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THE TECHNICAL ASSESSMENT OF THE LEVEL OF INNOVATIVE TRACTION TRANSMISSION OF RAILWAY VEHICLE

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Abstract

The article deals with the development of an innovative model of traction transmissions of railway vehicles with a higher technical level, which allows to eliminate the existing shortcomings of the mechanical system, simplify the repair processes and reduce the cost, and evaluate its technical level. By reducing the overall dimensions and weight of the mechanical system, increasing reliability due to equal distribution of the load and shortening the power arm, as well as reducing the number of structural elements, increasing the useful work coefficient due to the reduction of the mass of double sliding pads and rotating parts, saving electricity and thereby improving the technical level of rail transport. Traction transmissions consisting of an innovative reducer are offered that ensure the increase.

The technical level of the proposed dart transmission is determined based on three compatibility parameters with a creative approach. Compatibility parameters are determined according to the minimum value of the geometric dimensions characterizing the mass of the mechanical system, the maximum value of the useful work coefficient characterizing economic efficiency, as well as the maximum values of the degree of reliability characterizing safety. The technical level of the proposed project transmitter is determined and compared with existing buildings, its technical and economic advantages are highlighted. As a result of the application of the proposed innovative reducers in the traction drives of railway vehicles, the basis is created for reducing the cost and maintenance costs of traction vehicles, increasing the level of traffic safety, as well as improving the traction and braking characteristics.

Keywords: railway, train, locomotive, transport, model, innovative, reducer, reliability, efficiency, optimal.

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1. Introduction

In modern conditions, the main issue facing railway engineers is the issue of improving the quality indicators of railway transport, which means raising the technical level of vehicles, increasing economic efficiency, reliability, etc. depends on such factors [1]. Optimization criteria that take into account the interaction of rough transmission quality indicators should be selected based on the principle of a fundamental approach to the improvement of these factors. In other words, it is about creating a brake transmission model that provides maximum performance and reliability, is economical in terms of costs and operating costs, with minimum material consumption and minimum overall dimensions. However, this goal cannot be easily achieved, since in order to create a mechanism and a machine, it is necessary to coordinate a set of new effective technical solutions and inventions. This requires the analysis and synthesis of numerous options for technical solutions. Thus, the formation of a new transmission model and the programming of the search process are closely related to the formation and solution of technical creativity. One of the main requirements for trains today is acceleration. So, although it is possible to increase the power in terms of engine capability, transmission mechanism, coefficient of inertia of rotating parts, friction coefficient, etc. such factors should complete the question. Similarly, the same can be said about the braking force [2].

The study of vehicle traction transmissions shows that the acceleration time during acceleration and deceleration of the train can be reduced by increasing the technical level of traction transmission. One of the main factors influencing the improvement of the technical level is the reduction of the inertia coefficient of the rotating parts.

The improvement of the indicators characterizing the technical level mentioned above will make it possible to obtain certain advantages in the design and technological characteristics of the friction gear.

The main condition for achieving the proposed technical solution is to determine the shortcomings of existing structures as a result of studying various types of traction gears used in railway vehicles, collecting statistics of failures that occurred in traction vehicles, and identifying structural defects in traction gears used. in new generation vehicles, detection of their presence, allowing them to be eliminated, simplification of repair processes by reducing the overall dimensions and reducing the weight of the mechanical system and a new design that reduces the cost, increases reliability due to even distribution of the load and shortens the power arm, saves electricity by increasing the efficiency due to double sliding shoes, and also provides an increase in the technical level of vehicles. reducer type AN with effective design.

Package-type «AN» reducers developed at the «Mechatronics and machine design» department of Azerbaijan Technical University and applied in some fields of production (for example, in the field of oil production) can be considered the last achievement of scientific progress in the field of reducers [3–5].

The advantages that innovative traction transmission have in comparison with traditional gearboxes (minimum price of dimensions and weight, simplicity of production processes, a small number of organizers, high reliability, etc.) are the basis for the fact that their use in traction drives of railway vehicles will improve-economic efficiency of vehicles.

Since the twin-shaft spur traction transmission of the «AN» package type are the gearboxes of a new generation, although a number of issues related to their design and operational characteristics have been resolved, insufficient research has been carried out on them in terms of design, technology, and operation.

Reducers in general, their main functional and structural elements, gears, their designs and reliability were studied by a number of research scientists in different parts of the world at different times [6, 7].

Prominent scientists of Azerbaijan devoted their research work to the development of gearboxes, including package gearboxes of a new generation [8, 9].

It is known that, as in other machines, the main requirement for the functional chains of railway vehicles and their interacting parts is that they can reliably perform their functions against friction and wear. Well-known scientists who have studied the problems of friction and corrosion of machine parts and are devoted to large-scale studies of traction transmission elements, solving contact problems and increasing the corrosion resistance of parts [10].

Many questions have been resolved by conducting research in several directions regarding the AN package type traction transmission of the proposed innovative traction drive [11, 12].

Although much research has been devoted to the design of traction transmission and their elements and friction units, since AN package type gearboxes are innovative gearboxes, it is necessary to conduct large-scale studies and deepen their design and technical characteristics and capabilities, taking into account their application. With a high degree of probability, it is possible to assume that the weakest point limiting the reliability of innovative AN gearboxes is the increase in radial clearances between their nodes of double friction linings, their contact surfaces due to their wear. Therefore, it is very important to investigate the conditions of friction, wear in the functional friction units of package gearboxes, and improve their reliability.

The following tasks on friction units of package reducers have been solved [13]:

– friction torque and friction coefficient are set;

– a detailed report of hydrodynamic sliding pads in package reducers is given and theoretically substantiated;

– losses in double friction pads were estimated, analytical expression was obtained to calculate useful work factor etc.

One of the most important requirements of modern science and technology is that each designed and operated technical facility has optimal design parameters and performance indicators. The most decisive difference between package gearboxes and traditional gearboxes is that all stages have the same center distance (**Fig. 2, *b***). In multi-stage gearboxes of the «AN» package type, its value is doubled, since only one center distance is accepted. Therefore, in these gearboxes, the distribution of the total gear ratio over the steps, especially the gear ratio of the last low-speed stage, serves as the basis for ensuring the optimal design. So, the optimization of the distribution of the total number of gears between stages in multistage package gearboxes has the status of the most important problem [14–16].

Recently, extensive research has been carried out to optimize the distribution of the total number of gears between the stages in order to ensure equal strength and compactness of the transmission of multi-stage gearboxes. Famous scientists and other studies, in this direction the results are of particular importance. It can be noted without exaggeration that the modern, high level of development of the production of multistage gearboxes, their standardization became possible on the basis of the results obtained by these researchers [17, 18].

In the modern era, research work continues to optimize the designs of gearboxes and gear couplings in a wide range, with increased accuracy, using modern programs (for example, a genetic algorithm, an evolutionary algorithm, a simulation algorithm, etc.). Especially deserve attention research works [19–23].

Optimization of gearboxes was mainly carried out according to the following criteria:

– minimum sum of intercenter distances;

– minimum mass of the gearbox, mass of the gear;

– equality of strength in contact and bending stresses;

– minimization of angular errors;

– minimum input moment of inertia of the system;

– maximum physical working ratio etc.

Also have been resolved problems with optimization, increasing the load capacity of the mechanical system, reducing noise in gearboxes such etc.

Using the broad capabilities of modern computer programs, proposals were made by the researchers about the traction transmissions of railway vehicles and their dynamic characteristics, as well as many issues involving maintenance and repair processes in general. These mainly consist of identifying problems in time, optimizing solutions, increasing forecast accuracy, changing internal and external factors, and others [24–26]. The main goal of this research is the acknowledgement of reduction of the consumption indicator as the most optimal method based on the basic solution principles, which allows to improve the technical characteristics of the railway vehicle in order to fundamentally solve the problem. This issue is resolved by performing the following tasks:

– investigating the possibilities of applying an innovative reducer to the traction transmission of railway vehicles;

– evaluation of the technical level of the innovative traction transmission on the criteria of safety (reliability), economic efficiency (coefficient of performance) and performance (torque moment);

– comparative analysis of the innovative traction transmission with the existing mechanical system, etc.

2. Materials and Methods

2. 1. Development of an innovative traction transmission

A number of advantages of innovative gearboxes, a very compact design, low material consumption, a high coefficient of physical work, high speed, as well as functional and economic advantages form the basis for the study of their application in railway traction transmissions.

To do this, it is necessary to determine the compatibility parameters by investigating the possibility of using innovative package-type AN gearboxes in railway vehicles.

Compatibility options are defined by:

1. Geometric dimensions – $H \rightarrow \min$ (characterizes the mass. It directly affects the yeast cost and performance indicators).

2. Useful work coefficient – $\eta \rightarrow \max$ (characterizes energy costs and forms the basis of operating costs).

3. Reliability degree – $Q \rightarrow \max$ (characterizes indicators such as reliable operation, repairability, longevity and economic viability.

These compatibility parameters determine the triangle rule of the technical level of the considered mechanical system and can be used in the future to find the optimal value of all three parameters based on a systematic approach. The interrelationship of three interdependent parameters is shown in the form of a triangle to assess the technical level **(Fig. 1).**

Let's consider the kinematics of traction transmission of electric trains from modern railway vehicles in order to determine the parameters of compliance with the geometric dimensions of the technical level of traction transmission. In the traction transmission of modern electric trains, a gearbox is used, consisting of a one-sided two-stage gear transmission. A connecting element of large diameter is installed in the central part of the wheelset shaft, which limits the reduction in the distance between the centers and makes transmission possible only with the help of an intermediate shaft (**Fig. 2, *a***) [27].

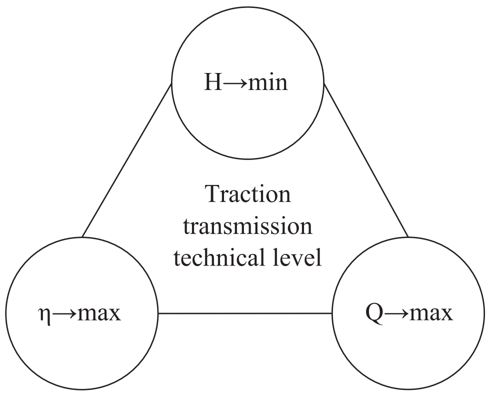
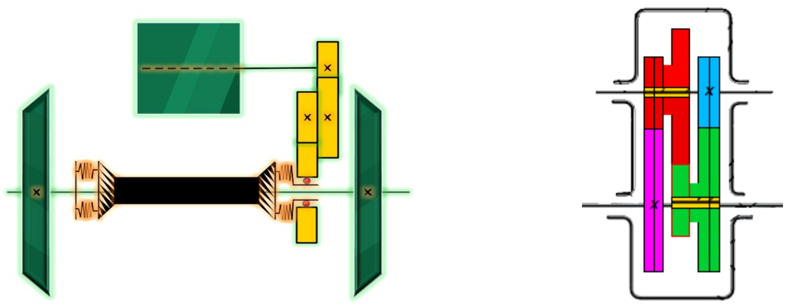


Fig. 1. Triangle technical level traction transmission



a *b*

Fig. 2. Traction transmissions of railway vehicles: *a* – existing; *b* – innovative

2. 2. Score on the first matching parameter: *H*→min

Based on the data in **Table 1**, let's calculate the geometric dimensions of the elements of the AN gearboxes of the «package» type.

Calculation of center distance. Calculate the minimum value of the center distance for spur gears as follows:

$$A_{w\min} = 0.5(d_m + d_{vdç}) + \Delta = 0.5(510+197)+30 = 383.5 \text{ mm}. \quad (1)$$

Table 1
Input parameters of the first boundary condition

Parameter	Express	Price
Engine power, kW	N	500
Shaft speed, cycle/min	n	2074
Module, mm	m	8
Transmission number	u	5.771
External diameter of the engine, mm	d_m	510
Diameter of the hub part of the wheel pair shaft, mm	$d_{v\max}$	230
Diameter of the part of the wheel pair shaft on which the gear wheel is mounted, mm	$d_{vdç}$	197
The minimum distance between the engine and the wheel pair shaft, mm	Δ	30

Let's take the value of the center distance equal to 385 mm.

Calculate the minimum diameter of the drive gear:

$$d_{1\min} = d_{v\max} + S = 230 + 20 = 250 \text{ mm}.$$

Here $S = 2.2$ m$+0.05 \cdot b = 2.2 \cdot 8 + 0.05 \cdot 12.5 = 18.23$ mm is the thickness of the rack.

Let's take $S = 20$ mm.

Let's determine the geometric dimensions of the gears and the number of teeth from the condition of the minimum values of the center distance and the diameter of the small gear:

$$d_2 = u_1 \cdot d_1,\ 0.5(d_1 + d_2) = a_w.$$

If in expression (3) let's substitute the values of the center distance and the number of gears, then:

$$d_2 = 1.793 \cdot d_1,\ 0.5(d_1 + d_2) = 385 \text{ mm}.$$

If to solve the resulting system of simple equations, let's obtain the following values:

$$d_1 = 275.9 \text{ mm},\ d_2 = 494.01 \text{ mm};$$

$$Z_1 = \frac{d_1}{m} = \frac{275.9}{8} = 34.5;\ Z_2 = \frac{d_2}{m} = \frac{494.01}{8} = 61.75;$$

$$Z_1 = 35;\ Z_2 = 62 \text{ accept}.$$

Let's determine the actual values of the diameters and center distances of the gears and the actual gear ratio:

$$d_1 = m \cdot Z_1 = 8 \cdot 35 = 280 \text{ mm},\ d_2 = m \cdot Z_2 = 8 \cdot 62 = 496 \text{ mm}, \quad (4)$$

$$a_w = \frac{d_1 + d_2}{2} = \frac{280 + 496}{2} = 388 \text{ mm}.$$

The actual value of the transfer number:

$$u_f = \frac{Z_2}{Z_1} = \frac{62}{35} = 1.77.$$

Transfer number error:

$$\Delta u = \pm \frac{u_f - u_1}{u_1} = \frac{1.771 - 1.793}{1.771} \cdot 100\,\% = -1.24\,\%.$$

Specify the price of the module:

$$m = \frac{2 \cdot a_w \cdot \cos\beta}{\sum Z} = \frac{2 \cdot 388 \cdot 1}{97} = 8.$$

The report results of the geometric dimensions of the reducer of the innovative traction transmission are given in **Table 2**.

Table 2
The resulting parameters of the first boundary condition

Parameter	Express	Price
Small gear diameter, mm	d_1	280
The minimum diameter of a small gear wheel, mm	$d_{1\min}$	250
Big gear diameter, mm	d_2	496
Gear width of the most loaded stage, mm	b	40
Number of steps	n	3
Number of sides	k	2
Total Width Ratio	y_{tot}	0.25
Minimum value of center distance, mm	$a_{w\min}$	383.5
Distance between centers, mm	a_w	388
Center distance reduction, %	$a_w = \frac{a_{wmdi} - a_{widi}}{a_{wmidi}} \cdot 100\,\% = 21.6\,\%$	

2. 3. Evaluation by the second parameter of correspondence: η→max

The evaluation of the second compatibility parameter characterizes the economic efficiency of dart transfer and is one side of the triangle of technical level. The main criterion for the economic efficiency of a new designed traction transmission is to increase labor productivity, and the ultimate goal is to save labor intensity, which is reflected in a significant reduction in the cost and operating costs of this mechanism. Energy costs form the basis of operating costs and determine the efficiency of the traction drive. Therefore, the minimum cost of electricity is taken as a more objective economic indicator. As it is already mentioned, electricity costs form the basis of operating costs and are characterized by the efficiency of the traction transmission. Thus, the second evaluation parameter of the technical level of traction transmission is calculated as follows [28]:

$$E_x = t_0 N_0 \cdot C_0 \left(1 - \eta\right) \frac{P}{\eta} \frac{1}{K_a}, \tag{5}$$

where $t_0 = k_{il} \cdot T = 0.73 \cdot 8760 = 6395$ hours working time of the tract transmission in one year; $T = 8760$ hours number of hours in a year; k_{il} – utilization factor of the year, take $k_{il} = 0.73$; N_0 – number 60 of dart passes being compared; $C_0 = 0.076$ price of 1 kW/h of electricity; $P = R_{e\eta k}$ – power on the traction motor shaft; K_{xa} – the average value of the reduction coefficient:

$$K_{xa} = \frac{1}{E_N \sum\limits_{t=1/E_N}^{t=0} \frac{1}{1 + E_N}} = 1.25, \tag{6}$$

t – the time from the start of operation to the present; E_N – normative coefficient of additional capital investments.

A comparison was made of the efficiency of work and energy consumption of the traction transmission mechanism:

$$\eta_m = \eta_{dc}^4 \cdot \eta_{dy}^6 = 0.98^4 \cdot 0.99^6 = 0.86,$$

$$\eta_{yki} = \eta_{dc}^{6} \cdot \eta_{dy}^{4}\left(1+\gamma+M\right) = 0.98^{6} \cdot 0.99^{4}\left(1+0.0459+0.041\right) = 0.899,$$

$$M_{\eta} = \left(1-\frac{\eta_{mdi}}{\eta_{idi}}\right) \cdot 100\,\% = \left(1-\frac{0.86}{0.899}\right) \cdot 100 = 4.34\,\%.$$

Here, η_{mdi} and η_{idi} are the useful work coefficients of existing and proposed traction transmissions; $\gamma = 0.0459$ – a coefficient that takes into account the effect of lubrication in double sliding bearings [28, 29]; M – a coefficient that takes into account the reduction of the mass of the rotating parts of the draft transmission [30].

E_{xmdi} and E_{xidi} – energy costs when using existing and proposed innovative dart transmission:

$$E_{xmidi} = t_0 N_0 \cdot C_0\left(I-\eta\right)\frac{P}{\eta} \cdot \frac{1}{K_{np}} = 6395 \cdot 60 \cdot 0.076 \cdot \left(1-0.86\right) \cdot \frac{500}{0.86} \cdot \frac{1}{1.25} = 1898869, \text{ man;}$$

$$E_{xmidi} = t_0 N_0 \cdot C_0\left(I-\eta\right)\frac{P}{\eta} \cdot \frac{1}{K_{np}} = 6395 \cdot 60 \cdot 0.076 \cdot \left(1-0.899\right) \cdot \frac{500}{0.899} \cdot \frac{1}{1.25} = 1310469, \text{ man;}$$

$$E_{\%} = \left(1-\frac{E_{xy}}{E_{xm}}\right) \cdot 100\,\% = \left(1-\frac{1310469}{1898869}\eta\right) \cdot 100\,\% = 30.9\,\%.$$

The report results of useful work coefficient indicators of the reducer of the innovative transmission are given in **Table 3**.

Table 3
Organizers of the second compatibility parameter

Parameter	Types of traction transmission	
	Available tract transmission	Innovative tract transmission
Number of gears	4	6
UWF of gear transmissions	0.98	0.98
Number of rolling pads	6	4
UWF of rolling cushions	0.99	0.99
Number of shafts	3	2
Number of sliding pads	–	2
Torque transmitted by the most loaded stage T, Nm	12706	12706
Electric motor power, kW	500	500
Advancement of technical level	–	0.0434
The coefficient that takes into account the co-directional rotation of the gears on the shaft	–	0.0459
The price of 1 sq/h of energy, in manats	0.076272	0.076272
UWF of DFZ	0.86	0.889
Electricity costs	1898869	1310469
Number of sides of transmission	1	2
Electricity savings in transmission, in percent	$E_{\%} = \frac{E_{xmdi} - E_{xidi}}{E_{xmidi}} \cdot 100\,\% = 30.9\,\%$	

2. 4. Evaluation according to the third fit parameter: Confidence level $Q \rightarrow$max

It is known that railway vehicles consist of several functional chains performing different amounts of the same function and different functions. These performance criteria of the functional chain characterize the operation of the DHV as a whole. For this reason, there is a need to improve tract transmissions.

Traction transmission transfers the functional chain to the wheelsets by changing the engine speed through gears.

It is clear that the traction transfer weight is inversely proportional to the stress that can be relieved and directly proportional to the safety factor. It turns out that the value of the safety factor has a significant impact on the cost and operating costs of the traction transmission, depending on the dimensions and weight of the designed traction transmission. The development of innovative traction transmission depends on various factors, such as the shape and size of the surface, the deformation of parts and the accuracy of preparation, the mechanical properties of the material, lubrication, ambient temperature, speed, strengthening of the contact surface, etc. it depends. Taking into account all these factors creates certain difficulties. Therefore, the influence of factors not taken into account when designing the circuit on the performance is taken into account by the safety factors of its individual parts.

As a result, consideration of the operation of the dart gear as a function of several random variables makes it possible to assess the reliability of the gear creates dependencies for determining the characteristic parameters of other parts in terms of the level of reliability of the main critical parts in the gear. Thus, the assessment of the degree of reliability of the functional circuit makes it possible to predict the degree of reliability of railway transport as a whole and to refine the efficiency factor.

Ensuring the maximum value of the degree of reliability, and at the same time, the minimum value of the safety margin must occur under conditions:

$$\inf \overline{S} \Leftarrow \overline{S} Q(t) \Rightarrow Sup Q(t),$$

$$Q_1(t) = Q_2(t) = \ldots = Q_i(t) = \ldots = Q_n(t) \Rightarrow \sup Q(t).$$

Here $Q_i(t)$ is the probability of failure of the parts of the dart transfer, in other words, the reliability of the parts.

The safety factors of the structural elements of the traction transmission must be consistent with each other and approach the lower limit:

$$S_1 \Leftrightarrow S_2 \Leftrightarrow \ldots S_i \Leftrightarrow \ldots \Leftrightarrow S_n \Leftrightarrow \inf S = 1.$$

Here S_i is the strong reserve coefficient of the functional chain.

The reliability of thrust transmissions is formed from the values of the reliability coefficients of the individual structural elements that make them up:

$$R = R_1 \cdot R_2 \cdot R_3 \cdot \ldots \cdot R_n = \prod_{k=1}^{n} R_i, \tag{7}$$

$$R_{mdi} = R_1^4 \cdot R_2^3 \cdot R_3^6 = 0.99^4 \cdot 0.995^3 \cdot 0.9^6 = 0.5016,$$

$$R_{idi} = R_1^6 \cdot R_2^2 \cdot R_3^4 = 0.99^6 \cdot 0.995^2 \cdot 0.9^4 = 0.5453,$$

$$R_{\%} = \frac{R_{idi} - R_{mdi}}{R_{mdi}} = \frac{0.5453 - 0.5016}{0.5016} = 100 = 8.7\ \%.$$

The report results of the reliability indicators of the reducer of the innovative transmission are given in **Table 4**.

The reliability of the existing draft transmissions, their transmission mechanism, reliability coefficients, as well as the reliability of innovative draft transmissions is formed from the values of the reliability coefficients of the separate structural elements that make them up.

Thus, the low reliability of the draft transmission not only reduces production, but also increases the number of repairs, which in turn leads to high maintenance costs. In many cases, the repair costs of the transmission exceed their production costs several times. From the comparison of the existing and innovative dart transmissions, it can be seen that the reliability has increased up to 9 %, which is an indicator of the technical level of the transmission.

Table 4
Organizers of the third compatibility parameter

Characteristic parameters	Types of traction transmission	
	Available tract transmission	Available tract transmission
Number of gears	4	6
Number of shafts	3	2
Number of rolling pads	6	4
Number of sliding pads	0	2
The degree of reliability of gear transmissions, Q_1	0.99	0.99
The degree of reliability of shafts, Q_2	0.995	0.995
Reliability rating of rolling bearings, Q_3	0.9	0.9
Reliability rating of anti-roll bars, Q_4	0.95	0.95
Confidence level of the dart functional chain, $Q(t)$	0.5016	0,5453
Increase in the degree of reliability of the dart functional chain, in percent	$Q=\frac{Q_n-Q_c}{Q_C}\cdot 100\ \% = 8.7\ \%$	

3. Results and discussion

3. 1. Advantages and technical level of innovative traction transfer

One of the main economic indicators of the traction transmission and the parts included in its composition is the achievement of a reduction in material consumption without changing the performance characteristics. To assess the technical level of machines and mechanisms of the same functional purpose, a quantitative parameter is used that reflects the ratio of the funds spent to the result obtained. As an objective measure of the funds spent, the mass of structural elements of the mechanical system is taken, which practically reflects the savings throughout the entire project process. As a result, a moment is taken that characterizes the bearing capacity of the mechanical system, the efficiency characterizes the efficiency, and the degree of reliability characterizes safety. It is known that the technical level of a mechanical system increases as the «result» per unit of flow (mass) (torque, efficiency and reliability) increases. High technical, economic and operational performance of railway vehicles, corresponding to samples with record performance, require parallel provision of their mechanical part with innovative devices and equipment. At the same time, high performance, reliability, manufacturability, maintainability, minimum dimensions and weight, ease of operation, as well as technical aesthetics and ergonomics are the most important factors of these mechanical systems.

In recent years, great changes have taken place in this area, all parametric standards have been developed, calculations have been improved and refined in order to ensure scientific and methodological unity in the rationalization of machines and units for various purposes and the choice of their parameters; standards for methods of their calculation have been developed; a new generation of machines and mechanisms used in some areas of mechanical engineering has been created, the main parameters of their carrying capacity have been unified; The design of the main transmission mechanisms has been significantly changed.

To do this, the cost reduction is justified by comparing the material consumption and overall dimensions of the proposed innovative traction drive and the existing traction drive. It should be noted that 85 % of the cost of gearboxes depends on the materials used.

3. 2. The main advantages of the innovative traction transmission

When comparing the design solution of the proposed innovative three-stage gearbox for traction transmission of railway transport with the design of the existing transmission mechanism, the following advantages were identified [31, 32]:

– in the proposed gearboxes, one intermediate shaft and one pair of rolling bearings are reduced, which greatly simplifies the design and increases the level of reliability of the mechanical system;

– the proposed gearbox is made on the basis of unified gears and two-crown blocks, depending on the pre-selected number of steps and the total number of gears. This creates favorable conditions for the lubrication of all gears;

– in the proposed transmission mechanism, two-ringed gear blocks assembled on sliding pads rotate in one direction, which significantly reduces the resistance force and increases the efficiency of the mechanical system.

Innovative traction transmission of railway transport, consisting of a three-stage gear mechanism – under the same conditions, the use of the proposed transmission mechanism instead of the existing transmission mechanism of traction transmission of railway transport provides a certain economic and technical advantage by reducing its material capacity.

The mass of the innovative reducer. The main characteristic parameters of the proposed innovative mechanism for the transmission of integral traction of railway vehicles are determined on the sample «TSA 009573». Thus, it is only necessary to determine the mass of the mechanical system with a known value of $T = 12706$ Nm of the torque of the output shaft of the innovative three-stage gear mechanism, that is, the wheelset shaft:

$$M = V\rho\varphi = \frac{\pi}{4}\left(d_{w1}\right)^3 \cdot \left(\psi_{bd}^{\Sigma}\right)\cdot\left(u_{\Sigma}^{k}+1\right)\cdot\rho\varphi, \tag{8}$$

$\psi_{bd}^{\Sigma} = \psi_{bd}^{*} + \psi_{bd2} + \psi_{bd1}$ – the sum of the dimensionless coefficients of the width of the gears; ψ_{bd}^{*}, ψ_{bd2}, ψ_{bd1} – the ratios of the driving gear of the double-crown gear block of the heavy-loaded stage, the next driving gear: $\psi_{bd}^{*} = 0.29 \approx 0.3$, $\psi_{bd2} = 0.2$, $\psi_{bd1} = 0.1$.

Constructively $\psi_{bd}^{\Sigma} = 0.7$ is taken.

At this time, intermediate spaces for cutting tools are also taken into account. $u_{\Sigma}^{k} = 0.1771$; $k = 1/3$ – transmission number of a stage; $p = 7800$ kq/m^3 – density of the material; $\phi = 0.9$ – fill factor; $M/2 = 0.735 \cdot 0.28^3 \cdot 0.7 \cdot 2.271 \cdot 7800 \cdot 0.9 = 219.7$, $M/2 = 219$ kq, mass of one innovative reducer.

3. 3. The technical level of the proposed innovative gear reducer

When the mass of the existing and innovative reducers of the traction transmission is known, let's evaluate the technical level according to the torque as follows:

– the mass of the innovative transfer – 438 kg;

– the mass of the existing reducer is 700 kg [33];

– the technical level of the proposed innovative gear reducer:

$$\gamma = \frac{M}{T}, \tag{9}$$

$$\gamma_{idi} = \frac{M_{idi}}{T_{idi}} = \frac{438}{12706} = 0.0345 \prec 0.06;$$

– current gear reducer technical level:

$$\gamma_{mdi} = \frac{M_{mdi}}{T_{mdi}} = \frac{700}{12706} = 0.0551 \prec 0.06.$$

If to compare the technical level of innovative and current reducers, a 37.4 % advantage is achieved:

$$\gamma = \left(1 - \frac{\gamma_{idi}}{\gamma_{mdi}}\right)\cdot 100 = 37.4\,\%.$$

The resulting product specifications show that the proposed innovative gear mechanism – a three-stage gear reducer located on two shafts – is suitable for record-breaking performance samples. Therefore, it is more efficient from an economic point of view to use a three-stage innovative gearbox located on two shafts in these mechanical systems when repairing, restoring and replacing traction gears of railway vehicles in operation.

The research paper may be considered in future theoretical studies based on the participation or consent of the authors. No negative aspects were detected during the research phase. The proposed reducer can be applied in railway vehicles, metro trains, trams and other rail vehicles.

4. Conclusions

If «package» type AN reducers are applied to traction transmissions of railway vehicles, it is justified to reduce the annual energy consumption by 30.9 % due to the increase of the useful work coefficient characterizing the economic efficiency by 4.54 %.

It is justified to increase the degree of reliability that characterizes safety up to 9 % in the case that AN reducers of the «package» type will be applied to the traction transmissions of railway vehicles.

If «package» type AN reducers are applied to traction transmissions of railway vehicles, it is justified to increase the «technical level» of the transmission by 37.4 % due to the torque characterizing the load-carrying capacity.

Optimality is achieved by reducing the cost of inter-center distance by 21.6 %.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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