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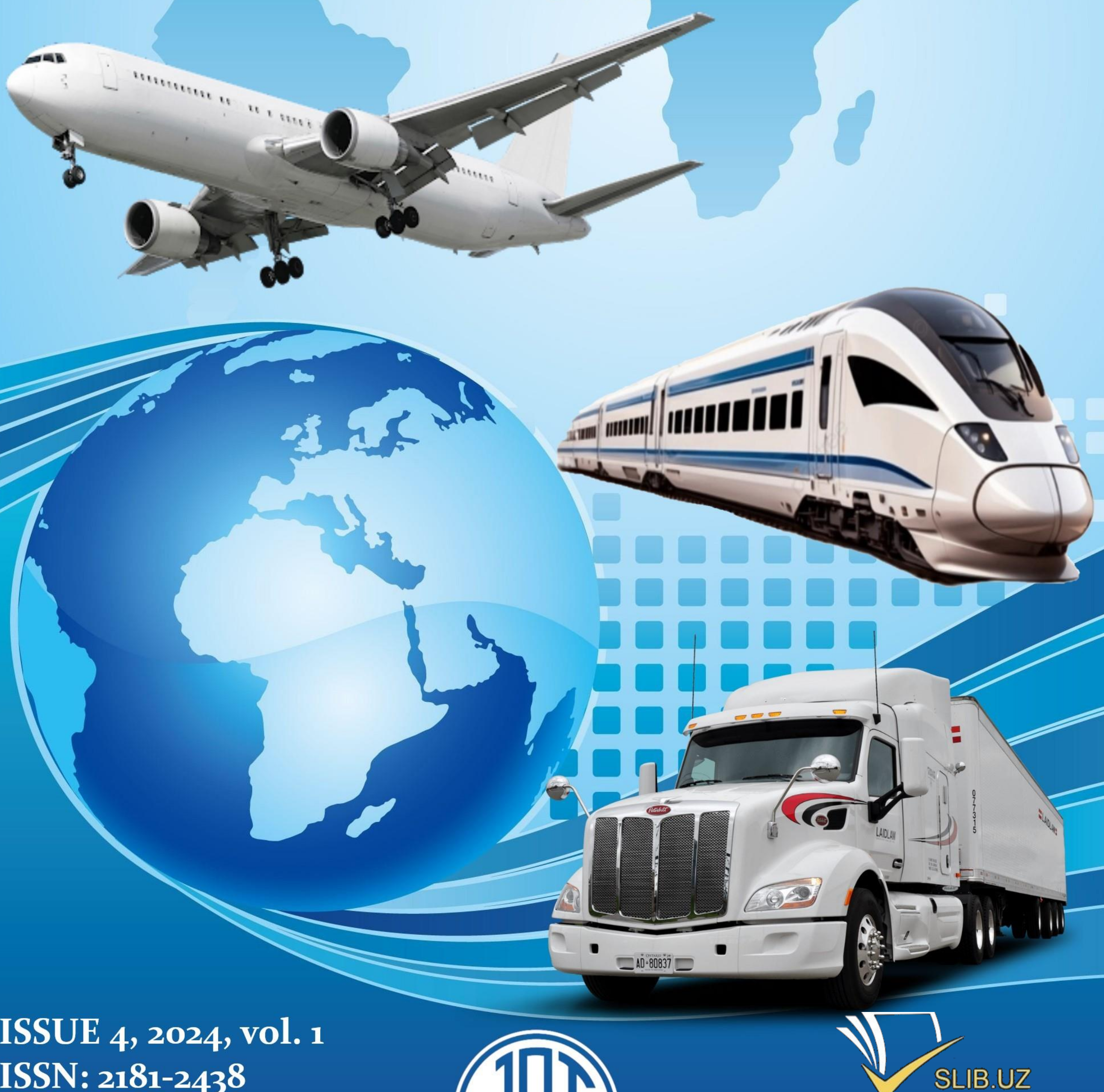

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The "Journal of Transport" publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

The journal is published 4 times a year and contains publications in the following main areas:

- Business and Management;
- Economics of Transport;
- Organization of the Transportation Process and Transport Logistics;
- Rolling Stock and Train Traction;
- Infrastructure;
- Research, Design, and Construction of Railways, Highways, and Airfields: Technology and Organization of Construction, Management Problems;
- Water Supply, Sewerage, Construction Systems for Water Protection;
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- Power Supply, Electric Rolling Stock, Automation and Telemechanics, Radio Engineering and Communications, Electrical Engineering;
- Materials Science and Technology of New Materials;
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- Car Service;
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- Traffic Organization;
- Operation of Railways and Roads;

Tashkent State Transport University had the opportunity to publish the scientific-technical and scientific innovation publication "Journal of Transport" based on the Certificate No. 1150 of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. Articles in the journal are published in Uzbek, Russian and English languages.

CONTEXT / MUNDARIJA

Characteristics of industrial traction units and their load-bearing structures

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Abstract: This article examines the characteristics of industrial traction units and their load-bearing structures, with a focus on models used in mining enterprises in Uzbekistan. It analyzes the design features of key components such as the control electric locomotive body, motor dumpcar body, bogies, and various support structures. The study emphasizes the importance of assessing and extending the service life of these units, given that many have exceeded or are approaching their established service life. The article provides detailed descriptions of the PE2, PE2M, PE2U, and MPE2U traction units, including their technical specifications and structural elements. Special attention is given to the load-bearing structures, including the body frames of control electric locomotives and motor dumpcars, as well as bogie frames. The materials used in construction and the design considerations for these critical components are discussed, highlighting their role in ensuring the strength, reliability, and safety of the traction units.

Keywords: frame structures, load-bearing structures, industrial traction units, remaining service life, service life extension

1. Introduction

Industrial traction units are powerful, specialized vehicles designed to move heavy loads in various industrial settings. Currently, industrial traction units are widely used in mining enterprises of the Republic of Uzbekistan, such as Almalyk Mining-Metallurgical Complex (AMMC) JSC and "Uzbekcoal" JSC. PE2M, PE2U, and MPE2U units make up the majority of traction units in the locomotive fleet of these enterprises [1]. A significant portion of the industrial traction units in use have already exceeded their established service life, and several more will reach the end of their service life specified in their technical documentation in the near future.

The extension of the service life of rolling stock is closely linked to the durability of its load-bearing structures [4-10]. The main load-bearing elements of rolling stock are its main frame and bogie frame [11, 12]. To justify the possibility of safe operation beyond the established service life, it is necessary to conduct a series of scientific studies in accordance with regulatory documents [13, 14]. To assess the residual life of load-bearing structures, modern automated design systems, engineering calculation systems, and technical diagnostic devices can be employed. Based on the results of these assessments, a final conclusion is made [15, 16].

Several researchers in their scientific studies have addressed issues such as assessing the residual life of rolling stock and extending its service life [17-22]. In particular, Bondarev et al. [23, 24] assessed the possibility of extending the service life of the OPE1A traction unit's load-bearing structures by studying their strength characteristics.

To perform strength calculations for the load-bearing structures of rolling stock, it is necessary to study their structure, the forces acting upon them, and the loading schemes. In doing so, factors such as the mechanical properties of the material used in the load-bearing structures and their operating conditions must be taken into account.

2. Methods and materials

2.1. PE2, PE2M, PE2U and MPE2U traction units

At present, over 70 traction units of PE2M, PE2U, and MPE2U types are in operation at enterprises such as JSC "AMMC" and JSC "Uzbekcoal". These traction units were manufactured between 1970 and 2021, and the total number of industrial traction units in service is shown in Table 1 [1].

The PE2, PE2M, PE2U, and MPE2U traction units (Figure 1) consist of a four-axle control electric locomotive and two four-axle motor dumpcars. They are designed for operation on open-pit mining railways electrified with 3000 or 1500 V DC, capable of handling ruling grades (inclines) of up to 60‰.

Table 1

The total number of all traction units in use

Enterprise	PE2M	PE2U	MPE2U
JSC "AMMC"	26	25	2
JSC "Uzbekcoal"	6	15	–
Total	32	40	2

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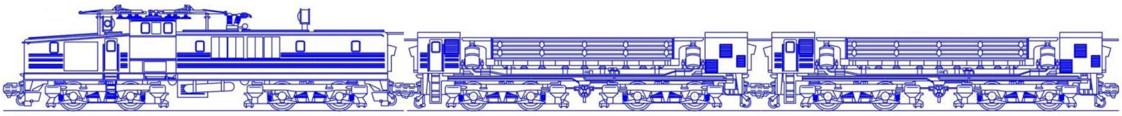

Figure 1. General view of PE2, PE2M, PE2U, and MPE2U traction units

Starting in 1967, the Dnipropetrovsk Electric Locomotive Plant (DELP) began manufacturing PE2 traction units. Initially, these units were equipped with traction electric motors from VL8 electric locomotives, with some modifications to the frame structure (electric motor NB-406D on PE2 units). Then, from 1970, DELP started producing and installing DT-9N traction electric motors on the units. With these electric motors, units designed for voltages of 3000 and 1500 V and designated as PE2M were built from 1970 to 1985. The PE2M traction unit was created as a result of modernizing the PE2 traction unit and serves as the basic model for the entire range of DC and AC traction units.

In 1985, DELP manufactured an experimental traction unit, which was designated PE2U, where the index "U" stands for "upgraded." Its main difference from the PE2M unit is a slight increase in power and tractive effort in 15-minute and one-hour modes (3000 V - 5520 kW, 1500 V - 2640 kW). The traction unit is equipped with NB-511 traction electric motors.

The maximum operating speed of the unit is 65 km/h, with a minimum curve radius of 80 m when traveling at 10 km/h. The adhesion weight of the traction unit, with 2/3 of the sand reserve in the control locomotive, is 368±11 tons, of which 120±3.6 tons are attributed to the electric locomotive and 2 (124±3.7) tons to two loaded dumpcars. The carrying capacity of the motor dumpcar is 45 tons [25-27].

In 2020, the Tbilisi Electric Locomotive Plant (TELP) manufactured the first MPE2U traction unit, which was delivered to Uzbekistan for AMMC. A year later, the second traction unit of this series was produced and also sent to Uzbekistan. The MPE2U traction unit was manufactured for AMMC in connection with the development of the new Yoshlik-1 deposit [28, 29].

2.2. Control electric locomotive body

The body of a control electric locomotive serves to accommodate electrical and pneumatic equipment, traction unit control devices, as well as to transmit tractive effort. The bodies of control electric locomotives for all types of units differ insignificantly from each other; the differences are due to some changes in the arrangement and installation of electrical apparatus [26].

The bodies of the control electric locomotives in the PE2, PE2M, PE2U, and PE1 traction units, as well as those in the OPE2 and OPE1A traction units, are unified. Therefore, the description of their design is provided with reference to the bodies of the PE2M and OPE2 traction units [25].

The electric locomotive has an open-type body, which provides good visibility and access to the running gear components during repair, maintenance, and lifting operations. The body rests on two two-axle bogies through central flat supports, and on the buffer beam sides through lateral supports with rubber cones (four per locomotive).

The body (Figure 2) consists of the following main welded components: main frame 1, cab 2, side walls 3, front walls 4, roofs 5, covers 6, track cleaner 7, and automatic couplers 8. These parts are assembled and welded separately, and then welded together (except for the covers, which are bolted to the roofs), resulting in a rigid structure. Inside this structure and partially on its exterior, the necessary equipment can be installed, and electrical and pneumatic systems can be mounted [2].

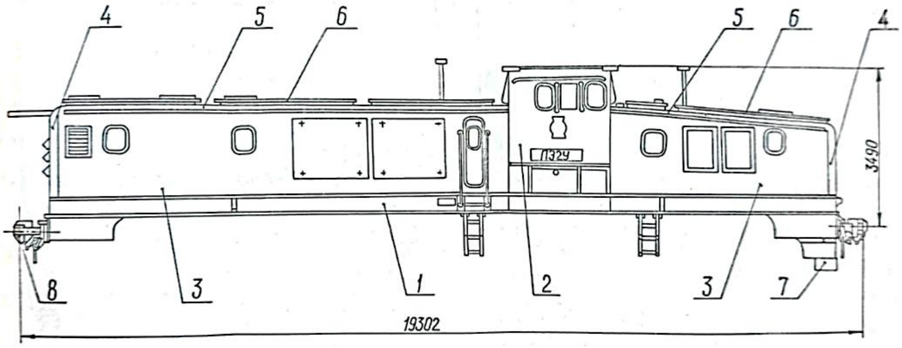

Figure 2. Body of the PE2U traction unit control electric locomotive:
1 - main frame; 2 - cab; 3 - side wall; 4 - front wall; 5 - roof; 6 - cover; 7 – track cleaner; 8 - automatic coupler.

The all-metal, welded bodies of electric locomotives controlling traction units PE2M, PE2U, MPE2U, and OPE2 are manufactured from special steels designed for welded structures: the frames of the driver's cab walls, sloped sections, and compartment are made of St3sp or St2kp steel, their cladding is made of 15kp or St3sp steel, while all load-bearing elements of the body frame and the binding profile of the roof for the sloped sections and compartment are made of low-alloy 09G2 steel [25].

2.3. Motor Dumpcar Body

The motor dumpcars are designed with overturning cylinders located at the ends of the body and are intended for loading heavy rocks using excavators with a bucket capacity of up to 12 m^3 [27].

The bodies of motor dumpcars are designed for mechanized unloading of rock mass, as well as for transmitting traction and braking forces to the train. The bodies of motor dumpcars (Figure 3) are transport containers with an open top and consist of a lower frame 1, an upper frame 2, a longitudinal side 3, a side opening mechanism 4, a machine compartment guard 5, and an automatic coupler installation 6.

The main body components are manufactured from low-alloy 09G2 steel, while the wall cladding sheets and their frames are made of 15kp steel and St3kp steel, respectively. The bodies of the motor dump cars of these traction units have many standardized components and differ primarily in the arrangement and design of brackets, frames, and openings in the side guards and lower frame [25].

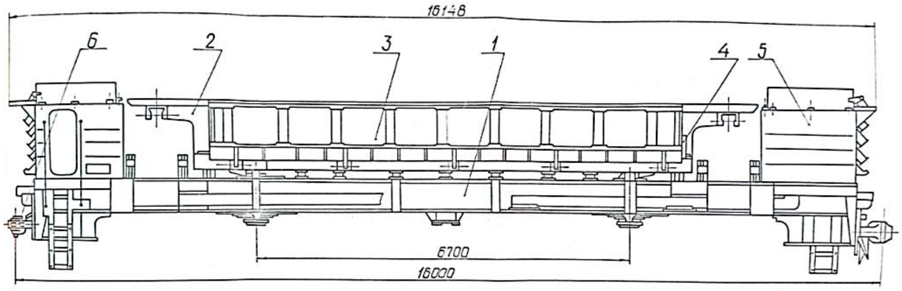

Figure 3. Body of the PE2U traction unit motor dumpcar:
1 - lower frame; 2 - upper frame; 3 - longitudinal side; 4 - side opening mechanism; 5 - guardrails; 6 - automatic coupler installation.

2.4. Bogie

The PE2, PE2M, PE2U, MPE2U, PE1, OPE2, OPE1A, OPE1B and PE3T traction units are equipped with two-axis disconnected jawless bogies with symmetrical traction motors and longitudinal balanced suspension. To enhance operational safety on railway tracks in open-pit mines with gradients up to 60‰, the bogies of these traction units are equipped with pneumatic casing brakes and electromagnetic rail brakes, as well as track detachment sensors. Additionally, to reduce the wear of wheel pair tires, these bogies are fitted with flange lubricators. Balancers are suspended from the frameless-type axle boxes, on which the bogie frame rests on one side through cylindrical springs, and on the other side - a leaf spring balancer. The bogie frame also rests on the middle sections of the balancer springs.

The bogies of traction units (Figure 4) are fully standardized. These bogies, equipped with DT-9N traction motors, differ from the bogies of the PE2 traction unit only in their wheel-motor blocks, which use the NB-406D motor [25-27]. The bogies of the PE2U traction unit employ the NB-511 motor [2].

The bogies of the control electric locomotives and motor dumpcars are interchangeable and have stronger safety beams in case of derailment.

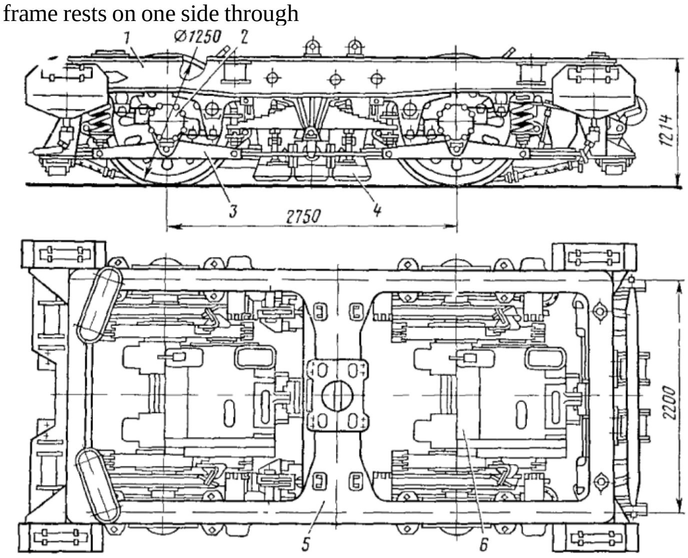

Figure 4. Traction unit bogie:
1 - bogie frame; 2 - axle box; 3 - spring suspension; 4 - electromagnetic rail brake; 5 - pivot beam; 6 - traction motor.

2.5. Body supports

2.5.1. Central Support

Connections between the body and the bogie serve to transfer vertical, horizontal, longitudinal, and horizontal transverse forces between the body and the bogie. The vertical load from the body to the bogie is transmitted by the central support and two lateral sliding supports.

The central support (pivot), in addition, serves to transmit horizontal longitudinal and horizontal transverse forces between the bogie and the body, and also acts as a kingpin around which the bogie can rotate in the horizontal plane.

The bodies of electric locomotives and motor dump cars have rigid supports consisting of a flat pivot 7 (Figure 5), which fits into a socket (center plate) 1 of the bogie with a clearance that allows free rotation in the horizontal plane and limited rotation up to 3° in the vertical plane.

The pivot and center plate are made of cast steel. To increase the wear resistance of the friction surfaces of the pivot and center plate, replaceable bushings 5, 4 and flat collars 3, 2 made of thermally hardened steel 45 are provided. The bushings are installed using a press fit and, like the collars, are additionally welded with intermittent seams.

To protect against contamination entering the support, there is a felt seal 6 with a support ring 9, which is secured to the center plate through two half-rings 8 using screws.

On traction units PE2, PE2M, PE2U, MPE2U, PE1, OPE2, and OPE1A, the central supports have an almost identical design to the body supports of D100m and D94 electric locomotives. They differ by the presence of an oil pipeline connected to the support pivot, with a filler neck located on the outer side of the bogie frame [25].

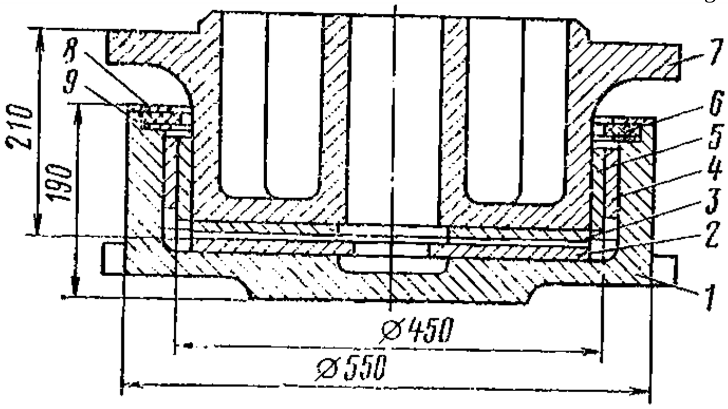

Figure 5. Central support

2.5.2. Lateral Support

The load on the hollow metal cone 2 (Figure 6, a) is transferred through the rubber cone 1. The cone is mounted on a center plate 4, which enters the bronze slide 7 with a spherical surface. The slide moves along the frame 9 of the support plate of the bogie frame. The bushing 5 is made of 110G13L steel, and the center plate is made of 45 steel and subjected to surface hardening, which ensures high wear resistance of this pair operating without lubrication. A spring 3 is installed to press the center plate 4 against the slide 7 when the bogie derails. The weight distribution of the traction units is adjusted by installing washers 13. The number of washers should not exceed ten under each support.

During relative movements between the car body and the bogie, the lower surface of slide 7 moves along the surface of a plate welded to the upper sheet of the bogie frame. This plate, together with a shell welded to it, forms an oil bath. To reduce wear on the friction surfaces of the slide and the plate, axle oil according to GOST 610 is poured into this bath [25].

The oil bath of the support plate is covered with a lid 6, which moves along the shell 8 together with the pivot. The connection between the pivot and the lid is protected by a felt seal 12, as well as a labyrinth seal formed by a shell 11 and a flange 10, which is secured to the lid by screws.

Auxiliary supports 1 are installed on the bogie frame under the body of the motor dumpcar (Figure. 6, b), which bear the forces from the dumpcar body during unloading.

The adjustment of the 5^{+3} mm distance from the auxiliary supports 1 to the corresponding pads on the dumpcars' lower frame is performed using washers 2 and 3 [2].

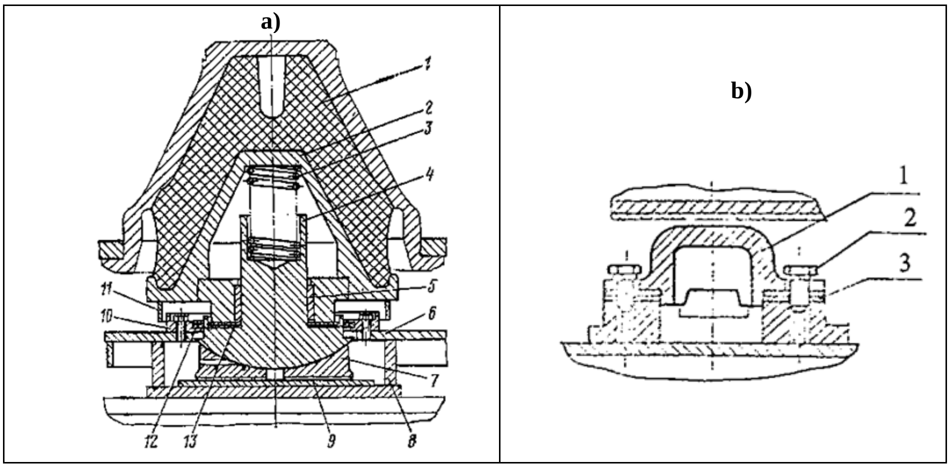

Figure 6. Body supports of the motor dumpcar:
a) lateral support; b) auxiliary support

3. Traction units load-bearing structures

The load-bearing structures of traction rolling stock play a key role in ensuring the strength, reliability, and safety of railway vehicles, such as locomotives and multiple-unit rolling stock. These structures include the main elements that bear loads and ensure the structural integrity of the traction rolling stock [30].

Requirements for load-bearing structures:

- The structures must withstand both static and dynamic loads that occur during movement;
- The durability of materials and components is crucial for ensuring the locomotive's long service life;
- The structures must ensure the safety of passengers and cargo in emergency situations;
- They must comply with the requirements of standards and regulatory documents.

3.1. Control electric locomotive body frame

The body frame (Figure 7) of the control electric locomotive in traction units is the main element of the body, bearing all types of loads. It consists of two longitudinal beams 8, bolster beams 5, 9, buffer beams 2, 11, under-cabin beams 7, and several other beams on which pneumatic and electrical equipment, as well as hand brake brackets, are located. Lateral support brackets are installed in the corners between the longitudinal beams and the buffer beams.

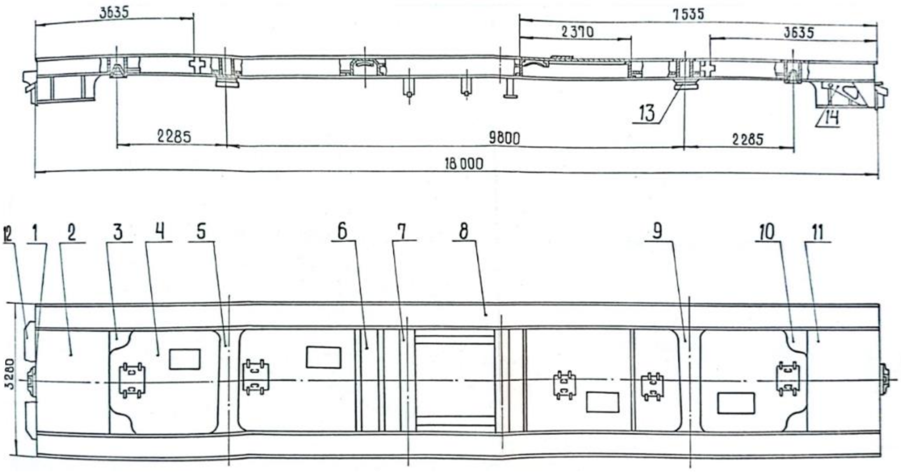

Figure 7. Body frame of the PE2U traction unit control electric locomotive:
1 - bracket; 2, 11 - buffer beam; 3, 10 - lateral support bracket; 4 - floor decking; 5, 9 - bolster beam; 6 - reservoir beam; 7 - beam; 8 - longitudinal beam; 12 - visor;13 - pivot; 14 - track cleaner bracket.

The body frame elements are designed to withstand a shock load of 250 tons along the axis of the automatic coupler. The longitudinal beams are made from two 36M I-beams connected by strips: upper and lower with a thickness of 10 mm (for OPE2 traction units, the upper strip is 16 mm and the lower is 20 mm), forming a box-shaped cross-section. Special cast brackets are welded to the walls of the I-beams for lifting the body with a crane using cables. Inside the longitudinal beam, a cast iron ballast is installed using a 6 mm diameter cable. To prevent longitudinal displacement, the ballast is secured by locking bolts screwed into plates on the beam walls.

The box-section bolster beams are welded from four sheets: an upper sheet 12 mm thick, a lower sheet 15 mm thick (for OPE2 traction units, the upper sheet is 16 mm and the lower sheet is 20 mm thick), and two vertical sheets 12 mm thick. To increase rigidity in OPE2 traction units, diaphragms and shells are welded into the bolster beams. The shells are used for transport and technological operations during the manufacture of the body frame, and also serve as part of the ventilation ducts.

A 16 mm thick flange is welded to the lower sheet of the bolster beam in the middle section (20 mm for OPE2 traction units) with a mounting hole for installing the central support 13 (pivot), and on the edges - special brackets that limit the angle of bogie rotation when it derails, allowing the bogies to be lifted together with the body of the control electric locomotive.

Buffer beams are made of four plates: two vertical plates 15 mm thick (16 mm for OPE2), an upper plate 10 mm thick (16 mm for OPE2), and a lower plate 15 mm thick (20 mm for OPE2). Diaphragms are welded between the plates, and in the middle part of the lower plate, there is a box with welded cast stops, in which a draw yoke with a draft gear and a thrust plate of the automatic coupler device are installed. Two brackets are symmetrically welded to the longitudinal axis of the body frame on the buffer beam, which are hinged to the track cleaner. The front plate features a strike plate, hatches with removable covers for installing ballast in the longitudinal beams, two buffer light housings, and a hood made of an 8 mm thick plate to protect the end pneumatic valves and buffer lights from being hit by pieces of rock or ore.

Cast steel housings for lateral supports are welded into the bottom sheet of the box-section brackets 3 and 10. In the middle part of the body frame, brackets for mounting levers, a balancer, and a chain of the manual brake system are welded to the box-section beams. The space between the Z-shaped beams 6 is used for installing the main reservoir.

The body frame floor decking is made from a 2 mm thick sheet and has removable hatches that provide access to the second and third traction motors [2, 25].

3.2. Motor dumpcar lower frame

The lower frame (Figure 8) is the main element of the body, bearing all types of loads, and is made of 09G2 steel. The lower frame consists of a center sill 4, with cantilevered brackets 11 and 12 welded to it under the upper frame supports, a bracket 10 for the side opening mechanism, brackets 8 and 9 for the tipping cylinders, special boxes 1 with impact brackets for installing automatic coupling devices, central supports 2, cones of side supports, restraining clamps limiting the angle of bogie rotation when it derails, platforms 7 for installing guardrails, a bracket 5 for the hand brake, air ducts 6, and troughs 3 for electrical wiring.

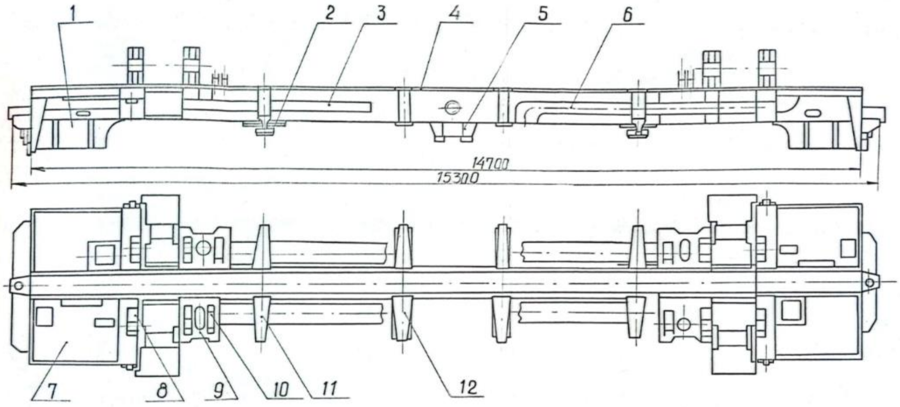

Figure 8. Lower frame of the PE2U motor dumpcar:
1 - buffer beam; 2 - pivot; 3 - electrical wiring troughs; 4 - center sill; 5 - bracket; 6 - traction motor air duct; 7 - guard platform; 8, 9 - tipping cylinder brackets; 10 - side opening mechanism brackets; 11, 12 - upper frame support brackets.

The center sill is made of two I-beams No. 55B2 with plates of sheet steel 16 mm and 20 mm thick and a 20 mm x 70 mm plate along the entire length of the beam. Flanges for installing pivot are welded to the bottom sheet from the outside.

Two pivot of central supports and a hand brake bracket 5 are attached to the lower plate of the center sill.

Two stops are installed on the upper plate of the center sill, limiting the longitudinal movement of the upper frame.

Air ducts for traction motors 6, electrical wiring troughs 3, and pneumatic main pipes are attached to the brackets of the lower frame.

Two hoods for installing buffer lights and one protective visor with holes for connecting units of the traction unit when replacing the automatic coupler are welded to the front plates of the lower frame. The platforms under the guards have support surfaces for the motor-ventilator and holes for air ducts, electrical and pneumatic installation [2, 25].

3.3. Bogie frame

The bogie frame (Figure 9) is designed to distribute the vertical load between individual wheelsets using spring suspension, absorb traction force, braking force, and lateral forces from the wheelsets, and transmit them to the body frame.

The bogie frames are welded from sheet steel and each consists of two side members, a center transom, and two end beams. The main load-bearing elements of the frame have box-shaped cross-sections, with the side members 8 and 18 and the end beams, front 23 and rear 14, welded from four sheets of rolled steel, while the center transom 19 is welded from five sheets: three vertical and two horizontals. Welded support brackets 2 and 9 are attached to the end beams, to which the safety beams of the bogie are fastened, as well as brackets 10 for derailment detectors.

On the upper part of the frame, at the points where the side panels connect to the front beam, plates 22 with facings are welded for the side sliding supports, while on the rear beam, brackets 15 for auxiliary supports (for dump truck bodies) are attached. In the middle of the kingpin beam 19, curved in the vertical plane, there is a foot with a mounting hole for installing the center pivot of the central support. In the brackets 20 along the edges of the beam, rotation limiters for the bogie under the body are fastened, as well as small beams that prevent the body from separating from the bogies in emergency situations.

Cast brackets 3 and 4 are welded to the bottom of the side panels and beams for installing axle box rods, as well as brackets 6 for mounting springs and components of the electromagnetic rail brake drive. The traction motor suspensions are fastened in brackets 24 and 26, while the braking system suspensions are secured in brackets 17.

The welded brackets 5 on the outer sides of the sidewalls are designed for lifting the bogie with jacks when the wheelsets derail, while brackets 1 and 12 are for attaching sandbox units. At the end of the frame near the rear beam, machined plates 25 are installed for mounting brake cylinders, and brackets 11 and 13 for hand brake levers. The bogie's braking system levers are attached to brackets 16. Support brackets 7 and 21 for the electromagnetic rail drive levers are mounted on pipes welded into the sidewalls and on the lower plates of the center pivot beam.

All welded elements of the bogie frame of the traction unit are made of M16C steel [25]. The welded elements of the OPE1A traction unit bogie frame are made of 16D grade steel [23, 24]. The cast elements are made of 20L-III steel with a carbon content of up to 0.22%. To relieve stress after welding, the frames undergo annealing [25].

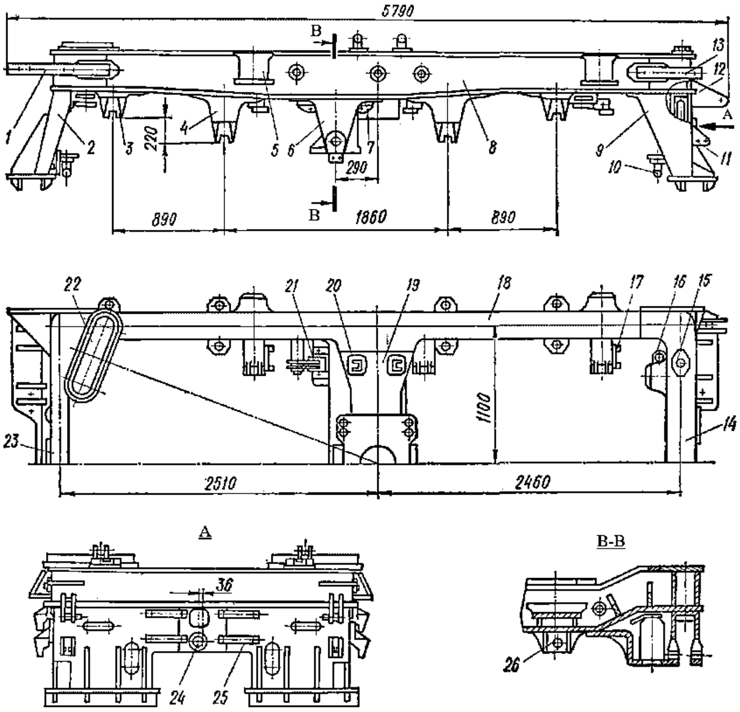

Figure 9. Bogie frame of PE2, PE2M, PE2U, MPE2U, OPE2, OPE1A, OPE1B, and PE3T traction units

4. Conclusion

The analysis of industrial traction units and their load-bearing structures reveals the complexity and importance of these systems in mining operations. The study highlights several key points:

1. The majority of traction units in use in Uzbekistan's mining sector are approaching or have exceeded their designed service life, necessitating careful assessment and potential life extension measures.
2. Load-bearing structures, particularly the main frame and bogie frame, are critical components that determine the overall durability and safety of the traction units.
3. The design of these units, including the PE2, PE2M, PE2U, and MPE2U models, incorporates various specialized features to handle the demanding conditions of open-pit mining, such as high gradients and heavy loads.
4. The materials used in constructing load-bearing structures, primarily various grades of steel, are chosen for their strength and durability to withstand the harsh operating conditions.
5. Ongoing assessment of the residual life of these structures is crucial for ensuring safe operation beyond the established service life.
6. Future research should focus on developing advanced methods for assessing structural integrity and exploring innovative materials or designs to enhance the longevity and performance of industrial traction units.

This comprehensive analysis provides valuable insights for mining enterprises, manufacturers, and researchers involved in the design, operation, and maintenance of industrial traction units. It underscores the need for continued research and development in this field to meet the evolving demands of the mining industry while ensuring safety and efficiency.

References

[1] Abdurasulov, S., Zayniddinov, N., & Yusufov, A. (2023). O‘zbekiston respublikasi tog‘-kon sanoatida foydalanilayotgan tortish agregatlari parkining tahlili. Journal of Research and Innovation, 1(9), 16-24.

[2] Агрегат тяговый постоянного тока без автономного питания типа ПЭ2У. Руководство по эксплуатации. 3ТП.002.008 РЭ1.

[3] Abdurasulov, S., & Zayniddinov, N. (2023). PE2M va PE2U tortish agregatlari rama konstruksiyalari parametrlari va o‘ziga xosliklarining tahlili. Journal of Research and Innovation, 1(10), 8–19.

[4] Abdurasulov, S. X., Zayniddinov, N. S. O. G. L., & Yusufov, A. M. O. G. L. (2023). Sanoat lokomotivlarining xizmat muddatini uzaytirishda bajariladigan asosiy ishlar. International scientific journal of Biruni, 2(3), 55-62.

[5] П.15.01-2009. Локомотивы. Порядок продления назначенного срока службы: положение: утв. Советом по железнодорожному транспорту государств - участников Содружества 20-21.10.2010 № 53 (в ред. от 27.10.2016).

[6] Khamidov, O., Yusufov, A., Jamilov, S., & Kudratov, S. (2023). Remaining life of main frame and extension of service life of shunting Locomotives on

railways of Republic of Uzbekistan. In E3S Web of Conferences (Vol. 365, p. 05008). EDP Sciences.

[7] Yusufov, A., Khamidov, O., Zayniddinov, N., & Abdurasulov, S. (2023). Prediction of the stress-strain state of the bogie frames of shunting locomotives using the finite element method. In E3S Web of Conferences (Vol. 401, p. 03041). EDP Sciences.

[8] Grishchenko, A. B., Yusufov, A. M., & Kurilkin, D. N. (2023). Forecasting the residual service life of the main frame and extending the service life of shunting locomotives JSC "UTY". In E3S Web of Conferences (Vol. 460, p. 06032). EDP Sciences.

[9] Зайниддинов, Н. С. (2010). Оценка остаточного ресурса рам тележек тепловозов (Doctoral dissertation, Doctoral dissertation, автореф. дис. на соиск. ученой степени канд. техн. наук: спец. 05.22. 07 Подвижный состав железных дорог, тяга поездов и электрификация/НС Зайниддинов).

[10] Насыров, Р. К., & Зайниддинов, Н. С. (2009). Оценка остаточного ресурса несущих конструкций локомотивов промышленного транспорта. Известия Петербургского университета путей сообщения, (3), 113-122.

[11] Abdurasulov, S., Zayniddinov, N., Yusufov, A., & Jamilov, S. (2023). Analysis of stress-strain state of bogie frame of PE2U and PE2M industrial traction unit. In E3S Web of Conferences (Vol. 401, p. 04022). EDP Sciences.

[12] Zayniddinov, N., & Abdurasulov, S. (2022). Durability analysis of locomotive load bearing welded structures. Science and innovation, 1(A8), 176-181.

[13] Зайниддинов, Н. С., Хамидов, О. Р., & Абдурасулов, Ш. Х. (2023). Анализ причин появления трещин в рамных конструкциях локомотивов и меры их предотвращения. In Железнодорожный подвижной состав: проблемы, решения, перспективы (pp. 164-170).

[14] Khamidov, O. R., Yusufov, A. M., Abdurasulov, S. X., & Jamilov, S. F. (2023). investigation of the stress-strain state of the bogie frame of shunting locomotives using the finite element method. In Железнодорожный подвижной состав: проблемы, решения, перспективы (pp. 504-509).

[15] Abdulaziz, Y., Otabek, K., Nuriddin, Z., Shukhrat, J., & Sherzamin, A. (2023). Application of computer-aided design (cad) systems when solving engineering survey tasks. Universum: технические науки, (3-5 (108)), 5-9.

[16] Khamidov, O. R., Yusufov, A. M., Kodirov, N. S., & Abdurasulov, S. X. (2023). Determination of the resource of parts and assembly of the traction rolling stock using non-destructive testing methods. In Железнодорожный подвижной состав: проблемы, решения, перспективы (pp. 510-514).

[17] Оганьян, Э. С. (2004). Критерии несущей способности конструкций локомотивов в экстремальных условиях нагружения (Doctoral dissertation, Моск. гос. ун-т путей сообщ. (МИИТ) МПС РФ).

[18] Волохов, Г. М. (2006). Остаточный ресурс несущих металлоконструкций тягового подвижного состава (Doctoral dissertation, Орловский государственный технический университет).

[19] Горобец, В. Л. (2009). Экспериментально-теоретические методы оценки ресурса несущих конструкций подвижного состава железнодорожного транспорта (Doctoral dissertation, Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна).

[20] Зайниддинов, Н. С. (2010). Оценка остаточного ресурса рам тележек тепловозов (Doctoral dissertation, Doctoral dissertation, автореф. дис. на соиск. ученой степени канд. техн. наук: спец. 05.22. 07 Подвижный состав железных дорог, тяга поездов и электрификация/НС Зайниддинов).

[21] Григорьев, П. С. (2016). Прогнозирование остаточного ресурса рам промышленных тепловозов (Doctoral dissertation, Моск. гос. ун-т путей сообщ. (МИИТ) МПС РФ).

[22] Гасюк, А. С. Оценка и прогнозирование технического состояния локомотивов по ресурсу их несущих конструкций: диссертация на соискание ученой степени кандидата технических наук / Гасюк Александр Сергеевич, 2022. – 162 с.

[23] Bondarev, O. M., Gorobets, V. L., & Myamlin, S. V. (2014). Methods and research concerning service life extension of suporting structures of traction rolling stock for industrial transport. Science and Transport Progress, (2 (50)), 130-151.

[24] Bondaryev, O. M., Dzichkovs'kyy, Y. M., Kryvchykov, O. Y., Yagoda, D. O., & Bondaryeva, V. S. (2012). Estimation of strength indices of parts of supporting structures of traction assemblies OPE1A and prolongation of their service life. Science and Transport Progress, (40), 17-27.

[25] Браташ В. А. Электровозы и тяговые агрегаты промышленного транспорта. — Москва: Транспорт, 1977. — 528 с.

[26] Раков В. А. Локомотивы и моторвагонный подвижной состав железных дорог Советского Союза, 1976–1985 / В. А. Раков. – Москва: Транспорт, 1990.

[27] Электроподвижной состав промышленного транспорта: Справочник/ Л. В. Баллон, В. А. Браташ, М. Л. Бичуч и др.; под ред. Л. В. Баллона. - М.: Транспорт, 1987.- 296 с.

[28] "Промышленные будни" или поход по Алмалыкскому ГМК. (2020). https://tashtrans.uz/ttf/topic/1022-%E2%80%9Cpromyshlennye-budni%E2%80%9D-ili-pohod-po-almalykskomu-gmk/.

[29] Тбилисский электровозостроительный завод. (2021). https://ru.wikipedia.org/wiki/Тбилисский_электровозостроительный_завод.

[30] Abdurasulov, S. (2023). REQUIREMENTS FOR THE STRENGTH OF LOAD-BEARING STRUCTURES OF LOCOMOTIVES. Acta of Turin Polytechnic University in Tashkent, 13(4), 44-48.

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