THE RESEARCH OF THE ENGINE-REDUCER ASSEMBLY IN THE TRACTION TRANSMİSSİON SYSTEM

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Resume

During the movement of the train in various operational regimes, a series of deficiencies arise in the mechanical components, which depend on kinematic and parametric factors affecting the working conditions of the traction drive. An innovative traction drive is discussed in this article, which prevents the non-uniform distribution of parametric factors, as well as dissipative, inertial, and elastic characteristics along the length of the track.

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1 Introduction

An innovative traction drive is proposed for railway vehicles, comprising a three-stage cylindrical gear transmission that minimizes parametric errors and is symmetrically arranged relative to the wheel pair, based on a detailed analysis of traction drives to eliminate the aforementioned deficiencies. The research was focused on studying the dynamic characteristics of the traction drive, developing a descriptive model, conducting verification calculations for the proposed traction drive, designing the placement scheme of the innovative gearbox, and evaluating the reliability of the proposed traction drive. To enhance the reliability of the traction drive, the selection of the motor-gearbox connection has been examined, and a dual-sided coupling has been deemed appropriate. In the dual-sided transmissions, uneven stress distribution does not occur, which significantly improves the reliability of the traction drive. According to statistical data, design considerations, and some test bench results, it is evident that compared to single-sided transmissions, dual-sided transmissions can improve the reliability of the traction drive by up to 15%. Another indicator is the determination of reliability based on the coefficient of variation and the reliability factor depending on the gear diameter, for which the graphical representations are provided.

Recently, the rapid development of science and technology in the world has necessitated researchers to actively participate in this dynamic progress and constantly create and design new constructions based on innovative thinking. The implementation of the innovative reducer, designed and patented as a result of the scientific activities of the staff of the "Mechatronics and Machine Design" department of the Azerbaijan Technical University [1-3], in various technical fields is of a great importance. A newly designed traction reducer has been developed as an analogue to these reducers, reducing overall dimensions and mechanical system weight to simplify maintenance, lower production costs, and improve the train's technical characteristics, enhancing reliability through even load distribution, shortening the lever arm, and decreasing the number of sequentially connected components and increasing efficiency, while saving electrical energy by minimizing the impact of meshing on the side surfaces of co-rotating gears on the shaft and utilizing double-sliding friction bearings [4].

Traction transmissions have been extensively studied by researchers worldwide, leading to commendable work in the modeling of transmissions and their components. The key outcome of these studies is the identification of issues within the transmission and the clarification of trends in the development of new transmission models.

In [5], the author developed an electromechanical coupling dynamic model by explicitly incorporating electrically induced traction force for railway vehicles to study the impact of traction drives on vehicle vibrations. The dynamic responses of vertical, lateral, and longitudinal accelerations in the axle box and bogie components were quantitatively analyzed.

In the research study [6], an optimized design scheme is proposed to reduce the noise in traction drives under operating conditions. Using the parametric model of the traction drive's gears, a modification plan for both the tooth profile and direction was developed. After the modification, the noise of the gear transmission system was analyzed under various operating conditions using the acoustic boundary element method. Subsequently, an optimal design scheme was obtained by combining the working duration under different conditions with the multi-condition modification parameters of the acoustic indicator.

In the article [7], an electromechanical coupling model for the high-speed trains is proposed. The model considers the interaction of the gear pair, the equivalent coupling mechanism of the transmission system, the equivalent circuit of the traction motor, and the direct torque control strategy. Additionally, the numerical simulation of the high-speed train model includes constant speed, traction, and braking conditions, and the impact on system reliability is analyzed.

A 3D model of the transmission system of the locomotive's traction reducer was created to verify the rationality of its design based on a computer software, and a dynamic model of the transmission system was developed. The model was then integrated into the simulation program, and the obtained simulation values were compared to theoretical values. The results indicate that the simulation outcomes fluctuate around the theoretical values, confirming the superior design of the traction reducer's transmission system [8].

Investigating fatigue damage, the most critical failure in the traction drive of urban railway transport vehicles, it has been determined that the passenger capacity is a crucial factor affecting the dynamic load characteristics of the traction transmission system. Therefore, in this study a dynamic model of the traction drive was developed and numerical simulations were conducted under various speeds and curve radii to analyze the impact of passenger capacity on fatigue life. The research results indicate that the passenger capacity is a significant factor influencing the fatigue life of mechanical components [9].

The safety, comfort, and reliability of traction drives are analyzed by integrating theoretical methods, analysis, numerical simulation, and optimization design theory. In the study [10], the focus was on developing a parameterized gear modification model, rational shape modification schemes, parameter design, dynamic characteristics, vibration response, and the acoustics of gear meshing under high-speed traction conditions.

Authors of [11] proposed innovative traction transmissions consisting of a gearbox that increases reliability by reducing the overall dimensions and weight of the mechanical system, optimizing load distribution, and improving the technical level of the traction drive. This is achieved through a reduction in the number of structural elements and the application of double sliding bearings, which also contribute to energy savings.

The traction transmission of modern STADLER KISS trains was examined in [12] and the impact of the technical level of the traction drive on the train's braking characteristics was discussed. The application of an innovative traction gearbox was proposed that can increase the outcome indicators in line with the unit consumption. The key factors, influencing the braking system, include the reduction of the mass of the proposed traction gearbox, the reduction of the inertia coefficient of rotating parts, and the technical parameters considered in the train's motion equation. Based on the braking distance calculation method, the braking distance is calculated for different speed ranges in a practical example, and it is shown that the braking distance can be reduced by 5%, with a proportional reduction in braking time.

Authors of articles [13] and [14] explored the issue of investigating the factors affecting the operating modes of railway vehicles. By examining the factors influencing the movement of trains, they identified the key solution principles that enable improvements, reduction in consumption indicators, or achieving better results without changing the consumption. The optimal approach based on these principles is the reduction of the mass of rotating parts. The application of an innovative multi-stage gear reducer for traction transmission in railway vehicles is considered, and the operating modes of the trains are studied. The main parameters for traction, braking, and free movement modes of Stadler electric trains are identified.

The traction transmissions of railway vehicles, which are an important component of the transportation industry, were explored in [15]. The structural condition of the main parts of the mechanical system was examined, identifying dynamic events in the functional chain as key factors ensuring the system's longevity. Effective measures for improving system performance, enhancing the operation of structures, and upgrading maintenance and repair technologies are discussed. The importance of evaluating technical quality is substantiated through the development of an innovative model. The current status, design, and operation of modern traction systems are explained.

In study [16] authors investigated the effect of the torsional stiffness of the coupled shafts, couplings, and the machine's working body, as well as the damping capacity of the coupling, on the torsional shock moment generated during the machine's transmission.

To explore the application possibilities of innovative gearboxes, the development trends of traction drives for railway vehicles have been investigated, and 12 key findings have been obtained [17]:

- The issue of developing the required traction drive remains unresolved, which is why frequent structural changes occur in the transmission;
- Traction drives operate in significantly more difficult and especially complex conditions compared to the majority of transmissions in other vehicles;
- Sometimes, production capacity may conflict with operational requirements, and in such cases, operational requirements take precedence, as the technical-economic efficiency of the transmission is determined by the service life and the efficient use of energy resources;
- The traction drive has no reserve, and its failure practically leads to the failure of the train;
- Since the entire useful power flow of the train passes through the traction drive, the transmission must have high efficiency.
- Efforts are made to reduce energy loss, material consumption, and labor intensity during maintenance work;
- Structural and technological solutions are considered appropriate to ensure a high level of standardization and unification of parts and components, as well as their suitability for maintenance and inspection;
- During the production stage of the transmission, a reduction in labor, energy, and material consumption is also required;
- The requirements for the traction drive are primarily operational in nature;
- Typically, only verification calculations are performed during the development of the transmission, as dimensions are determined based on specific alignment conditions rather than project calculations;
- The key outcome for engineers and researchers is conducting effective studies aimed at reducing metal consumption, improving efficiency, and increasing reliability.
- The literature review reveals that the development trends of traction drives, the research results of various authors, as well as the fundamental design, manufacturing, and operational flaws identified during the studies, demonstrate that the investigation of the motor-gearbox connection in traction drives is highly relevant.

The correct structural selection of the motor-gearbox connection would help to solve many problems related to the transmission in the future. To achieve this, the research focuses on the following issues:

Studying the dynamic characteristics of the traction drive and developing a descriptive model;

- Conducting verification calculations for the proposed traction drive;
- Developing the placement scheme of the innovative gearbox;
- Evaluating the reliability of the proposed traction drive.

2 Methods and materials

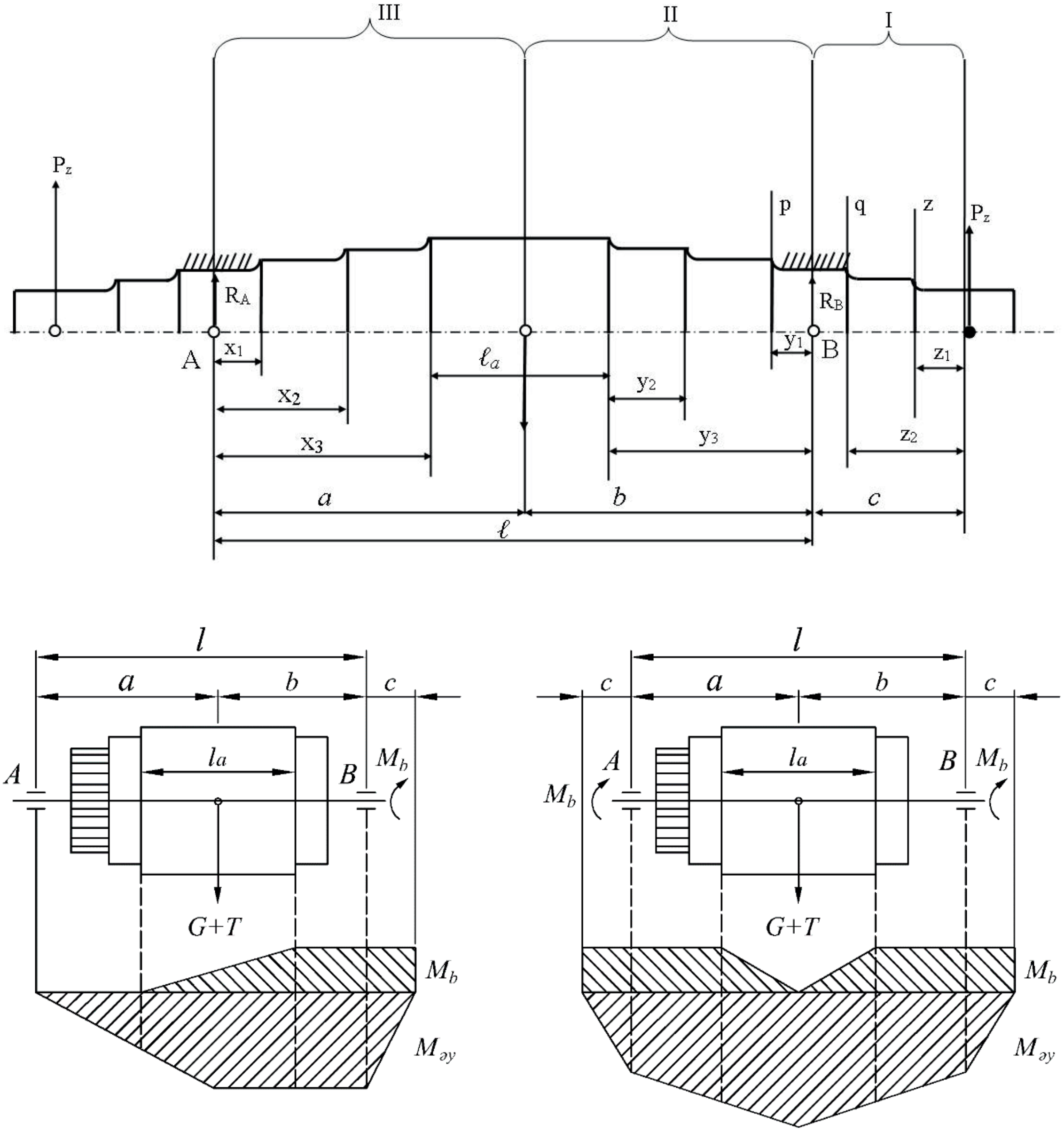
The research was conducted using a heuristic method based on exploration and design. The tasks set forth were solved through theoretical and experimental studies conducted under laboratory and industrial conditions.

2.1 Study of the dynamic characteristics of the traction drive and development of a descriptive model

Like any mechanical system, railway vehicles are affected by numerous excitation factors. These can be classified into two categories: external and internal. External factors are those that are independent of the characteristics of the traction system, while internal factors are those directly related to the properties of the traction system. Additionally, force, kinematic, and parametric excitations are distinguished. External force excitations arise when there is a change in the resistance to the movement of the train (locomotive). Kinematic excitations are caused by deformations of the rail profiles, such as subsidence and bulging, as well as by local defects in the upper layer of the track, resulting in non-linearity in the track profile. Parametric factors are associated with the uneven distribution of the dissipative, inertia, and elasticity characteristics of the track along its length [18].

Internal force excitations are caused by the electromagnetic torque of traction motors and the imbalance of rotating parts. Due to the non-ideal circularity and conicity of the wheel's rolling surface relative to the geometric axis of the wheelset, as well as the kinematic errors of gear meshing and the traction coupling, internal kinematic excitations arise. These include changes in the radial stiffness of the coupling along a given coordinate (where the inclination of the elastic elements in the environment changes during rotation) and parametric excitations due to changes in the adhesion conditions between the wheel and the rail.

When studying traction drives, the kinematic diagram must be examined first. Based on the



a) Single-sided transmission *b) Dual-sided transmission*

Figure 1 *Load distribution scheme on the motor shaft*

arrangement of the reducers, there are two main types of motor-gearbox connections.

In a single-sided transmission, the force is applied from one side of the motor. In this case, uneven effects occur in the system, leading to negative impacts on the reliability of the drive. To increase the reliability in such designs, additional elastic elements and increased mass are applied, which require extra costs and reduce the technical level of the transmission.

In a dual-sided transmission, the force is applied symmetrically from both sides of the motor to the wheelset. In this case, the reduction of parametric effects, an increase in reliability, and an improvement in the technical level are ensured.

Figure 1 presents a distribution model (diagram) illustrating the load distribution in single-sided and dual-sided traction drive designs.

The calculation of shaft strength consists of comparing the effects acting on its individual sections to their limit values. The shafts are analyzed based on the evaluation of torsional and bending moments. These calculations are carried out based on the traction force of a single axle of a vehicle. The traction force must correspond to the maximum value of the wheel-rail adhesion.

The traction motor shaft is usually made of 20XH3A grade steel (with a fatigue limit of σ_{-1} = 330 MPa). In double-sided transmissions, this stress value can be reduced by 15–20%. This is because, in double-sided transmissions, uneven stress distribution does not occur, which significantly positively affects the reliability of traction shafts [19].

2.2. Verification calculation of the traction transmission

When designing the gears of the reducers, two types of calculations are carried out - verification and design calculations [19-20]. In traction transmissions of railway vehicles, design calculations are usually not required because the sizes of the transmission elements are determined based on adaptation to a specific installation condition. When the dimensions and transmitted load are known, the goal of the verification calculation is to determine the mechanical system's durability limit under the given conditions. During the verification calculation, the calculated stresses are determined, and a comparison is made to the allowable stress. The following sequence of calculations is carried out for this purpose.

The circumferential force of the gear reducer is found by Equation (1);

$$F_{Ft} = \frac{2T_3}{d_1} = \frac{2 \cdot 6050 \cdot 10^3}{496} = 24.39 \cdot 10^3 \ N , \tag{1}$$

here: T_3 - the torque of the most loaded gear, N·m; d_1 - the diameter of the gear, mm.

The load applied to the contact line of the tooth is found by Equation (2);

$$\begin{aligned} W_{Ft} &= \frac{F_{Ft} \cdot k_{F\alpha} \cdot k_{F\beta} \cdot k_{Fv}}{b_\omega} = \\ &= \frac{24.39 \cdot 10^3 \cdot 1 \cdot 1.5 \cdot 1}{80} = 475 \ \frac{N}{mm}, \end{aligned} \tag{2}$$

here: $k_{F\alpha}$ is the coefficient that accounts for the uneven load distribution between the teeth, and for the straight-cut gears, the value is $k_{F\alpha} = 1$, $k_{F\beta}$ is the coefficient that accounts for the uneven distribution of the load along the tooth contact line, and for the straight-cut gears, the value is $k_{F\beta} = 1.5$; k_{Fv} is the internal dynamic load coefficient; for double-sided transmissions $k_{Fv} = 1$; b_ω is the width of the gear, mm.

The bending stress of the teeth is determined by the Equation (3);

$$\begin{aligned} \sigma_F &= \frac{Y_F \cdot Y_{F\varepsilon} \cdot Y_{F\beta} \cdot W_{Ft}}{m} = \\ &= \frac{3.75 \cdot 1 \cdot 1 \cdot 457}{8} = 214MPa, \end{aligned} \tag{3}$$

here: Y_F - Tooth form factor, which is selected based on the number of teeth; $Y_{F\varepsilon}$=1 - Coefficient that accounts for the contact ratio of the teeth.

The specific load applied to the center of the tooth is determined by Equation (4);

$$\begin{aligned} W_{Ht} &= \frac{2000T_3 \cdot k_{H\alpha} \cdot k_{H\beta} \cdot k_{Hv}}{b_\omega \cdot d_{\omega 1}} = \\ &= \frac{2000 \cdot 6050 \cdot 1 \cdot 1.7 \cdot 1.03}{80 \cdot 496} = 534 \frac{N}{mm}, \end{aligned} \tag{4}$$

here: $k_{H\alpha}$ - Coefficient that accounts for the uneven distribution of load between the teeth; for spur gears, $k_{H\alpha} = 1$; $k_{H\beta}$ - Coefficient that considers the uneven distribution of contact stress along the tooth length; for traction reducers, $k_{H\beta} = 1.7$; k_{Hv} - Internal dynamic coefficient; for traction reducers, $k_{Hv} = 1.03$.

The contact voltage is calculated by Equation (5);

$$\begin{aligned} \sigma_H &= 275Y_H \cdot Y_{H\varepsilon} \cdot \left[\frac{W_{Ht} \cdot (u_3 + 1)^{0.5}}{u_3 \cdot d_{\omega 1}}\right] = \\ &= 275 \cdot 1.76 \cdot 0.867 \cdot \left[\frac{534 \cdot (1.771 + 1)}{1.771 \cdot 280}\right] = \\ &= 725 \ MPa, \end{aligned} \tag{5}$$

here: Y_H - Coefficient that accounts for the shape of the tooth, determined based on the total number of teeth; $Y_{H\varepsilon}$ - Coefficient that considers the total length of the contact line,; $d_{\omega 1}$ - Base circle diameter of the gear, mm; u - Transmission ratio; W_{Ht} - Specific load applied to the middle of the tooth, N/mm.

Bending and contact stresses are compared to the permissible calculated stresses. The approach here is that the center distance is chosen not according to the contact stress, but according to the design and location possibilities. The bending and contact stresses are calculated according to the obtained center distance and compared with the allowable stress values of the material. The values of the bending and contact stresses of the material are taken from the report of the classic gearbox example.

$$\begin{aligned} \sigma_F &= 214MPa \le \sigma_{Fh} = 236MPa \\ \sigma_H &= 725M\rho a \le \sigma_{Hh} = 900MPa \end{aligned} . \tag{6}$$

2.3 Development of the layout scheme of the innovative traction reducer

One of the key parameters that shapes the traction characteristics of railway vehicles and ensures that the traction reducer fits within the required dimensional framework in both vertical and horizontal directions is the transmission ratio of the reducer. To determine the transmission ratio, it is sufficient to know the engine shaft speed, wheel diameter, and maximum operating speed. According to Equation (7), the suitability of the transmission ratio within the given parameters is checked and the transmission ratio is determined for each stage of the three-stage innovative reducer.

$$\begin{aligned} u_{\max} &= \frac{n_{\max} \cdot D_{to}}{5.3 \cdot v_{\max}} \cdot 10^{-3} = \frac{5831 \cdot 880}{5.3 \cdot 160} = \\ &= 6.055 > u_\Sigma = \frac{n_1}{n_2} = \frac{2074}{359.4} = 5.557, \end{aligned} \tag{7}$$

here: D_{to} - mean diameter of the wheel; u_{max} - maximum speed of the train; n_{max} - maximum rotational speed of the engine shaft, rpm.

The selection and calculation of the main parameters of the traction reducer are based on determining the maximum value of the transmission ratio [21].

The elements of the traction drive must be positioned at a distance from the rail head in such a way that, in the vertical direction, the wheelset axle remains within the smallest possible radius around its axis. In the transverse direction, they must be placed within the distance between the wheels, ensuring maximum ease of installation while considering manufacturability. Thus, the value of the transmission ratio is determined based on the condition that the safety clearance between the traction reducer housing and the track superstructure conforms to the design dimensions that characterize the reducer's structural features. The maximum outer diameter of the gears is determined by the Equation (8).

$$d_{a2} = D_k - 2 \cdot (\delta_1 + \delta_2 + \delta_3), \tag{8}$$

here: $\delta_1 = (120 \div 140)$ mm - distance from the rail head to the reducer housing; $\delta = (4 \div 12)$ mm - thickness of the bottom wall of the traction reducer housing; $\delta_3 = (8 \div 10)$ mm - distance between the gear and the reducer housing.

The placement of the traction drive within the dimensions limited by the distance between the wheels is determined as follows: B_D - length of the motor housing; b_1 - distance from the reducer housing to the wheel and traction motor, at least 30 mm; b_2 - thickness of the side wall of the reducer, selected based on whether the housing is load-bearing or non-load-bearing, 10 mm; b_3- distance between the side of the gear and the inner wall of the reducer housing, 10 mm; b_{w1}, b_{w2} b_{w3} - widths of the gears of the first, second, and third stages, respectively. Based on the above dimensions, the width of the traction reducer is determined by Equation (9).

$$b_k = b_{w1} + b_{w2} + b_{w3} + 2b_2 + 2b_3 = 20 + 40 + \\ + 80 + 20 + 20 = 180. \tag{9}$$

An outline diagram is prepared according to the selected and calculated dimensions of the traction drive (Figure 2).

2.4 Reliability of the innovative traction transmission

The reliability level defines the safety of railway vehicles. Enhancing reliability is regarded as one of the key requirements in the design and development of the transmission system.

Ensuring the maximum value of the reliability level must occur under conditions where the strength safety factors take their minimum values. The reliability level of all the structural elements of the traction drive must be equal and should approach the upper limit.

$$Q_1(t) = Q_2(t) = \ldots = Q_i(t) = \ldots = Q_n(t) \Rightarrow \sup Q(t), \tag{10}$$

Here, $Q_i(t)$ - is the failure probability of the traction transmission components, in other words, the reliability of the components.

The strength safety factors of the structural elements of the traction drive must be consistent with each other and should approach the lower limit.

$$S_i \Leftrightarrow S_2 \Leftrightarrow \ldots \Leftrightarrow S_i \Leftrightarrow \ldots \Leftrightarrow S_n \Leftrightarrow \inf S = 1, \tag{11}$$

Here, S_i - is the strength safety factor of individual parts of the traction drive. Table 1 presents the required parameters and their values for determining the reliability of the drive system [22].

The reliability of traction devices is formed on the basis of the reliability coefficients of the individual structural elements that make them up and is calculated by Equation (12).

$$Q = Q_1 \cdot Q_2 \cdot Q_3 \cdot \ldots \cdot Q_n = \prod\nolimits_k^n Q_i, \\ Q_{ir} = Q_1^6 \cdot Q_2^2 \cdot Q_3^4 \cdot Q_4^2 = 0.99^6 \cdot 0.995^2 \cdot 0.96^4 \cdot \\ \cdot 0.95^2 = 0.7144, \tag{12}$$

here, Q_1, Q_2, Q_3, Q_4 - are the reliability levels of the gear transmission, shaft, a pair of rolling bearings, and sliding bearing, respectively.

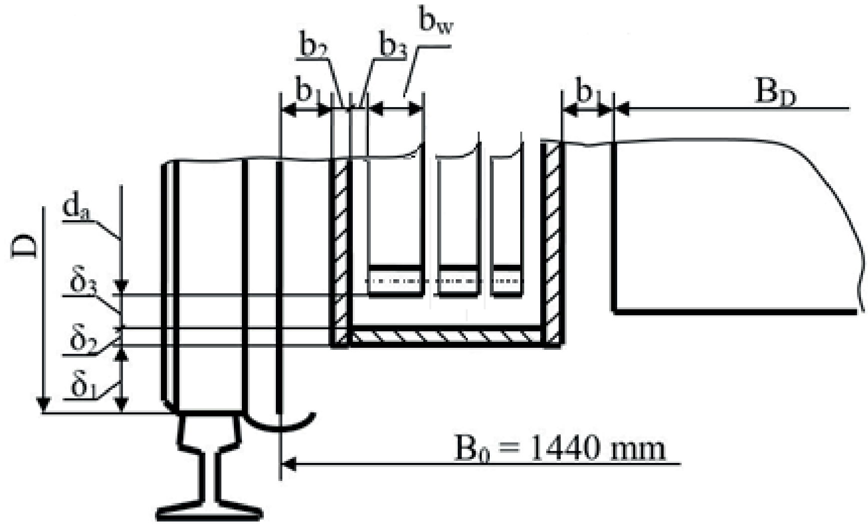


Figure 2. *Layout scheme of the innovative traction reducer*

***Table 1** Quantities required for determining reliability*

s/s	Parameter	Symbol	value
1	Number of gears	$n_{dç}$	6
2	Number of the rolling bearings	n_{dy}	4
3	Number of the shafts	n_u	2
4	Number of sliding bearings	n_{sy}	2
5	Number of sides	K	2
6	Reliability level of the gear	$Q_{dç}$	0.99
7	Reliability level of a pair of rolling bearings	Q_{dy}	0.9
8	Reliability level of the shaft	Q_V	0.995
9	Asymmetry coefficient due to supports	K_{qs}	1
10	Reliability level of sliding bearings	Q_{sy}	0.95

***Table 2** Results of stand tests for determining vibrations at different rotational speeds of the motor shaft in electric locomotives*

Number of measurements	Vibration measurement, mm/s			
	Frequency, rpm		Frequency, rpm	
1	2800	1.6	1.0	37.5
	2000	1.4	1.2	14.3
	1000	0.6	0.5	16.7
2	2800	1.5	1.2	20
	2000	1.9	0.9	52.6
	1000	1.8	0.7	61
3	2800	1.0	0.7	30
	2000	0.8	0.5	37.5
	1000	0.5	0.4	20
4	2800	2.0	1.6	20
	2000	1.6	1.2	25
	1000	1.0	0.8	20
5	2800	1.4	0.9	35.7
	2000	1.9	1.0	47.4
	1000	1.0	0.8	20
6	2800	1.4	1.2	14.3
	2000	1.3	0.8	38.5
	1000	1.1	0.7	36.4
7	2800	1.6	0.8	50
	2000	1.4	0.7	50
	1000	1.2	0.8	33.4
8	2800	1.3	0.7	46.1
	2000	0.9	0.6	33.4
	1000	0.6	0.5	16.7
9	2800	1.4	0.6	57.1
	2000	0.6	0.4	33.4
	1000	0.6	0.4	33.4
10	2800	1.4	0.7	50
	2000	1.6	0.7	56
	1000	1.6	1.0	37.5
Average value K_{qs}=1.32				32.2

3 Discussions and conclusions

A detailed analysis of the traction drives of railway vehicles has been conducted, and an innovative three-stage cylindrical gear traction drive has been proposed to eliminate several known shortcomings by minimizing parametric errors and ensuring symmetric placement relative to the wheelset. The design solution has been accepted and approved by the Eurasian Patent Organization with a corresponding decision [4].

Considering that the reducers are placed in parallel, the asymmetry coefficient will be K_{qsi}=1. If the transmission is asymmetrically positioned relative to the supports, its value can be determined through the experimental and analytical methods. The stand tests have been conducted on traction reducers of railway vehicles with asymmetrically positioned transmissions relative to the supports at different rotational speeds, measuring the effects of vibrations (Table 2).

It was found that the impact of vibrations on the side where the reducer is mounted on the engine shaft is up to 30% lower compared to the opposite side. Various structural solutions have been developed to neutralize these negative effects of vibration. One of the most widely applied methods in recent years is the placement of a hollow shaft over the wheelset axle and utilizing its elasticity properties to reduce vibration effects. However, based on structural considerations and experimental results, it can be concluded that, despite all these measures, when reducers are asymmetrically positioned, the asymmetry coefficient takes a value greater than one. On the other hand, increasing the mass of rotating components negatively affects the technical characteristics of the train.

The reliability level of a typical traction reducer is compared with the reliability level of the innovative traction reducer, and the results are presented in Table 3. As can be seen the application of innovative reducers significantly increases the reliability of the transmission.Thus the low reliability of the traction drive not only reduces production but increases the number of repairs as well, which in turn leads to high maintenance costs. In many cases the repair costs of the transmission exceed its production costs several times. A comparison of existing and innovative traction drives shows that the reliability has increased by up to 13%

***Table 3** Comparison of existing and innovative traction drives*

Characteristic parameters	Types of traction drives	
	Existing	Innovative
Number of shafts	4	6
Number of rolling bearings	3	2
Number of sliding bearings	6	4
Reliability level of gear transmissions. Q1	-	2
Reliability level of shafts. Q2	0.99	0.99
Reliability level of rolling bearings. Q3	0.995	0.995
Reliability level of sliding bearings. Q4	0.96	0.96
Asymmetry coefficient. K_{qs}	0.95	0.95
Reliability level of the traction functional chain. Q(t)	1.12	1
Increase in the reliability level of the traction functional chain. %	0.6352	0.7144
Characteristic parameters	$Q = \frac{Q_i - Q_m}{Q_m} \cdot 100\% = 12.5\%$	

***Table 4** Indicators of Reliability Level*

	Diameter of the driving gear in the heavily loaded stage. d. mm				Factor ensuring reliability. U_p	No.
Reliability Level Q(t)	0.9999	290.92	301.84	312.76	3.9	1
	0.999	290.64	301.128	311.92	3.8	2
	0.99	286.44	292.88	299.32	2.3	3
	0.95	284.592	289.184	293.776	1.64	4
	0.9	283.5	287	290.5	1.25	5
	0.85	282.912	285.824	288.736	1.04	6
	0.8	282.352	284.704	287.056	0.84	7
		Coefficient of Variation V_t				
		0.01	0.02	0.03		

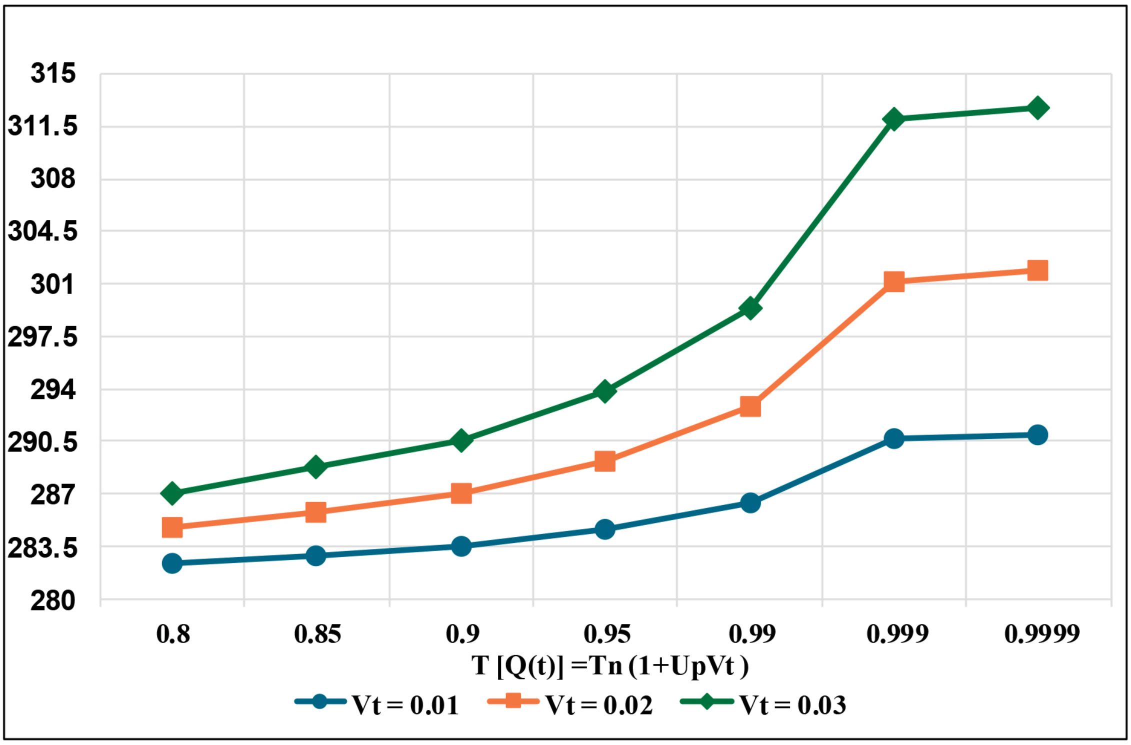


Figure 3. *Dependence of reliability degree on gear wheel diameter*

which is an indicator of an improvement in the technical level of the transmission.

Another indicator for increasing reliability is ensuring the minimum difference between the outer and inner diameters of the gears. In other words an increase in the inner diameter of the gear is directly proportional to an increase in reliability. As seen this condition is met in the innovative traction drive.

The reliability of gears depending on their diameter is determined based on the factor u_p - which ensures the required level of reliability and the coefficient of variation. The reliability level values are presented in Table 4 and Figure 3.

4 Conclusion

In this research study the application possibilities of an innovative traction transmission system for railway vehicles were explored. The dynamic characteristics of the traction transmission are analyzed and along with the development of its descriptive model methodological steps are taken to conduct verification calculations develop the placement scheme of the innovative gearbox and assess its reliability.

By conducting the verification calculations of the traction transmission the permissible stress value of the gear transmission is determined and compared with the calculated value. The selection of the main parameters of the traction motor is based on the maximum transmission ratio of the gearbox (U_m=6.055). An optimal placement scheme for the innovative traction gearbox within the traction transmission system is developed. and installation dimension parameters are determined accordingly.

The correctness of the transmission design and the choice of the constructive scheme are validated by ensuring a 13% increase in reliability and achieving parametric compliance through verification calculations.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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