the consumption of energy resources by diesel and electric traction along the entire route of the passenger train according to the variants of cars. For this, the distance of service of the route by diesel and electric traction, which is given in table 9, should be taken into account.

*Table 9.* **Distance of service of the route by locomotive and electric traction**

| Characteristic | Odd direction | Even direction | Together |
|---|---|---|---|
| The distance of service of the route by locomotive traction, km | 155.6 | 155.6 | 311.2 |
| The distance of service of the route by electric traction, km | 333.4 | 333.4 | 666.8 |
| Together | 489 | 489 | 978 |

The results of calculating the consumption of energy resources by types of traction are shown in tables 10 and 11.

*Table 10.* **Results of calculation of fuel consumption by locomotive traction for moving a passenger train by wagon variants**

| Characteristic | Variant of the car | |
|---|---|---|
| | base | modernized |
| **Odd route direction** | | |
| The distance of service of the route by locomotive traction, km | 155.6 | 155.6 |
| Mass of the composition, t | 1071 | 1044 |
| Passenger turnover, pass-km | 97561.2 | 97561.2 |
| Technical speed km/h. | 68.4 | 68.6 |
| Specific fuel consumption per gauge, kg/1000 pass-km | 4.94 | 4.89 |
| Fuel consumption for traction, kg | 482 | 477 |
| **Even direction of the route** | | |
| The distance of service of the route by locomotive traction, km | 155.6 | 155.6 |
| Mass of the composition, t | 1071 | 1044 |
| Passenger turnover, pass-km | 97561.2 | 97561.2 |
| Technical speed km/h. | 64.2 | 64.3 |
| Specific fuel consumption per gauge, kg/1000 pass-km | 5.05 | 4.99 |
| Fuel consumption for traction, kg | 492 | 486 |
| **On average per revolution of the locomotive** | | |
| The distance of service of the flight by diesel locomotive, km | 311.2 | 311.2 |
| Mass of the composition, t | 1071 | 1044 |
| Passenger turnover, pass-km | 195122.4 | 195122.4 |
| Fuel consumption for traction, kg | 975 | 963 |

*Table 11.* **Results of calculation of fuel consumption by electric traction for moving a passenger train by car options**

| Characteristic | Variant of the car | |
|---|---|---|
| | base | modernized |
| 1 | 2 | 3 |
| **Odd route direction** | | |
| The distance of service of the route by electric traction, km | 333.4 | 333.4 |
| Mass of the composition, t | 1071 | 1044 |
| Passenger turnover, pass-km | 209041.8 | 209041.8 |
| Technical speed km/h. | 67.9 | 68.1 |
| Specific consumption of electrical energy per meter, kWh/1000 pass-km | 36,57 | 34,27 |
| Electricity consumption for traction, kWh. | 7644 | 7165 |

*Table 11.* **Continued**

| 1 | 2 | 3 |
|---|---|---|
| **Even direction of the route** | | |
| The distance of service of the route by electric traction, km | 333.4 | 333.4 |
| Mass of the composition, t | 1071 | 1044 |
| Passenger turnover, pass-km | 209041.8 | 209041.8 |
| Technical speed km/h. | 65.3 | 65.3 |
| Specific consumption of electrical energy per meter, kWh/1000 pass-km | 37.83 | 35,33 |
| Electricity consumption for traction, kWh. | 7908 | 7386 |
| **On average per revolution of the locomotive** | | |
| The distance of service of the flight by electric traction, km | 666.8 | 666.8 |
| Mass of the composition, t | 1071 | 1044 |
| Passenger turnover, pass-km | 418083.6 | 418083.6 |
| Electricity consumption for traction, kWh. | 15551.5 | 14551.0 |

The saving of energy resources for the traction of a passenger train per flight is determined by the following formulas:

with locomotive traction

$$\Delta \mathrm{G}_{\mathrm{d}} = \mathrm{G}_{\mathrm{d}}^{\mathrm{b}} - \mathrm{G}_{\mathrm{d}}^{\mathrm{m}}, \tag{9}$$

with electric traction

$$\Delta \mathrm{A}_{\mathrm{e}} = \mathrm{A}_{\mathrm{e}}^{\mathrm{b}} - \mathrm{A}_{\mathrm{e}}^{\mathrm{m}}. \tag{10}$$

where $\mathrm{G}_{\text{п}}^{\text{б}}$, $\mathrm{G}_{\mathrm{d}}^{\mathrm{m}}$ is the fuel consumption for traction of a passenger train per flight, respectively, with basic and new cars, kg;

$\mathrm{A}_{\mathrm{e}}^{\mathrm{b}}, \mathrm{A}_{\mathrm{e}}^{\mathrm{m}}$ – electricity consumption for traction of a passenger train per flight, respectively, with basic and new cars, kWh.

According to the schedule of traffic along the route (table 12), we will determine the turnover of the passenger train.

*Table 12.* **Passenger train schedule by route**

| The name of the course route | Time | | |
|---|---|---|---|
| | departure | arrival | on the route, hours |
| A forming station is a turnover station | 22:30 | 6:10 a.m | 7.67 |
| The idle carriage by turnover | | | 16.75 |
| Turnover station-formation station | 22:55 | 6:27 a.m | 7.53 |
| Idle wagon at the home depot | | | 16.05 |
| Turn of the passenger train | | | 48.00 |

The number of turns of a passenger train per year is determined by the formula

$$N_o = \frac{365 \times 24}{O_{p.p}}, \qquad (11)$$

where p.p is passenger train turnover, h.

The annual savings in energy costs for the traction of passenger trains under the conditions of running on a specific route is determined by the following formulas:

with locomotive traction

$$\Delta E_d = \Delta G_d \times N_o \times \text{Ц}_f, \qquad (12)$$

with electric traction

$$\Delta E_e = \Delta A_e \times N_o \times \text{Ц}_e, \qquad (13)$$

where $\text{Ц}_f$, $\text{Ц}_e$– the price, respectively, of the 1st kg of fuel and the 1st kWh. of electricity, UAH

Tables 13 and 14 show the results of determining the annual savings in energy costs for the traction of passenger trains under the conditions of running on a specific route.

*Table 13.* **Results of determining the annual savings in fuel costs for the traction of passenger trains under the conditions of running on a specific route**

| Characteristic | indicator value |
|---|---|
| The number of passenger train turnovers per year | 182.5 |
| Economy of fuel consumption for traction per flight, kg. | 11 |
| Annual saving of fuel consumption for traction along the route, kg | 2094 |
| The price of 1 kg of fuel, UAH. | 58.43 |
| Annual savings in fuel costs for traction, thousand hryvnias. | 122,332 |

*Table 14.* **Results of determining the annual savings in electricity costs for the traction of passenger trains under the conditions of running on a specific route**

| Characteristic | indicator value |
|---|---|
| The number of passenger train turnovers per year | 182.5 |
| Savings in power consumption for traction per flight, kWh. | 1000.5 |
| Annual savings in electricity consumption for traction along the route, kWh. | 182584 |
| The price of 1 kWh. of electricity, UAH | 4.6 |
| Annual savings in electricity costs for traction, thousand UAH. | 839,887 |

Thus, the annual saving of energy costs for the traction of passenger trains when using passenger cars with a reduced tare weight under the conditions of running on a specific route is

$$\Delta E = 122{,}332 + 839{,}887 = 962{,}219 \text{ thousand UAH.}$$

**Conclusions.** According to the results of statistical processing the results of the metal structures of compartment cars bodies technical condition and open-type cars that have already exhausted their resource it was determined that the lower strapping (more than 7 mm, 50% of the nominal size), the roof slope (more than 2 mm, 35% of the nominal size), and the lower part of the side wall (over 2 mm, 42% of the nominal size)..

It is proposed to carry out modernization of the bodies of passenger cars by replacing the steel sheet and rolled metal with aluminum alloy in the above-mentioned places during capital renovations. This makes it possible to reduce the tare weight of the car and the consumption of fuel and electricity for train traction.

During the calculations, it was considered that for the movement of passenger trains, the TEP70 series diesel locomotive is used for diesel traction, and the CHS4 series alternating current electric locomotive is used for electric traction. Annual saving of energy costs for the traction of passenger trains when using passenger cars with a reduced tare weight 962,219 thousand UAH.

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# Визначення ефективності модернізації кузовів пасажирських вагонів

*Пасажирські вагони АТ «Укрзалізниця» практично вичерпали свій ресурс. Підвищення ефективності роботи залізниць вимагає використання нових інноваційних технічних рішень. У статті проаналізовано технічний стан кузовів пасажирських вагонів, які відпрацювали свій ресурс. Всього перевірено 540 вагонів різних років побудови. У ході аналізу результатів перевірок товщини металоконструкцій вагонів були розділені на п'ять умовних груп залежно від терміну служби. При цьому порівнювалися номінальні значення товщин елементів конструкції автомобіля та фактичні значення. Встановлено, що найбільше спрацювання знос мають нижня обшивка, скат даху та нижня частина бічної стінки. Для модернізації кузовів пасажирських вагонів пропонується використовувати алюмінієві сплави. Перевагою такого технічного рішення є підвищення корозійної стійкості кузова, підвищення довговічності та зменшення вагу тари вагону. Зменшення тари дозволяє зменшити питомий опір руху поїзда та витрати палива та електроенергії на тягу поїзда. Для зниження експлуатаційних витрат з використанням основних положень теорії локомотивної тяги проведено розрахунки визначення енерговитрат* *на рух пасажирського поїзда за профільними умовами реальної ділянки регіональної філії Південна залізниця дизель- та електричною локомотивною тяги з базовим та модернізованим варіантом пасажирських вагонів. Встановлено, що річна економія енерговитрат на тягу пасажирських поїздів при використанні пасажирських вагонів зі зниженою тарою становить близько 1 млн. грн.*

***Ключові слова:*** *пасажирський вагон, кузов, ресурс, знос, модернізація, економічний ефект/*