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The "Engineer" 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.

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- Computational Mechanics;
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- Safety, Risk, Reliability and Quality;
- Media Technology;
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EDITORIAL BOARD

Improvement of pavement concrete by industrial waste microfillers

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Abstract: Determination of the composition of pavement concrete using industrial waste in the most optimal options, determination of its flow limit, surface activity, and other properties of the composition, such as water separation, are presented.

Keywords: Pedestrian road surface, concretes, paving slabs, microfillers, putty

1. Introduction

Pedestrian pavement has long been firmly established in the image of a modern city. ¬A distinctive feature of the pavement made of composite material with concrete coating is its diverse properties and various configurations. At the same time, the strength and frost resistance of concrete are of great importance for road pavements. However, the tendency to use vibrocompression concrete products in areas where heavy vehicles move, combined with the aggressive effect of freezing and thawing on the properties of the pavement concrete, leads to a decrease in these physical and mechanical properties. The use of composite binders is an effective tool in eliminating this problem. At the same time, the multi-component composition of the pavement concrete is a product based not on reducing the amount of clinker in the mixture, but on effectively controlling the processes of structure formation, ensuring high quality of the resulting concrete.

At the same time, current trends in building materials science today are reducing the energy intensity of building materials production and the use of man-made raw materials in their production. From this point of view, one of the effective materials in terms of saving cement is crushed high-calcium oxide slag. The advantages of binders made from this type of slag and cement compared to Portland cement binders are greater resistance to chemical influences, hydration at low temperatures, and cost-effectiveness. Adding slag to Portland cement is an effective means of combating the harmful effects of hydroxide oxides. Therefore, it is proposed to use a composite slag-cement binder for the production of vibropressed roadbed slabs.

Today, the amount of PM particles in the air around the world is increasing, polluting the air. The main reason for this is the large amount of industrial waste, its non-recycling, the expansion of waste areas and the dumping of large amounts of waste into water resources. These harmful substances are causing widespread diseases among humanity.

In this article, we propose a simple, inexpensive, and safe method for disposing of slag waste.

Although slag is a waste product resulting from the melting of various substances, it can be used as a binder in the building materials industry.

Literature analysis shows that, based on previous studies, binder granules are crushed fractions of slag, the specific surface tension of which should not exceed at least 2000 m2/kg and a maximum of 3000 m2/kg. Slags with this surface tension are optimal for use in road construction and pavements.

Figure 1. Various types of pavement slabs

Currently, in developed foreign countries, natural stone and cement-based paving slabs are used in the construction of pedestrian crossings, squares and other road structures, and they have become very widely used in our country. Decorative concrete paving elements are increasingly used on sidewalks in city centers, playgrounds, pedestrian recreation areas, and pedestrian walkways of civil buildings. The main reason for this is their variety of configurations and rich colors (Figure 1). Also, the resistance of the paving slabs to various climatic conditions, frost and various climate changes ensures a long service life even in urban conditions [1-6].

Figure 2. Types of paving slabs

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Pedestrian paving slabs add a cultural and aesthetic appeal to urban or suburban areas, and replacing cobblestone and gravel pavements with concrete pavements has many advantages (Figure 2). The advantages of this type of pavement are ease of installation with minimal labor, attractive appearance, absence of small water puddles, and durability of paving slabs compared to other coatings [7].

At the same time, this type of pedestrian pavement can be used in the construction of highways. In this case, replacing asphalt concrete with concrete pavement helps to eliminate one of the current pressing environmental problems. Thus, the effect of evaporation on asphalt concrete surfaces, which increases in our region, especially on hot summer days, is often not taken into account. It is known that during the preparation and laying of hot asphalt concrete mixtures, this concrete releases polycyclic hydrocarbons. To improve the adhesive properties of the binder, surface-active additives, such as toxic coal tar products, are added to them during surface treatment. During operation, they are partially washed out and evaporated, thereby polluting the environment [8-10].

2. Materials and method

Experimental studies Laboratory tests using waste materials from copper mining at the Almalyk Mining and Metallurgical Combine were carried out using non-standard methods developed by scientific research specialists according to generally accepted standards.

The average density and water absorption of cement stone were studied in cubic samples measuring 2x2x2 cm in accordance with GOST 12730.1-78 and 12730.3-78, and the above-mentioned properties of cement-sand mixture and heavy concrete were studied in prisms measuring 4x4x16 cm and cubic samples with sides of 10 cm after drying to constant mass at a temperature of 105ºC.

Determination of water release of the components was carried out in accordance with GOST310.6-2020 “Cement. Method for determining water release”. When conducting research, 350 g of cement and 350 g of water are weighed. Cement is weighed to an accuracy of 1 g, and water is weighed to an accuracy of 0.5 g or measured in a beaker with a volume of 0.5 cm3.

Water is poured into a beaker, then the measured cement is added for 1 minute, the contents are continuously stirred with a metal spatula for another 4 minutes, and carefully poured into a graduated glass cylinder.

The cylinder is placed on a horizontal surface and the volume of the cement paste is marked on the cylinder scales (cm3). During the study period, the cylinder should be placed in a stationary position in a place free from air currents, vibrations, and other external factors.

The grinding process of mineral raw materials was carried out in the impact-erosion mode of a ball mill. The dispersion of the obtained minerals was evaluated by the relative surface area on the PSX-11A device. The relative surface area on the PSX-11A device is determined based on the Kozeni-Karman method (via the air permeability and porosity of the compacted powder layer). The granulometric composition of microfillers was studied by laser particle diffraction on the MicroSizer 201 device. This method allows for a complete distribution of particle sizes and obtaining accurate results. The MicroSizer 201 device allows for the study of particles from 0.2 to 600 microns and dividing the specified range into 40 fractions.

3. Results and discussion

The transition to the construction of rigid road structures using cement as a binder reduces the total emissions of dust particles and toxic substances released during the asphalt concrete production process (Table 1) [11].

Table 1

The amount of harmful gases emitted from surfactants

The substance name	Concentration, g/m
Inorganic dust	12-40
Sulfur dioxide	0.016
Carbon oxide	0.0008
Nitrogen oxides	0.00007

A decisive factor in favor of expanding the construction of cement-concrete pavements in the future is the indispensability of bitumen in the repair of almost all types of pavements. Unlike bitumen, the raw material reserves for the production of cement are almost unlimited [12-13].

One of the important properties of concrete mixtures for monolithic structures is not only viscosity, but also flowability and its change over time. For this reason, the change in flowability of concrete mixtures over time for composites was studied (Figure 3).

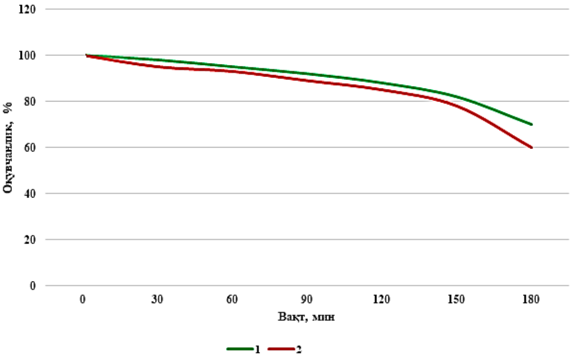

Figure 3. Change in flowability of concrete mix over time (1-Cement + OKMK microfiller; 2-cement)

Analysis of the obtained data shows that the control compositions of the concrete mix with a KCH of 4-6 cm lose their initial fluidity after 20-30 minutes. The addition of the SP modifier extends the period of formation of the coagulation structure and maintains the fluidity of the concrete mix for a long time. After 2 hours, the fluidity index of this composition is 85-88% of the initial value.

The finite element method uses a numerical approach to solve complex engineering problems. It allows you to approximate complex geometric structures and materials by dividing them into simpler elements. This method is widely used in various fields such as mechanics, heat transfer, electromagnetism, etc. We will consider the basic principles of the finite element method, its advantages and disadvantages, as well as examples of its application.

The finite element method (FEM) is a numerical method used to solve various mathematical modeling and analysis problems. It is based on dividing a complex geometric domain into simpler subdomains called finite elements. Each finite element represents a small part of the domain for which the mathematical model can be easily defined and solved analytically or numerically.

The finite element method is widely used in various fields such as mechanics, heat transfer, electromagnetism, fluid dynamics, etc. It allows modeling and analyzing the behavior of complex systems such as mechanical structures, electrical circuits, thermal processes, etc.[1]

The basic idea of the finite element method is to approximate the solution of the problem over the entire domain by combining the solutions of individual finite elements. To do this, each finite element is described by a set of equations that relate the values of the desired function and its derivatives at the boundaries of the element under consideration.

4. Conclusion

It was found that using 12% micro aggregate is sufficient to obtain a self-compacting concrete mix with a low viscosity value. Using 8% slag increases the effect of reducing the viscosity of the concrete mix.

The use of microfiller admixture and binary microfiller allows maintaining the flowability of the concrete mix for 100-120 minutes, which helps to increase the efficiency of the self-compacting mix for monolithic pedestrian pavement.

Mathematical models were obtained that depended on the strength of concrete, microfiller additives, cement consumption, recipe, and technological factors, based on which the composition of the concrete mix was optimized.

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Modeling of curing under IR lamp of multilayer fiberglass parts based on epoxy binder and determination of heating effect on the process kinetics

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Abstract: The results of modeling the kinetics of the heating process of a 20 mm thick GFRP part are presented. Exothermic effects related to the peculiarities of epoxy binder curing were taken into account during modeling. Using Siemens NX software, the temperature distribution along the thickness of the fiberglass sample was determined. It was found that the curing process of composite structures of large thickness is significantly influenced by self-heating of oligomer, as well as the changing value of volumetric heat capacity in the process of polymerization.
Keywords: fiberglass, glass fiber-reinforced polymer (GFRP), epoxy binder, curing, infrared heating

1. Introduction

Nowadays, such polymer composite materials as glass plastics, organoplastics and basalt plastics are becoming more and more widespread and are used in aircraft construction, mechanical engineering, in the manufacture of rocket and space technology products and in many other industries [1, 2]. If the reinforcing filler in such PCMs is a fabric, in conditions of single and small-scale production, the main technology of parts manufacturing is vacuum infusion, and in conditions of mass production - pressure impregnation (a variation of which is RTM technology) [3].

As a rule, epoxy materials are used as a binder in the production of composite structures, the curing of which can occur at elevated temperatures ranging from 100°C to 200°C. The process of curing (or formation of mesh polymers) is an irreversible transition of the binder from liquid to solid state, which leads to polymers with a spatial structure. The choice of curing temperature is determined by the composition of the binder used, however, the kinetics of the heating process and the total duration of the curing process is influenced by the heat transfer mechanism, which is completely determined by the technological equipment used. In addition, the effect of self-heating has a significant influence, which is greater the greater the height of the liquid column of the polymerizing oligomer.

Most fiber reinforcing materials have low thermophysical characteristics (heat capacity and thermal conductivity), which leads to the occurrence of large temperature differences across the thickness of the composite structure during curing. Such reinforcing fillers include glass, basalt and organic fabrics (tapes, fibers). In the scientific literature, much attention has been paid to the study of the kinetics of the heating process during the curing of PCM parts, including glass-reinforced plastics [4-8], however, the vast majority of researchers considered only heating under convection conditions, in which drying cabinets (or ovens) are used as the technological equipment for heating. Nowadays, infrared heating units (IR units), which provide fast heating of thin-walled composite structures to temperatures of +150°C and even more due to radiation, are becoming more and more widespread.

The aim of the work is to study the kinetics of the curing process of fiberglass parts under the influence of infrared heaters of different radiation power.

2. Objects and methods of research

Theoretical evaluation of temperature distribution in the process of heating the part depending on the power of the used heater is carried out in this work. The calculation model is a square part made of fiberglass (Table 1) with geometric dimensions of 200x200x20mm. The tooling is made of the same material as the part. Stochastic glass mat was used as filler, which allowed to consider this PCM as isotropic. As a binder the epoxy composition of VSK-14-1 grade was used, which is widely used in aircraft construction.

Table 1

Properties of GFRP

Density, kg/m^2	1800
Specific heat capacity, J/(kg·°C)	900
Thermal conductivity, W/(m·°C):):	
λ_1	0,55
λ_2	0,55
λ_3	0,51
Coefficient of thermal expansion, °C^{-1}	5·10^6

The simulation process was performed in the CAD/CAM/CAE program Siemens NX in the Pre/postprocessor application with tools for finite element modeling and visualization of results, which includes reference multidisciplinary simulation workflows.

The modeling process consisted of several steps:

- creation of an electronic geometric model of the part and tooling;
- creation of a finite element model that takes into account material properties and thermophysical properties of the structure;
- setting of boundary conditions and loads on the modeling object.

In addition, convection is modeled on all surfaces of the part, except for the bottom surface, to take into account the

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characteristics of the environment - the air in the room. For this purpose, characteristics such as:

- convection coefficient, with a value of 15 $\frac{W}{m^2K}$;
- the initial ambient temperature is 25°C.

But at the same time, the settings were set to heat the ambient air at a rate of 0.5$\frac{°C}{min}$ max. to 36°C.

The next step was to set the radiation heating directed from the heaters from top to bottom on the part. The settings were:

- IR spectrum;
- value of heat loads at different lamp heating modes of 1600W and 2400W.

The thermo-optical properties of fiberglass with an emission coefficient equal to 0.8 were set for the parts.

The values of heat load, depending on the power of the used heating source, are given in Table 2.

Table 2

Heat load values as a function of time per grid element

Time, minutes	IR lamp power, W	Heat load
0-37	1600	0,05
37-40		0,14
40-…		0,27
0-20	2400	0,07
20-23		0,1
23-…		0,35

3. Results and discussion

Figure 1 shows the temperature distributions on the top, center and bottom of the part at 55 minutes of heating. Initially, heating was carried out to a temperature of +120°C. It was assumed that the heating duration would not exceed 30 min. Figs. 2 and 3 show how the temperature value changes along the thickness of the GFRP part depending on the power of the IR unit used for heating.

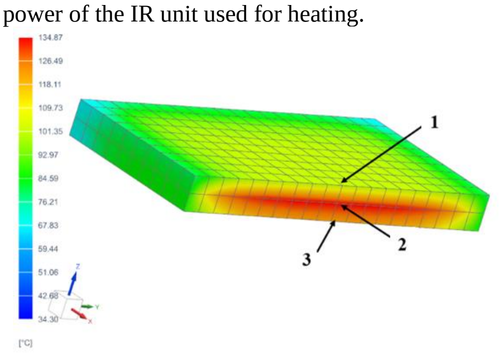

Figure 1. Example of temperature calculation on different parts of the part: 1 - top; 2 - middle; 3 - bottom

As a result of calculations, it was found that at the power of the heating unit of 1600 W (Fig. 2) it is not possible to provide heating to the required temperature for a given period of time (30 min) and therefore we limited heating to a temperature of +110°C. At 35 min, the heating was turned off, resulting in the top of the part cooling very quickly to a temperature of +80°C. However, at the same time, an exothermic reaction began, which actually provided an additional source of heat, allowing the temperature in the middle part of the part to reach +130°C at 55 minutes. The exothermic reaction provided heating of the middle and bottom parts of the part, e.g., the temperature on the bottom part of the part reached a temperature of +100°C only by 60 min. Thus, the use of an IR unit for heating, with a power of 1600 W not only does not provide uniform heating of the fiberglass part thickness, but also does not allow to reach the required heating temperature in a given period of time. At 60 minutes of heating, the difference between the top and bottom of the GFRP part was just over 20 °C.

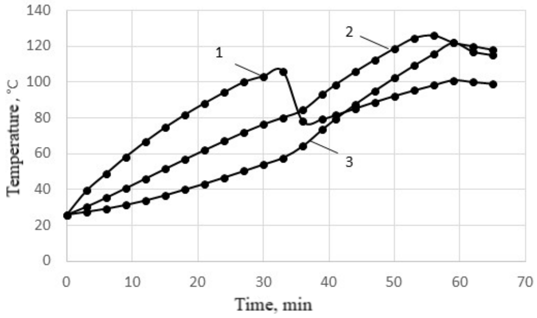

Figure 2. Temperature gradient along the thickness of the specimen at 1600W heater power for different parts of the part: 1 - top; 2 - middle; 3 - bottom.

Analysis of the results shown in fig. 3, allows us to draw the following conclusions: at a power of 2400 W the fiberglass part is heated significantly faster and reaches the temperature +160°C within 30 min. However, the character of temperature distribution in different parts of the part is completely similar to that presented in Fig. 2, i.e. immediately after switching off the heating source, there is a rapid cooling of the upper part of the part, while the middle and lower parts, on the contrary, are heated. Thus, at the peak of the exothermic reaction, a more uniform heating of all layers and reaching the required temperature values is observed over the entire time interval. At 50 minutes of heating, the difference between the upper and lower parts of the GFRP part was about 10°C.

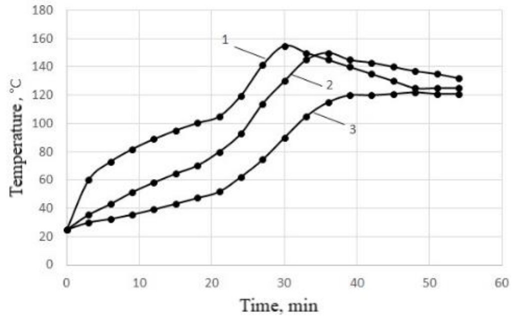

Figure 3. Temperature gradient along the specimen thickness at 2400W heater power for different parts of the part: 1 - top; 2 - middle; 3 - bottom

As the thickness of the part decreases, there is a proportional decrease in the values of the temperature gradient along the thickness, and for fiberglass parts, 5 mm thick, it is not more than 15°C, and for parts, 10 mm thick, it does not exceed 26°C.

4. Conclusion

A model of isotropic fiberglass plastic was developed and calculations were performed to determine the kinetics of temperature changes in different parts of the part (top, middle and bottom) when using infrared units for heating.

As a result of these calculations it was found that for an isotropic fiberglass part with a thickness of 20 mm, it is not possible to ensure its uniform heating along the thickness when using infrared heating units with a given power of 1600W and 2400W. The comparative analysis of two considered installations showed that only the installation with the power of 2400W allows to provide heating of the upper part of the fiberglass part up to the set temperature of +130°C for 22 min, but the values of temperature gradient along the thickness amounted to 45°C.

Thus, only the IR-heating unit with the power of 2400 W can be used for curing of GFRP parts with the thickness of 20 mm and more.

The structural properties are much better for composite parts with foam filler. While the Airex is about 1.5 times thicker, it is 4 times lighter than impregnated non-woven reinforcement material.

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Investigation of impregnation speed depending on fillers during the manufacturing of parts by the vacuum infusion method

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Abstract: In the article examines the process of manufacturing three-layer carbon-fiber-reinforced plastic (CFRP) panels using the vacuum infusion method. A comparative analysis is conducted to assess the impact of various fillers on the manufacturability of the three-layer panel. Specifically, the study compares the impregnation speed of the part depending on the type of filler used.
For the research, the layers of carbon fabric and filler were laid simultaneously before sealing with vacuum film. A comparison was made between the manufacturability of using a non-woven reinforcing material (Soric) and polystyrene foam (Airex).
Keywords: polymer composite materials, carbon-fiber-reinforced polymer, vacuum infusion, filler, non-woven reinforcing material, polystyrene foam

1. Introduction

Polymer fiber composites have become indispensable in the aviation industry due to their unique combination of structural and special properties. Composite materials are an excellent alternative to traditional materials, as they offer significant advantages in terms of specific strength and stiffness. However, composite material products have significant anisotropy of properties. The three-layer design of the panels allows to adjust their stiffness anisotropy within wide limits, significantly increasing the stiffness of the structure with a slight increase in mass.[1]

The principles of operation of I-beam and three-layer structures are identical. In a three-layer structure, the role of the wall is played by the filler, due to which the load-bearing layers are separated, which gives the package of layers high characteristics of stiffness and strength at a relatively low weight. By combining materials of bearing layers and filler, it is possible to achieve the desired physical and mechanical properties of three-layer structures. The outer layers are called bearing layers and the inner layer is called filler. The outer layers are made of stronger materials (carbon fiber reinforced plastic). The inner layer (filler) is made of relatively low-strength materials with low density (nonwoven materials, plastic, polymer foam, lightweight methane.[2]

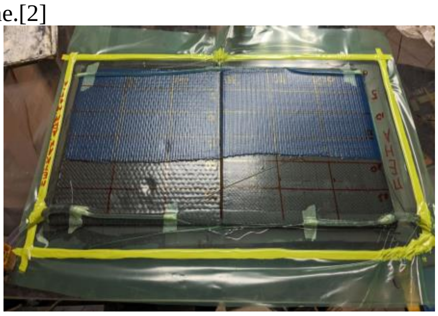

Figure 1. Test specimen

For products with small wall thicknesses, the most suitable is the technology of three-layer plate production, the carbon fiber cladding that is produced directly during panel forming by vacuum infusion. This production technology does not require expensive equipment and a large-sized production room, but makes it impossible to use honeycombs and corrugations as filler.

2. Research methodology

Degassed binder is fed into the prepared samples under pressure P=0.9 atm through the drainage system and distributed over the surface of the sample using a distribution grid. Then the binder is distributed on the package.

The package surface is marked in the Cartesian coordinate system to simplify the tracking of the binder front movement. During the experiment, time-synchronized photographic recording of the test was performed. During the test, the movement of the binder front was tracked from the top and bottom sides of the plates. Figure 2 is labeled: 1 - specimen with nonwoven reinforcing filler, 2 - specimen with foam, 3 - sacrificial fabric layer, 4 - conductive mesh, 5 - spiral tube, 6 - binder supply tube, 7 - tubes of connection to vacuumization unit.

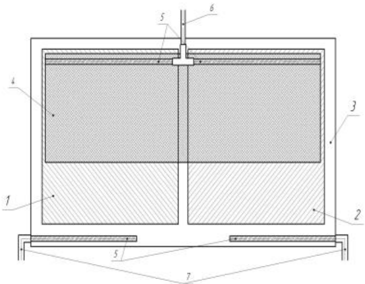

Figure 2. Schematic of the test specimen

3. Materials

2 laminates with dimensions of 300 x 300 mm were prepared as samples: 1st of 5 layers of carbon fabric, non-woven reinforcing material, 5 layers of carbon fabric; 2nd of 5 layers of carbon fabric, layer of perforated foam, 5 layers of carbon fabric. The detailed characteristics are summarized

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in Table 1 and Table 2. A glass plate was chosen as the tooling. On top of the carbon fabric, 1 layer of sacrificial fabric and a layer of conductive mesh were placed over the entire area.

Table 1

Characteristics of carbon fabric

Carbon fabric	
Weave type	Twill
Fiber	UMT45
Surface density, g/m²	240
Reinforcement directions, °	+45/-45

Table 2

Characteristics of fillers

Fillers	
Material type	Non-woven reinforcing material
Material grade	Lantor Soric XF
Density, g/m²	180
Impregnated density, kg/m³	600
Thickness, mm	3
Material type	Structural foam
Material grade	AIREX C70
Density, g/m²	200
Impregnated density, kg/m³	70
Thickness, mm	5

Table 3

Characteristics of consumables

Material type	Peel ply
Density, g/m²	80
Material type	Resin-conducting mesh
Surface density, g/m²	160

Table 4

Technological characteristics of epoxy resin

Wide processing window	2 hours
Initial viscosity, mPa*s	300
Binder temperature, °C	17-30

The first advantage of nonwoven reinforcing material - flexibility - is revealed at the stage of package molding; in order to bend the foam, it is necessary to heat it up to 70°C. It is also necessary to perforate the foam to improve the impregnation of the lower crust. However, the impregnated density of the foam is much lower.

4. Results and discussion

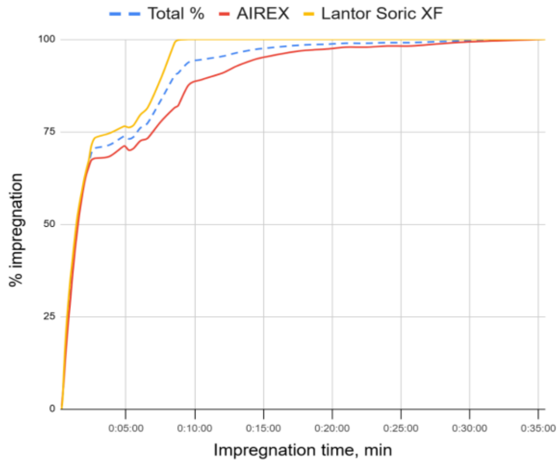

Figure 3. Graph of time dependence of percentage of binder impregnation on the top part of the plate

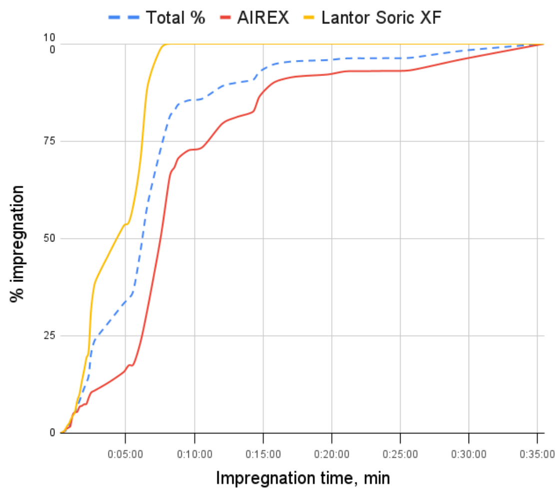

Figure 4. Graph of time dependence of the percentage of binder impregnation of the bottom part of the plate

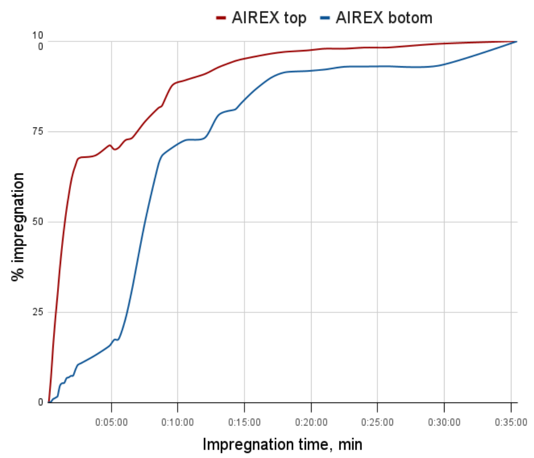

Figure 5. Graph of time dependence of the percentage of binder impregnation of the top and bottom part of the AIREX plate

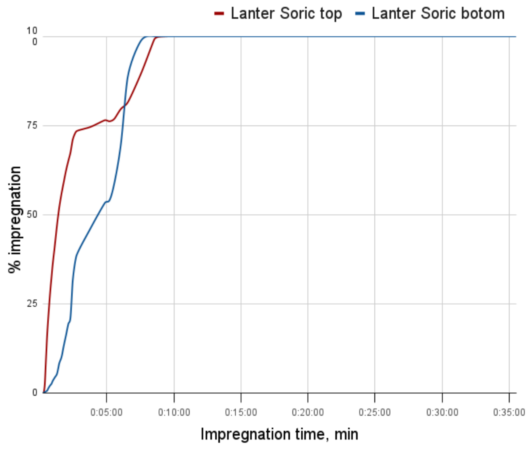

Figure 6. Graph of time dependence of the percentage of binder impregnation of the top and bottom part of the SORIC plate

Based on the processed results (fig. 3-6), the impregnation of the bag can be divided into 3 stages: 1 all inlets and outlets were open, until the binder passed through the entire distribution grid; 2 blocking the exit on the foam side; 3 Opening the exit on the foam side and blocking the exit on the SORIC side. The plate with SORIC soaked 3.7 times faster (9:20) than the similar plate with Airex(35:15). The lower crusts of both plates soaked much slower than the upper crusts, this is due to the presence of a distributing grid on the top. However, as soon as the binder front has reached the end of the distribution grid, the lower crust of the plate with SORIC starts to soak much faster than the upper crust due to the good conductivity of the non-woven filler. In the case of foam, this does not happen due to its lack of any conductivity.

5. Conclusion

Technological properties of non-woven reinforcing material are much better than similar properties of foam filler. Soric is easier to lay out, it is much better impregnated (3.7 times faster than foam).

When using non-woven reinforcing materials, it is necessary to leave a much larger retaining strip because of their good conductivity.

The structural properties are much better for composite parts with foam filler. While the Airex is about 1.5 times thicker, it is 4 times lighter than impregnated non-woven reinforcement material.

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Strength requirements for locomotive load-bearing structures: a literature review

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Abstract: This analytical article explores the strength assessment of locomotive load-bearing structures, focusing on the critical role these components play in railway safety and efficiency. The article examines international and national standards, including EN 12663, EN 13749, and GOST 34939-2023, outlining their requirements for structural design, fatigue resistance, and testing methodologies. It highlights key aspects such as permissible stresses, material selection, and advanced evaluation methods, providing a framework for structural health monitoring and maintenance optimization. By addressing emerging technologies and their potential impact, this study offers valuable insights into the challenges and opportunities in modern railway engineering, emphasizing the necessity of rigorous and standardized approaches to structural analysis.
Keywords: traction rolling stock, locomotive, load-bearing structures, strength assessment, stress-strain state, static strength, fatigue strength

1. Introduction

The load-bearing structures of locomotives serve as the backbone of railway vehicles, transferring forces, absorbing impacts, and ensuring operational stability [1-12]. Given their exposure to dynamic loads, fatigue stresses, and environmental conditions, the accurate assessment of their strength is paramount for design validation and operational safety [13-15]. These critical components, including frames, bogies, and suspension systems, form the foundation of safe and efficient railway operations [16-18]. Recent advances in materials science and computational methods have revolutionized how engineers assess and predict structural behavior under various loading conditions. Modern engineering approaches aim to achieve an optimal balance between structural robustness and weight efficiency, demanding increasingly precise evaluation techniques.

The evolution of railway transportation systems has highlighted the critical importance of structural integrity assessment in preventing operational disruptions and ensuring public safety. While traditional evaluation methods have served the industry well, emerging technologies and analytical approaches offer new opportunities for enhanced structural health monitoring. These developments come at a crucial time, as railway operators worldwide face mounting pressure to extend equipment life cycles while maintaining rigorous safety standards. The integration of advanced materials, sophisticated computational models, and innovative testing methodologies presents both opportunities and challenges for the railway industry.

This review examines current methodologies for evaluating the strength of locomotive structural components, focusing on structural analysis techniques, material testing, and non-destructive evaluation (NDE) methods [19]. By comprehensively analyzing these approaches, this study aims to provide railway operators and engineers with a framework for implementing effective structural health monitoring systems, optimizing maintenance interventions, and enhancing overall railway safety and reliability. Furthermore, this research addresses the growing need for standardized evaluation protocols that meet both regulatory requirements and practical operational demands in modern railway systems.

The scope of this investigation encompasses both theoretical foundations and practical applications, with particular attention to emerging technologies that promise to transform traditional assessment methods. Through critical analysis of current practices and exploration of future possibilities, this study contributes to the ongoing dialogue about the evolution of structural integrity assessment in railway engineering. The findings presented here have significant implications for industry practitioners, regulatory bodies, and researchers working to advance the field of railway structural analysis.

2. Research methodology

Key regulatory documents

The evaluation of locomotive load-bearing structures requires strict adherence to a complex framework of regulatory and technical documentation. This analysis examines the current state of international and national standards, technical specifications, and regulatory requirements governing the assessment of structural integrity in railway applications.

Below is a list of international and national regulatory technical documents governing the assessment of the strength of load-bearing structures in locomotives:

- EN 12663: - Railway applications. Structural requirements of railway vehicle bodies [20];
- EN 13749: - Railway applications - Wheelsets and bogies - Method of specifying the structural requirements of bogie frames [21];

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- GOST 34939 Locomotives. Requirements for bearing structure strength and dynamic properties [22].

Requirements for locomotive bodies in accordance with EN 12663

EN 12663 is a European standard that defines structural requirements for railway vehicle bodies, ensuring safety, reliability, and performance. It is mandatory for railway manufacturers and operators in the European Union and serves as a benchmark globally.

The standard outlines comprehensive guidelines for the structural design and strength of passenger and freight vehicles. Key aspects include:

- Defining structural strength requirements for various vehicle types;
- Specifying load cases and design criteria under static and dynamic conditions;
- Establishing rules for mechanical strength and load-bearing structures;
- Setting requirements for body shell design and structural integrity.

EN 12663 ensures that railway vehicle structures are robust enough to withstand operational stresses and comply with stringent safety standards, making it critical for the design and maintenance of rolling stock in Europe and beyond.

Key aspects of strength requirements

The standard defines strength requirements through several key aspects:

1. Structural Load Cases

The standard specifies multiple load cases that railway vehicle bodies must withstand:

- Vertical static loads;
- Longitudinal static loads;
- Lateral static loads;
- Torsional loads;
- Fatigue loads;
- Exceptional loads (including potential collision scenarios).

2. Design Categories:

Strength requirements vary based on the vehicle category (L, P-I to P-V, F-I, F-II), with different design criteria for:

- Locomotives L;
- Passenger vehicles (urban rail vehicles, light rail vehicles) P;
- Freight vehicles F.

3. Key Strength Parameters:

- Maximum allowable stress levels;
- Deformation limits;
- Structural integrity under different load conditions;
- Fatigue life requirements;

Safety factor calculations

Permissible stresses for materials

When assessing structural stresses, the analysis must align with established material standards from European or national sources. It's crucial to carefully interpret stresses derived from finite element analysis or strain measurements.

For materials with ductile properties, a linear elastic analysis requires verifying that the stress range meets specific local stress concentration criteria.

$$|\sigma_{max} - \sigma_{min}| \leq 2 \times \frac{R}{S_1} \qquad (1)$$

where

σ_{max} - is the maximum calculated stress of all static load cases;

σ_{min} - is the minimum calculated stress of all static load cases;

σ_{max} and σ_{min} - are oriented in the same direction;

R - is the material yield (R_{eH}) or 0.2 % proof stress (R_{p02}), in N/mm^2;

S_1 - is the safety factor (1.15 or 1).

Material strength limits should be defined by the lowest proof or yield strength and ultimate strength specified in the material's technical documentation.

For fatigue loading characteristics, engineers should rely on established standards from European, International, or national sources. If standard reference data is unavailable, organizations must conduct specialized tests to develop verified material performance information. When existing sources are insufficient, alternative credible references of equivalent quality may be used to determine material fatigue behavior.

Requirements for locomotive bogies in accordance with EN 13749

EN 13749 is a European Standard that specifically relates to the design and testing of railway bogie frames and associated components. This standard provides technical specifications and requirements for the design, calculation, and testing of railway bogie frames and their structural elements (bolsters and axlebox housings).

Key aspects typically covered in EN 13749 include:

- Structural design requirements for railway vehicle frames;
- Stress analysis methodologies;
- Fatigue and load testing procedures;
- Material selection and performance criteria;
- Safety and reliability standards for railway vehicle structures.

The standard is particularly important for manufacturers and engineers involved in designing railway rolling stock, ensuring that bogie frames meet rigorous safety and performance standards across European rail systems.

Key aspects of strength requirements according to EN 13749

EN 13749 outlines specific strength requirements for railway bogies, focusing on structural integrity, safety, and durability under various operational conditions. Here are the key aspects:

1. Static Strength:

- Defines load cases to simulate typical operating and extreme conditions (e.g., vertical, lateral, and longitudinal forces);
- Requires safety factors to account for uncertainties in material properties, manufacturing, and usage;
- Ensures bogies can withstand loads during normal operation and overload scenarios without permanent deformation or failure.

2. Fatigue Strength:

- Specifies cyclic loading tests to evaluate resistance to material fatigue over the bogie's service life;
- Includes stress limits and load cycles based on operational and environmental conditions;
- Focuses on critical components such as axles, frames, and welds.

3. Material and Joint Requirements:

- Specifies minimum properties for materials used in bogie construction, including high strength and fatigue resistance;
- Includes stringent requirements for welding quality and inspection to prevent structural weaknesses.

These requirements ensure bogies are designed to handle operational stresses reliably, reducing the risk of structural failure and enhancing railway safety.

Fatigue tests

The fatigue tests include dynamic twist loads, representing the stress on the bogie frame when navigating a 0.5% track twist. The programme has three stages (Figure 1):

1. **Stage 1:** 6 million cycles of vertical and transverse forces, plus 0.6 million cycles of twist loads.
2. **Stage 2:** 2 million cycles of vertical and transverse forces, with quasi-static and dynamic components increased by 20%, and 0.2 million cycles of twist loads, also increased by 20%.
3. **Stage 3:** Same as Stage 2, but with a 40% increase instead of 20%.

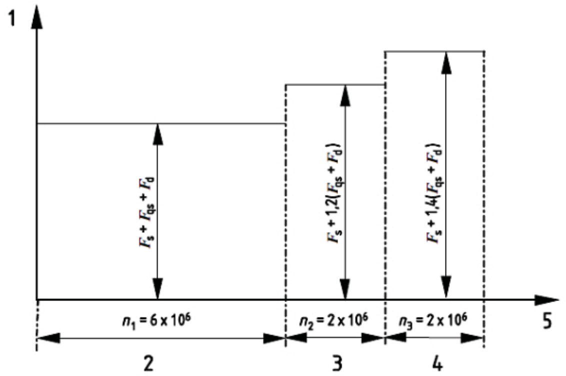

Figure 1. Variation of vertical and transverse force magnitudes during the test:
1-force magnitude; 2-first load sequence; 3-second load sequence; 4-third load sequence; 5-cycles

Requirements in accordance with GOST 34939-2023

GOST 34939-2023 is an interstate standard that establishes specific requirements for the strength and dynamic characteristics of locomotives intended for operation on railways with various speed regimes [23]. This standard plays a crucial role in ensuring the safety and reliability of railway transport.

Key strength requirements

The standard covers a wide range of requirements aimed at ensuring the strength and durability of locomotives:

- Strength of the running gear components: Special attention is paid to the strength of the frame, bogies, suspensions, and other elements that ensure reliable interaction between the locomotive and the railway track.
- Structural rigidity: The standard establishes requirements for the rigidity of load-bearing structures to minimize deformations and vibrations occurring during locomotive movement.
- Service life of components: Permissible wear and damage values for various locomotive components are determined to ensure their safe operation throughout their service life.
- Fatigue resistance safety factors: The fatigue resistance safety factors have been refined based on the intensity of locomotive operation, ensuring reliability under different operating modes.
- Operating conditions: The standard takes into account various operating conditions of locomotives, including climatic factors, loads, and other external influences.

The load-bearing capacity of the crew compartment structural elements is evaluated under the design loads established by this standard according to the permissible values of:

- stresses;
- strains;
- fatigue resistance safety factors;
- stability safety factors.

Stresses in structures under design loads must not exceed the permissible values given in Table 1.

The strength of the body (main frame) under the action of the standard longitudinal force applied along the axes of the coupling devices should be confirmed by collision testing, as well as by calculation or results of static bench tests with two-sided compression and tension. The following conditions determine the strength of the body (main frame):

- during impact testing: $\sigma \leq \sigma_{0.2}$;
- under static loading: $\sigma \leq 0.9\sigma_{0.2}$.

where $\sigma_{0.2}$ is the yield strength of the material used in manufacturing;

σ is the stress corresponding to the standard longitudinal force.

The fatigue resistance safety factors for the structures of the vehicle body (excluding wheelsets, traction drive shafts, gear wheels, and suspension springs) must be at least:

- 2.0 for steel structures;
- 2.2 for aluminum alloy structures.

To assess the fatigue resistance of bogie frames and intermediate frames (beams, crossbeams, etc.) of the secondary suspension system, bench vibration tests are conducted based on 10 million loading cycles. One sample is subjected to testing.

The stability factor for body elements (main frame) should be at least 1.10 for design modes I and IV.

Methods for strength evaluation

To confirm the conformity of locomotives to the requirements of GOST 34939-2023, the following methods of strength assessment are applied:

- Calculations: Complex engineering calculations are conducted using modern software to evaluate the strength of locomotive components under various loads.
- Tests: Locomotives undergo various tests, including static and dynamic, to verify their strength and reliability under real operating conditions.

Material quality control: The quality of materials used in locomotive manufacturing is rigorously monitored to ensure their compliance with established requirements

Design load cases

Calculation modes I-IV are used to assess strength based on permissible stresses (Table 1) relative to the material's yield strength.

To assess fatigue resistance, calculation mode III is used.

Mode I include:

- Mode Ia for accounting for maximum longitudinal quasi-static forces;
- Mode Ib for accounting for maximum longitudinal impact forces on the coupling device.

Mode II includes:

- Mode IIa for accounting for forces acting when moving in curved sections of the track with the maximum allowed uncompensated acceleration;
- Mode IIb for accounting for forces acting during start-up;
- Mode IIc for accounting for forces acting during emergency braking.

Mode III takes into account forces acting at various speeds, up to the design speed, along a straight section of track.

Mode IV is designed to account for forces caused by repair technology and emergency restoration work, arising:

- When lifting the body (main frame) on two diagonally positioned jacks;
- When lifting the locomotive by the automatic coupling device assembly;
- When rolling out a wheelset.

Table 1

Permissible stresses for body elements and bogies

Calculation mode	Permissible stress for elements	
	Body (main frame)	Bogie
Mode I, IV	$0.9\sigma_{0.2}$	
Mode II, III	$0.6\sigma_{0.2}$	

3. Conclusion

The evaluation of locomotive load-bearing structures is a cornerstone of railway safety and operational reliability. Through a detailed examination of standards such as EN 12663 and EN 13749, the article demonstrates the significance of structural design, material selection, and fatigue testing in meeting stringent safety requirements. GOST 34939-2023, with its specific provisions for different operational modes and climatic conditions, underscores the regional adaptability of such standards.

The study also reveals the transformative potential of advanced materials and computational methods in enhancing structural assessment, offering pathways to achieve a balance between robustness and weight efficiency. However, the integration of these technologies demands harmonised regulatory frameworks and comprehensive testing protocols to ensure consistent application across the industry.

Future advancements in structural health monitoring, including non-destructive evaluation techniques and predictive analytics, promise to revolutionise maintenance strategies, extending the lifecycle of railway equipment while maintaining safety and performance. This research reinforces the imperative for continued innovation and standardisation, enabling railway systems worldwide to meet the growing demands of safety, reliability, and sustainability.

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Principles of forming an innovative architectural and planning structure for preschool institutions

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Abstract: The article is devoted to the study of foreign experience in designing innovative-type preschool institutions for children. The analysis of design solutions has allowed us to identify the main principles of architectural and planning structure of preschool institutions, taking into account climatic, geophysical and national characteristics of the region: providing multifunctional educational process, transformation of space, mobility, inclusiveness, architectural expressiveness, integration with the landscape, implementation of the principles of sustainable architecture. The established principles can contribute to the creation of innovative types of educational preschool institutions capable of meeting the needs of modern society in the Republic of Uzbekistan.
Keywords: preschool institution, architectural and planning structure, planning modules, space transformation, kindergarten architecture, educational environment

1. Introduction

A characteristic feature of modern society is the activation of innovative processes in education, including preschool education. Teaching standards and methods are changing, and components of the educational process are being updated to ensure its mobility, flexibility, and variability. Moreover, the rapid development of information technologies, the need to create an atmosphere of creativity, and the trend towards child-centered education require special organization of the architectural and planning space of preschool institutions. As a result, existing standard designs for nurseries and kindergartens do not meet the demands of the times, and architects and designers face the challenge of developing new conceptual approaches to the design of preschool buildings. In foreign countries, considerable work is being done to expand the typology of preschool buildings, demonstrating a variety of approaches to their design and an effort to align them with the concept of modern preschool education development [1, 2, 3, 4]. Therefore, studying and borrowing foreign experience may help create a domestic innovative architectural and planning structure for preschool institutions that takes into account the climatic, geophysical, and national characteristics of the region.

2. Results and discussion

2.1. Foreign Experience in Designing Preschool Institutions

To establish modern trends in improving the architectural and planning structure of preschool institutions, recent projects of such buildings were studied. It should be noted that all of these buildings implemented common principles, such as considering child psychology, creating environments that develop children's intellectual, physical, and creative abilities, using environmentally friendly materials, applying unconventional energy sources, creating bright and unusual architectural forms, and adapting to the surrounding landscape. However, the primary interest for our research was focused on objects with new functional and planning solutions for preschool buildings.

For example, the kindergarten in Vinh (Vietnam, 2019) can be characterized as a developing, safe, and sustainable facility (Fig. 1) [5]. In addition to the standard set of rooms, this kindergarten features new functional spaces, such as a sports center with a swimming pool, art classrooms, a media center, and open recreation areas that are oriented towards active learning and interaction with the surrounding natural environment.

Fig. 1. The kindergarten in Vinh, Vietnam [5]

The Kaleidoscope Kindergarten in Tian Shui (China, 2020) is notable for its planning, which includes a three-story multifunctional atrium that can be used depending on the events being held (Fig. 2).

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Fig. 2. Interior with atrium of a kindergarten in Tianshui, China [5]

In the kindergarten building in Wuxi (China, 2014), one of the main principles is ensuring the safety of children in the midst of multi-story buildings and intensive traffic on nearby streets. This is achieved by creating an inner courtyard for children's walks and play, located at the center of the building in an oval shape (Fig. 3).

Fig. 3. Kindergarten building in Wuxi, China [5]

The method of internal transforming spaces is implemented in the innovative kindergarten in Stupino (Russia, 2023) (Fig. 4). Here, the technology of transforming partitions allows the expansion of play areas or, conversely, the partitioning of a small part of the room for educational activities [6].

Fig. 4. Kindergarten in Stupino (Russia)

The Timayui preschool in Santa Marta (Colombia, 2011) was designed based on a universal modular system (Fig. 5) [7]. Each module consists of three rectangular blocks: two contain group rooms, and the third is a multifunctional open room with sanitary facilities, connected by a recreational area. The modules are linked by galleries and can be adapted for other purposes, such as kitchens, dining rooms, and service areas.

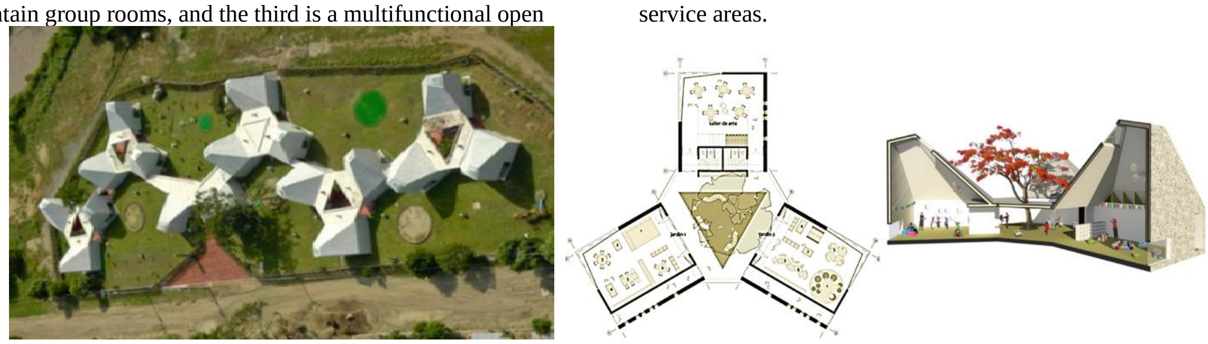

Fig. 5. Timayui kindergarten in Santa Marta, Colombia [7]

This modular structure allows the building to have flexible planning and the potential for "growth" (adding more modules) if needed due to functional requirements or increased capacity.

The analysis of modern foreign preschool buildings has allowed us to identify key principles for forming an innovative architectural and planning structure for these institutions, which have been further adapted to the climatic, geophysical, and national characteristics of Uzbekistan.

2.2. Principles of Forming the Architectural and Planning Structure of Innovative Preschool Institutions for the Republic of Uzbekistan

1. Ensuring the Multifunctionality of the Educational Process.

The modern preschool education system is highly dynamic, responding to the needs of society and individuals. It must guarantee a high level of education necessary for a child's comprehensive development and successful socialization, as well as the development of skills such as curiosity, creativity, and communication. Therefore, the structure of preschool institutions should include an increased number of rooms for educational, creative, cognitive, research, play, and sports purposes: media centers, libraries, museums, exhibitions, art workshops, music and dance classes, playrooms, sensory and cognitive development centers, recreational spaces, swimming pools, physical education halls, etc.

Spaces for cognitive research activities, defined by short-term sessions, can also be used by children who live in the area but do not attend the preschool regularly.

2. Transformation of Space

The emergence of various functional and spatial areas within preschool institutions requires rational use of space, minimizing underutilized corridors and passageways. One of the ways to achieve this is by implementing transforming partitions, which allow large spaces to be divided into smaller zones or, conversely, combine small rooms into one large space.

For example, group rooms in modern preschools should be flexible and adapted to changing ecosystem conditions. The classic zoning scheme, based on isolating rooms (cloakroom, group room, bedroom, bathroom), no longer meets these requirements. Transforming partitions can be used to include additional spaces such as recreation areas and corridors into the required zone.

Another example could be the transformation of adjacent halls for physical and music classes, separated by a transforming partition, which can be combined if needed for mass events. Additionally, if there are rooms such as a dance hall or storage rooms next to these halls, transforming partitions can create additional space for temporary seating during holidays or sports events.

3. Mobility

A preschool building should be able to change in line with the rapid development of innovative pedagogical technologies, improvements in teaching methods, and societal needs. The most convenient spatial structure is modular, allowing for gradual expansion and transformation of the building. However, the territory of the preschool institution should also have corresponding reserves.

4. Inclusivity

Preschools should integrate children with disabilities, creating conditions for the successful learning and development of every child. Buildings should ensure comfortable movement through ramps, elevators, and wide, accessible corridors.

5. Architectural Expressiveness

The architecture of a preschool building should reflect the spiritual and emotional world of children, as well as the natural and national characteristics of the region. The facade should be enriched with details that convey positive and educational messages, which can be expressed through the use of "smart surfaces" that react to human actions and large glazed areas. The aesthetic quality of the building can be enhanced by using colored, tinted glass in communication zones (corridors, staircases, vestibules).

6. Integration with the Landscape

To promote ecological education and harmonize with the surrounding environment, the building should include winter gardens and recreation areas with large glass surfaces, primarily oriented toward the southern horizon. Another approach, particularly useful in densely built urban areas, is to create an open playground with grass on the roof of the preschool. Natural landscape elements (biozones, barriers for regulating air flow) should be used to create a favorable microclimate for the area.

7. Implementation of Sustainable Architecture Principles

Preschools should be designed to be durable, seismic-resistant, and long-lasting. To allow for changes in planning structures based on evolving societal demands, a frame construction system is most suitable.

Preschools should also be energy-efficient buildings, using eco-friendly construction materials that are low-energy in production. To maintain a comfortable microclimate, renewable energy sources (solar panels, heat pumps, wind turbines, etc.) should be incorporated, depending on their efficiency in the given climate zone [8]. Solar shading devices, reflective materials, and "horizontal" and "vertical" greenery elements can protect the building from excessive solar radiation during hot periods.

3. Conclusion

The basic principles of formation of architectural and planning structure of children's preschool institutions established on the basis of foreign experience can contribute to the expansion of the typology of buildings of this purpose, to orient their volume-planning solution to meet the rapidly developing innovative processes in preschool education and to ensure the formation of children's modern outlook and their socio-cultural adaptation.

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Distribution of braking forces between vehicle bridges and redistribution of braking mass

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Abstract: The distribution of braking forces between vehicle bridges and the redistribution of braking mass are crucial factors affecting vehicle stability and braking performance. In multi-axle and articulated vehicles, improper braking force distribution can lead to instability, reduced braking efficiency, and increased risk of accidents. This study investigates the dynamics of braking force distribution and mass redistribution using theoretical models, computational simulations, and experimental testing. Theoretical models based on Newtonian mechanics predict that the front axles bear more braking force due to load transfer during deceleration. Simulations using multi-body dynamics software confirm that suspension systems and braking technologies like Electronic Brake force Distribution improve force balance. Experimental testing on various vehicles validates these results, demonstrating how load distribution affects vehicle stability during braking. The findings highlight the importance of optimizing braking force distribution in multi-axle and articulated vehicles to ensure safe and efficient braking under diverse conditions.

Keywords: braking forces, vehicle, rear axles, maneuvers, safety

1. Introduction

The braking system is one of the most critical components in a vehicle, responsible for ensuring its safe operation by reducing speed or bringing it to a complete stop when necessary. In particular, the distribution of braking forces and the redistribution of braking mass play pivotal roles in optimizing braking performance, vehicle stability, and overall safety [1]. The interaction between the braking forces applied to the vehicle's axles (or bridges) and the mass redistribution during braking is essential for understanding the vehicle's behavior under different driving conditions, especially in emergency or high-speed situations [2,3].

Braking forces are the forces exerted on the vehicle to decelerate or stop it. When a driver presses the brake pedal, hydraulic or pneumatic pressure is applied to the brake pads or shoes, creating friction against the rotating wheels [4]. This frictional force is transmitted through the vehicle's suspension system to the axles, ultimately affecting the vehicle's speed. The force generated by the braking system is not uniformly distributed across the vehicle's axles; instead, it is subject to a variety of dynamic factors that influence how these forces are shared between the vehicle's front and rear axles, and in the case of multi-axle vehicles, across additional axles or bridges [5,6].

Braking force distribution refers to the way in which the total braking force is allocated between the vehicle's front and rear axles [7]. Ideally, the braking force should be split in a manner that optimizes vehicle stability and minimizes the risk of skidding or loss of control. An improperly distributed braking force can lead to dangerous outcomes, such as the vehicle's rear end lifting off the ground or the front tires losing traction, leading to instability and a potential loss of control [8].

Vehicle bridges, in this context, refer to the segments of the vehicle's structure that connect multiple axles, such as in articulated or heavy-duty vehicles (trucks, buses, or trailers). In these vehicles, braking forces must be distributed across the multiple bridges to ensure the vehicle maintains stability and effective stopping power. For example, a trailer with multiple axles (bridges) requires careful management of braking forces, with each axle receiving a different proportion of the total braking force based on factors like load, weight distribution, and braking system design [9].

The interaction between the braking system and the bridges involves dynamic forces during braking, including load transfer from the front to the rear of the vehicle, as well as the redistribution of mass across the vehicle's structure. These forces can cause significant changes in how the vehicle behaves under braking, potentially leading to uneven tire wear, increased stopping distances, and vehicle instability. Hence, the design of braking systems must account for the distribution of braking forces across vehicle bridges, ensuring that each bridge handles its designated portion of the braking load. When a vehicle brakes, the forces applied to the vehicle cause a redistribution of its mass, primarily due to the inertia of the vehicle. This redistribution occurs because the vehicle experiences dynamic load transfer during deceleration. Load transfer refers to the shift in the vehicle's weight between the axles as the braking forces act on the vehicle [10,11].

2. Research methodology

Many countries have conducted research on the distribution of braking forces and the redistribution of braking mass between automotive bridges (Fig 1).

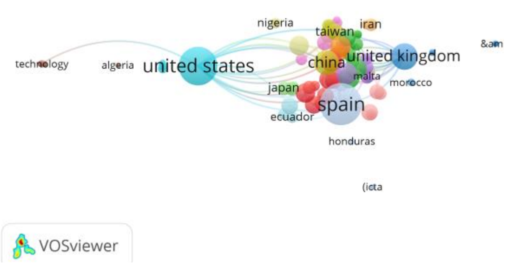

Fig. 1. List of top countries on vehicle bridges and redistribution of braking mass

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The study of the distribution of braking forces between vehicle bridges and the redistribution of braking mass is approached through both theoretical modeling and computational simulations [12]. The first step involves developing a theoretical framework that accounts for the basic principles of vehicle dynamics under braking. This framework relies on Newtonian mechanics, focusing on how braking forces are distributed between the vehicle's axles and how mass is transferred from the rear to the front of the vehicle during deceleration [13].

The braking force distribution is modeled using the following equations:

$F_{front} = W_{front}/W_{total} * F_{total}$

$F_{rear} = W_{rear}/W_{total} * F_{total}$

Where Wfront and Wrear represent the weight at the front and rear axles, and Ftotal is the total braking force. The load transfer effect is accounted for by calculating the shift in weight during braking, using a load transfer equation [14]:

ΔW=m·g·d \L·a

Where ΔW is the change in load, mm is the vehicle’s mass, d is the distance from the center of gravity to the axle, and a is the deceleration.

3. Results and discussion

The analysis of braking force distribution between vehicle bridges and the redistribution of braking mass produced several key findings regarding the dynamics of braking in multi-axle and articulated vehicles. The theoretical models, computational simulations, and experimental testing all provided insights into the behavior of braking forces and how mass is redistributed during deceleration.

1. Theoretical Model Results

The theoretical model provided a foundational understanding of how braking forces are distributed between the front and rear axles and between different vehicle bridges. The equations used to calculate braking force distribution and load transfer showed that, under typical braking conditions, the front axle carries a greater share of the braking load due to the forward load transfer that occurs during deceleration.

For example, in a typical passenger vehicle with a 60/40 front/rear weight distribution, the braking force on the front axle is approximately 60% of the total braking force, with the remaining 40% applied to the rear axle. The theoretical model also confirmed that as deceleration increases, the load transfer to the front axles becomes more pronounced, particularly at higher speeds or under emergency braking conditions. This result aligns with the basic principles of braking dynamics, where the vehicle's center of gravity shifts forward, increasing the load on the front tires.

In multi-bridge vehicles, such as trucks and trailers, the model showed that the braking force is more complex, with multiple axles (or bridges) sharing the total braking load. The force on each axle is influenced by the weight distribution, suspension characteristics, and the distance between the axles and the vehicle’s center of gravity. For articulated vehicles, the braking force distribution was found to be more sensitive to the relative load on each bridge, with larger shifts in braking force between the front and rear bridges.

2. Experimental Testing Results

Experimental testing involved real-world braking tests on different vehicle types, including light-duty cars, trucks, and buses. The tests focused on measuring the braking forces on each axle, as well as assessing the redistribution of mass during braking.

For light-duty vehicles, the results showed that the braking force distribution was consistent with the theoretical model, with approximately 60% of the total braking force applied to the front axle. The braking forces were measured using strain gauges and force sensors placed on the axles, and load transfer was quantified using accelerometers to track shifts in the vehicle’s center of gravity. During emergency braking, the front axle consistently experienced higher braking forces, while the rear axle experienced a reduction in braking force due to the load transfer.

For heavy-duty trucks and articulated vehicles, the experimental results demonstrated the significant role of bridge configurations in braking force distribution. When braking forces were applied to a multi-axle vehicle with a semi-trailer, the results indicated that the braking forces were not evenly distributed across all axles. The tractor’s front axle bore a higher proportion of the braking force, while the rear axles of both the tractor and trailer showed greater load transfer. However, the presence of EBD systems in the tests helped balance the braking forces, preventing excessive force on any single axle and ensuring a more stable braking performance.

In addition to measuring braking forces, the experimental tests also included evaluations of vehicle stability during braking. For articulated vehicles, tests under high-speed conditions showed that improper braking force distribution could lead to instability, such as trailer swing or jackknifing. These issues were mitigated by adjusting the braking force distribution through EBD and enhancing the coordination between the tractor and trailer brakes

4. Conclusion

The distribution of braking forces between vehicle bridges and the redistribution of braking mass are crucial factors that influence vehicle stability, safety, and performance during braking. By understanding and optimizing the way braking forces are distributed across the vehicle’s structure and how the mass is redistributed during braking, engineers can improve the safety and efficiency of braking systems, particularly in multi-axle and articulated vehicles. Future research and advancements in braking technology, including adaptive systems that dynamically adjust braking force distribution, hold the potential to further enhance vehicle performance and contribute to the development of safer, more efficient transportation systems.

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Influence of sulphur on mechanical properties of foundry steels and ways to minimise it

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Abstract: The influence of sulphur on mechanical properties of foundry steels used for the production of highly responsible parts of railway transport has been investigated. It is shown that the sulphur content in steels above 0.025% leads to a sharp decrease in their strength, impact toughness and ductility, which significantly reduces the operational durability of castings. Studies have been carried out to determine the critical limit of sulphur content, at which the properties of steel remain at an acceptable level. On the basis of the obtained data effective technologies of steel desulphurisation have been proposed, which can be introduced in foundry production, in particular, in conditions of Tashkent LMP.
Keywords: foundry steel, ITP, sulphur, non-metallic inclusions, mechanical properties

1. Introduction

Foundry production in Uzbekistan plays a key role in providing machine-building complex with billets, and its development directly depends on the growth rate of machine-building in general. Unlike billets obtained by metal forming (rolled, stamped, forgings), castings retain all the disadvantages and peculiarities of melting and casting, which further affect the properties of finished cast products.

One of the main problems in foundries is the use of outdated regulatory and technical documents, where the levels of harmful impurities in steels do not meet the modern requirements of steel casting metallurgy. Foundry production ensures the manufacture of workpieces of complex geometry with minimal material losses, which makes it one of the key processes in mechanical engineering and metallurgy. However, the quality of castings is largely determined by the content of harmful impurities such as sulphur, phosphorus and oxygen. These elements, even in small quantities, can significantly degrade the mechanical properties of the metal, such as strength, ductility and impact toughness.

Nowadays the problem of sulphur content control in foundry steels is especially urgent. Sulphur, as a non-metallic element, is highly soluble in liquid iron, but when the metal solidifies, it forms sulphide inclusions (e.g. FeS) that precipitate at grain boundaries. This leads to a reduction in the ductility and impact toughness of the steel, and increases the risk of defects such as redbreakage (brittleness at high temperatures). In addition, sulphide inclusions impair the metal's machinability and corrosion resistance.

The influence of sulphur is particularly critical in steels used for the manufacture of critical parts, such as railway components, where high reliability and durability are required. Therefore, control of sulphur content and development of effective methods of its removal (desulphurisation) are important tasks of modern metallurgy.

Modern GOSTs and international standards regulate the maximum sulphur content in steels at the level of 0.010-0.025%. However, foundries often have difficulties in achieving these values due to the use of outdated equipment and insufficient efficiency of steel cleaning methods. This paper discusses methods of steel desulphurisation, their effect on mechanical properties and possible ways of implementation in industrial production. However, the main difficulty lies in the fact that foundries produce small volumes of steel, and the introduction of expensive equipment used in large-scale metallurgy (e.g., vacuum degassers, furnace-ladle units, etc.) to improve quality is practically impossible. The use of such devices significantly increases the cost of castings and leads to long payback periods.

Improved performance and mechanical characteristics of the casting are possible if harmful impurities such as sulphur, phosphorus, gases, non-metallic inclusions and others are effectively removed from the metal. The quality of the casting depends to a large extent on low sulphur content in the final metal.

Sulphur is a non-metallic element that:

Easily dissolves in liquid iron.

Virtually insoluble in the solid state.

According to studies [1, 2], sulphur has unlimited solubility in liquid iron and very low solubility in solid iron. At 1365°C, the limiting solubility of sulfur in u-iron is from 0.04% to 0.05%, and it decreases with decreasing temperature (in the temperature range from 1365°C to 915°C during the transition of u-iron to a-iron). The transition to a-iron causes a sharp formation of sulphides, the concentration of sulphur in iron decreases to 0.01%, and its content continues to decrease with further cooling. Excessive sulphur content, exceeding the solubility limit, leads to a phenomenon called red-brittle (metal fracture). This is especially pronounced in the cast state, where sulphide inclusions are deposited on the boundaries of primary crystallites, which reduces the strength, ductility and toughness of both the metal itself and finished products from it (castings, ingots).

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2. Material and research methodology

The studies were carried out on 20GL casting steels melted in induction crucible furnaces ICF-6 with the main lining at the LMP in Tashkent. The following methods were used for analyses:

Determination of chemical composition of metal by spectral analysis method;

Mechanical tests for tensile, impact toughness and hardness;

Microscopic studies of metal structure and non-metallic inclusions;

Statistical analysis of sulphur content at different stages of production.

Sulphur in steel is mainly present in the form of sulphides (FeS, MnS), which are distributed at grain boundaries and lead to brittleness of the metal. The most dangerous phenomenon is red brittleness - metal fracture when heated above 900°C due to the formation of FeS-Fe eutectic, which has a low melting point (988°C).

As a result of the conducted research it was found that:

When the sulphur content is above 0.025%, the impact toughness of steel decreases by 60-70% at -60°C.

Tensile strength of steel decreases by 8% on average.

The ductility (relative elongation) drops by 50% when the sulphur content increases from 0.013% to 0.043%.

Increased sulphur content reduces the fatigue strength of steel by 1.5-2 times.

Methods of sulphur content reduction

1. desulphurisation technologies

Desulphurisation is the process of removing sulphur from steel, which can be carried out by various methods.

A) Effectiveness of different deoxidising agents in desulphurisation process

The diagram (Fig. 1) shows the effectiveness of different deoxidising agents in the desulphurisation process of steel. It can be seen that calcium and magnesium are the most effective deoxidisers, significantly reducing the sulphur content of steel. Aluminium and silicium also contribute to desulfurisation, but their efficiency is lower.

Key Observations:

1. Calcium reduces sulphur content by 70-80%.
2. Magnesium reduces sulphur content by 60-70%.
3. Aluminium reduces sulphur content by 30-40%.
4. Silicea reduces sulphur content by 20-30%.

The effectiveness of deoxidisers depends on their chemical activity and ability to form stable compounds with sulphur. Calcium and magnesium are highly active and form sulphides (CaS, MgS), which are easily removed to slag. Aluminium and silicium are less active but can also bind sulphur, although to a lesser extent.

Reaction formulas:

Reaction with calcium:

$$Ca + S \rightarrow CaS$$

Reaction with magnesium:

$$Mg + S \rightarrow MgS$$

Reaction with aluminium:

$$2Al + 3S \rightarrow Al_2S_3$$

Reaction with silicium:

$$Si + 2S \rightarrow SiS_2$$

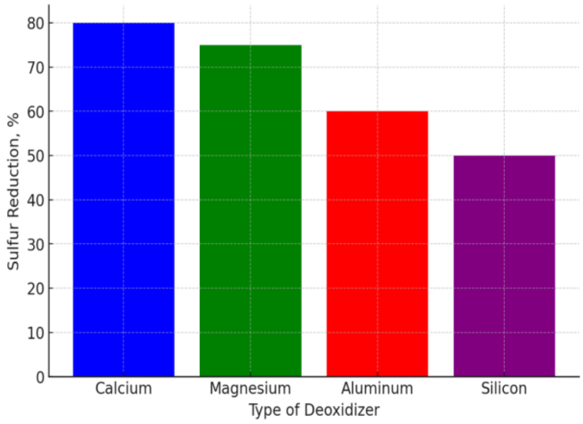

Fig. 1. Effectiveness of different deoxidising agents in the desulphurisation process

B) Basic formulae of desulphurisation

Equilibrium distribution of sulphur between metal and slag

$$L_s = \frac{\%S_{met}}{\%S_{slag}}$$

Where:

L_S - sulphur distribution coefficient,

$\%S_{met}$ - sulphur content in metal,

$\%S_{slag}$ - sulphur content in slag.

Desulphurisation reaction involving calcium

$$Ca + S = CaS$$

where: Calcium (Ca) binds sulphur (S) into a stable compound calcium sulphide (CaS), which is removed to the slag.

Desulphurisation reaction involving magnesium

$$Mg + S = MgS$$

where: Magnesium (Mg) also actively binds sulphur to form MgS.

Kinetics of sulphur removal during vacuumisation process

$$\frac{dS}{dt} = -k[S]$$

where: dS/dt is the rate of sulphur reduction,

k - reaction rate coefficient,

[S] - current sulphur content in the metal.

Steel processing outside the furnace

Methods include: Vacuuming.

Processing of metal in furnace-ladle units.

Introduction of modifiers into the metal to bind sulphur into stable compounds. Figure 2 shows the scheme of the desulphurisation process using synthetic slags. This process includes consecutive stages: addition of deoxidising agents, binding of sulphur into sulphides, slag formation and its removal. This approach allows to effectively reduce the sulphur content in foundry steels, which significantly improves their mechanical properties.

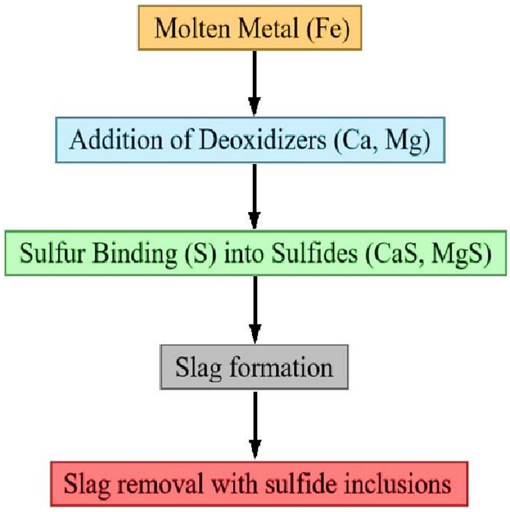

Fig. 2. Scheme of desulphurisation process using synthetic slags

Control of raw materials

Sulphur content reduction is possible at the raw material preparation stage, including the use of high-quality ores and carbonaceous additives.

Influence of temperature on desulphurisation

Dependence of sulphur content in steel on melting temperature

The diagram (Fig. 3) shows the dependence of sulphur content in steel on melting temperature. It can be seen that as the melting temperature increases from 1400°C to 1700°C, the sulphur content of the steel decreases. This confirms that high temperatures promote more efficient desulphurisation.

Main observations:

At 1400°C, the sulphur content is about 0.040%.

When the temperature is increased to 1600°C, the sulphur content decreases to 0.020%.

When the temperature is further increased up to 1700°C, the sulphur content reaches the minimum values of 0.010% and below.

The efficiency of desulphurisation at high temperatures is explained by the following factors:

Acceleration of chemical reactions: Higher temperatures increase the rate of reactions between sulphur and deoxidising agents (e.g. calcium or magnesium), which favours the formation of sulphides (CaS, MgS) and their removal to the slag.

Improved slag mobility: High temperatures make the slag more liquid, which facilitates its interaction with sulphur and its removal from the metal.

Increased sulphur solubility in the slag: At high temperatures, sulphur dissolves better in the slag, which facilitates its more efficient removal.

Reaction formulas:

Reaction with calcium:

$$Ca + S \rightarrow CaS$$

Reaction with magnesium:

$$Mg + S \rightarrow MgS$$

Reaction with lime (CaO):

$$CaO + S \rightarrow CaS + O$$

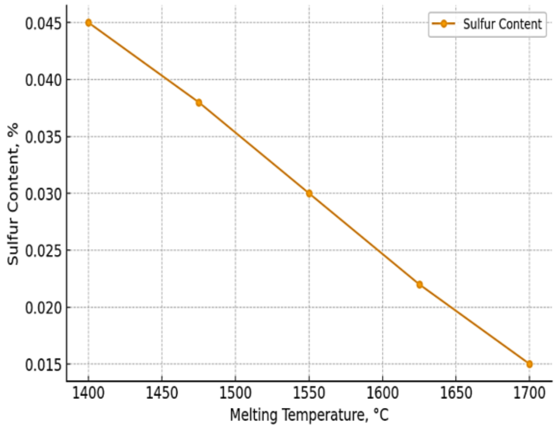

Fig. 3. Dependence of sulphur content in steel on melting temperature

Reduction of sulphur content in metal significantly depends on the melting temperature. The higher the temperature, the faster the desulphurisation processes occur, especially when using active slags and deoxidizers.

Properties were determined in the heat treated state, i.e. after normalisation at (H) 880-890°C;

Statistical analysis of steel melting for sulphur content in the metal during melting and in the liner, as well as analysis of the influence of sulphur on the mechanical properties of steel was made in Excel.

3. Results and discussion

When melting 20GL steel in an induction furnace, the largest number of melts, more than 60%, is characterised by sulphur concentration in the melt from 0.021 to 0.030% by mass. The values of sulphur content in the range of 0.040-0.050%, close to the upper limit of GOST, are about 6%, which is 10 times less than for the above-mentioned values. The largest share of smelts (more than 73.0%) has sulphur content in finished metal in the range from 0.016 to 0.025% by mass.

Additional research

Influence of non-metallic inclusions

Sulphides, formed at high sulphur content, form inclusions that: deteriorate the ductility of steel, reduce corrosion resistance, complicate cutting.

Graphical representation of the results shows a linear dependence of the deterioration of properties on the level of sulphur content.

Tables 1-3 present data on mechanical properties of the above steels at different sulphur content.

The impact toughness of 20GL steel decreases with increasing sulphur content due to the formation of brittle sulphide inclusions. This is especially critical at low temperatures, when impact toughness decreases by 3-4 times. Table 1 presents data on impact toughness of 20GL steel at different temperatures.

Table 1

Impact toughness of 20GL steel at different sulphur content*

Steel grade	KCU, MJ/m², at sulphur content, %			
	0,013	0,023	0,033	0,043
20GL	0,62 0,38	0,56 0,31	0,40 0,21	0,31 0,12

* Numerator - at test temperature +20°C, denominator - at -60°C.

As the sulphur content increases, a decrease in the tensile strength is observed, which makes the steel less resistant to mechanical loads. Table 2 shows the experimental strength data of 20GL steel.

Table 2

Strength of steel at different sulphur content

Steel grade	$a_в$, MPa, at sulphur content, %			
	0,013	0,023	0,033	0,043
20GL	650	635	610	605

Ductility is an important parameter affecting the technological properties of steel. Increased sulphur content leads to the formation of brittle grain boundaries, which reduces the relative elongation of steel, as shown in Table 3.

Table 3

Relative elongation of steels at different sulphur content

Steel grade	б, %, at sulphur content, %			
	0,013	0,023	0,033	0,043
20GL	21	20	15	10

Sulphur significantly reduces the fatigue strength of steel, as sulphide inclusions act as stress concentrations, which leads to crack initiation. According to studies, when the sulphur content increases above 0.025%, the fatigue strength of 20GL steel decreases by 1.5-2 times.

It was found that a sharp decrease in all properties of steels, especially toughness and ductility, is observed at sulphur content above 0.023%. For example, for most steels when increasing the sulphur content from 0.013% to 0.043%, impact toughness at normal test temperature decreases almost twofold, and at -60°C - more than three times. The graphs below show the dependence of mechanical properties of steel on sulphur content.

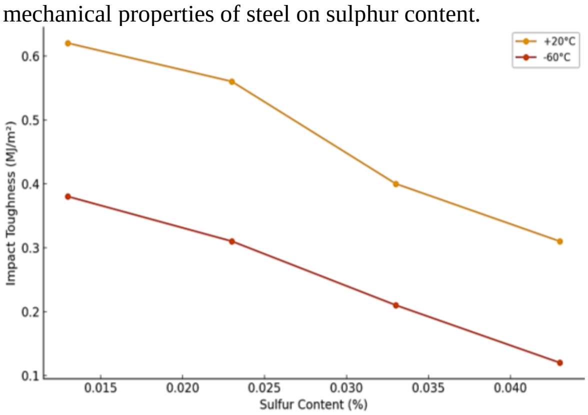

Fig. 4. Effect of sulphur content on impact toughness of steel at different temperatures

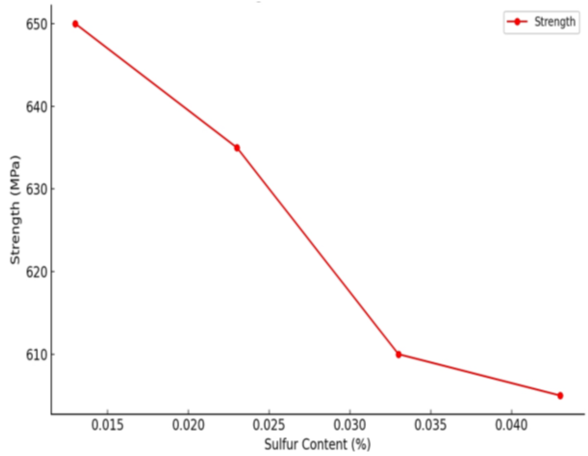

Fig. 5. Dependence of steel strength on sulphur content

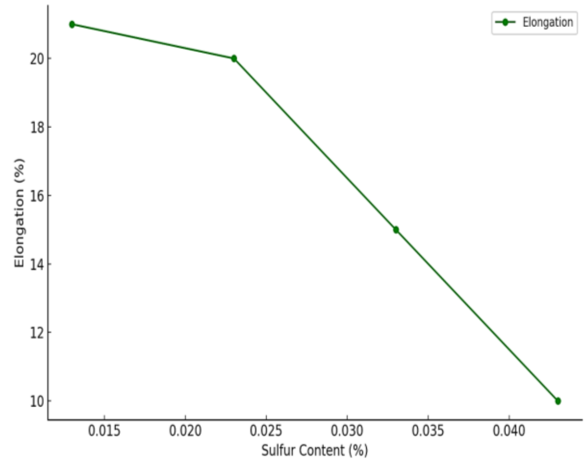

Fig. 6. Dependence of steel ductility on sulphur content

This effect is explained by the fact that sulfide and oxysulfide non-metallic inclusions are formed in the metal at the grain boundaries of the primary crystals, which weaken their bonding, which in turn leads to a decrease in the ductility and toughness of the cast metal. Thus, the higher the concentration of sulphur in the metal, the more non-metallic inclusions are present in the metal, resulting in lower mechanical properties such as impact toughness, strength and relative elongation.

4. Conclusion

The analysis of the conducted research has shown the necessity and expediency of developing technologies for refining steel melts in induction crucible furnaces (ICF) in order to achieve a stable reduction in sulphur concentration. This will allow to provide high quality characteristics of castings, especially in the conditions of production of critical parts for railway transport.

It is also required to make additional changes in steel casting melting technologies aimed at controlling and reducing the sulphur content in steels. The research results demonstrate that the increase of sulphur content in 20GL steel above 0.025% leads to a significant deterioration of mechanical properties. In particular:

The impact strength (KCU) decreases by a factor of 3 at -60°C, making the steel more brittle in low temperature applications.

The strength of the steel decreases by an average of 8%, which reduces its ability to withstand mechanical loads.

The ductility of the steel (relative elongation) is reduced by 50%, increasing the risk of failure under dynamic loads.

Fatigue strength decreases by 1.5-2 times, which is especially critical for parts operating under cyclic loads.

The obtained data confirm the necessity of strict control of sulphur content in foundry steels. The optimum sulphur level for 20GL steel is 0.015-0.025%, which provides high mechanical properties such as strength, impact toughness and ductility.

To achieve these indicators, it is recommended to implement modern desulphurisation methods, including:

Use of synthetic slags with high lime content.

The use of deoxidising agents (calcium, magnesium) to bind sulphur into stable compounds.

Treatment of steel outside the furnace (e.g. in furnace-ladle units or using vacuum treatment).

These measures will not only improve the performance characteristics of castings, but also increase their durability and reliability under conditions of intensive use.

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Systematization of factors influencing train movement

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Abstract: The main goal of the work is to identify and systematize the factors that determine the quality indicators of railway transport, affecting traffic safety, and to develop directions for increasing the level of traffic safety. Factors influencing the safety of train traffic have been identified and systematized according to 7 criteria. In order to increase the level of train safety, based on the results of analysis and assessment of the factors influencing them along the route, the main directions of measures to improve the level of safety were developed based on the Hoshina-Kanri principle. The developed mechanism determines what measures should be implemented at stations, terminals and freight facilities to improve train safety.
Keywords: Train movement, factor, systematization, traffic safety, transportation process, productivity

1. Introduction

Efficient and safe management of train traffic during transportation is important to ensure the efficiency and reliability of the transport system [1-8].

The timely delivery of trains (without excessive loss of time at stations, freight facilities and terminals) to their destinations (cargo receivers, passengers and designated disembarkation points) while ensuring the safe movement of trains along the route is determined by the image of this transport in the market [6-8]. Of course, to achieve this, one of the pressing issues is the search for continuous integrated solutions in the process of railway transportation and their implementation. In this case, the first main task is to identify factors that have a negative impact on the transport process, their systematization (in the source) and the search for comprehensive solutions to eliminate them.

The following factors are of great importance in this process:

saving time - accurate planning of train movements allows passengers and goods to reach their destination on time;

economic efficiency – ensures the rational use of resources, including fuel, electricity and employee working time;

ensuring safety - train collisions, delays and other emergency situations can be prevented through clear organization of traffic;

increasing the capacity of passenger and cargo transportation – effectively organized traffic increases the capacity of passenger and cargo transportation;

reliability of the transport system – the stability of train traffic increases the confidence of passengers and customers, since all processes are carried out on the basis of a clear schedule;

environmental efficiency – optimal operating mode reduces fuel consumption, which helps reduce environmental damage.

Also, the introduction of automation and train traffic control systems using modern technologies will make this process more efficient. Through them, traffic schedules can be constantly monitored and, if necessary, quickly changed.

To assess the efficiency of organizing train traffic, the following indicators are used (Table 1).

Table 1

Indicators for assessing the efficiency of train traffic management

Indicator name	Evaluation Mechanisms	Explanation
Time indicators	Level of compliance with train schedules	It evaluates how accurately trains adhere to specified time intervals.
	Delays	Number of delays and their total duration
	Average movement speed	Determines the average speed of the train along the track.
Indicators of cargo and passenger transportation	Load capacity	Amount of cargo transported per unit of time (tons/km)
	Passenger capacity	Number of passengers transported per unit of time (passenger/km)
	Level of wagon capacity utilization	Overloading (loading) of passenger (freight) carriages
Safety indicators	Number of emergencies	Number of road safety violations
	Performance of traffic control systems	Level of operation of security automation systems
Economic indicators	Amount of fuel or energy consumed	Fuel or electricity used for propulsion
	Total costs for organizing traffic	Road infrastructure, maintenance, staff salaries and other expenses

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	Income/cost ratio	Ratio of income from train traffic to expenses
System stability and efficiency	Flexibility of train schedules	Stable adherence to the schedule, despite the intensity of train traffic
	Number and duration of stops	Time of stops along the way and their brevity
Environmental indicators	Exhaust gases	The amount of CO_2 emitted while a train is moving
	Energy efficiency	Ratio of energy consumed to cargo or passenger transported

Based on these indicators (Table 1), the efficiency of organizing train traffic and the possibilities for their improvement are analyzed and appropriate decisions are made.

measures should be implemented. In addition, the systematization of factors influencing the movement of trains throughout the entire traffic cycle has not been sufficiently studied.

2. Methods and materials

Organization and management of railway transportation, development of systems and methods for ensuring train traffic safety, increasing the productivity of participants in the transportation process, as well as identifying, assessing and eliminating factors affecting traffic safety, laboratory scientists have conducted scientific research [1-8].

Scientific works [2-6] made the following conclusions: strict adherence to the placement of workers at work places in accordance with their qualifications; establishing constant control over the movement of trains; optimization and digitalization of processes; comprehensive mechanization of loading and unloading operations; improvement of railway transport management systems, etc. However, most scholars have not specified the exact mechanisms of how these

3. Results and discussion

The indicators of train traffic organization are influenced by various factors [1-6]. Assessing their impact is important to improve efficiency and eliminate problems. It is important to use monitoring systems and data analysis techniques to determine the level of impact of each factor and manage them effectively. This allows you to organize traffic more efficiently.

As a result of the analysis of scientific works [1-6, 10], various factors were identified that influence the movement of trains along the route, which, based on the results of the analysis, were conditionally divided into 7 criteria (technical factors, organizational factors, natural factors, human factors, load factors , economic factors, information factors) and systematized (Fig. 1).

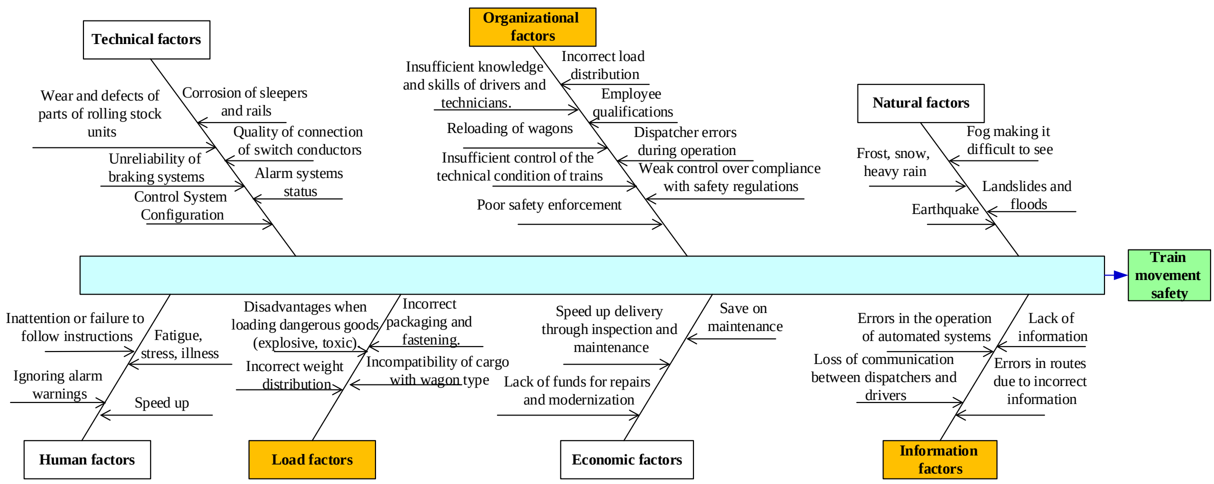

Fig. 1. Factors influencing the movement of trains along the route

Description of the factors influencing the movement of trains in this form allows us to determine which group each factor belongs to, assess the level of their impact and develop appropriate measures for timely elimination.

These factors (Fig. 1) have different effects on trains during their movement. Therefore, comprehensive approaches are needed to eliminate them.

A number of factors listed in Figure 1, which took place in the process of organizing train traffic at the stations of Uzbekistan Railways JSC and adjacent branches and stations, were studied. The study was carried out on the site of the railway departments (Fig. 2).

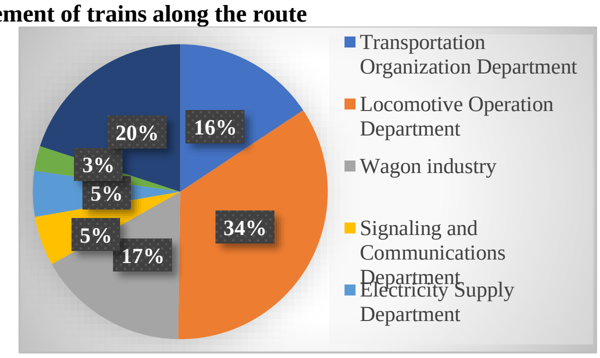

Fig. 2. Share of road safety violations attributable to organizations of the joint stock company “Uzbekistan Railways”

The largest share of traffic safety violations occurs in the "Use of Locomotives" (34%) and "Road Maintenance" (20%) divisions. Therefore, it is important to develop the necessary measures to improve the level of road safety in these departments.

Effective provision of transport safety in transit is carried out through a combination of technical, organizational and technological measures aimed at preventing emergency situations and minimizing their consequences.

The safety of trains during transportation at stations requires taking into account many factors related to the characteristics of the infrastructure, the movement of rolling stock, the organization of station operations and the human factor.

To improve safety at stations, it is necessary to combine the efforts of all participants in the process: from drivers and dispatchers to engineering services. This ensures stable and safe operation of the station when transporting passengers and cargo.

In addition, the safety of trains when transporting goods by rail depends on many factors related to the state of infrastructure, rolling stock, organization of loading and unloading operations and compliance with regulatory requirements. Below are the main aspects.

1. Infrastructure factors:

condition of roads of cargo facilities: condition of railway tracks, switches and loading platforms; absence of deformations and obstacles on the roads.

loading and unloading areas: lack of modern equipment for loading and unloading (cranes, conveyors, etc.); lack of clearly organized areas for equipment operation.

engineering structures: unreliability of warehouses, bridges and platforms; unsuitability of access roads to branches.

2. Moving content:

technical condition of cars: presence of defects in freight car bodies, brake systems and wheel pairs; without taking into account the maximum load capacity to avoid overloading.

load securing: failure to use secure securing methods to prevent cargo from shifting; failure to maintain proper weight distribution in the carriage.

use of special wagons: do not use tanks, platforms and semi-open wagons for the transportation of certain types of cargo (dangerous, volatile, container).

3. Organization of the transportation process:

route planning: without taking into account the condition of roads along the entire route; not taking into account capacity when choosing the optimal traffic schedule.

compliance with the speed limit: not taking into account the weight of the train and the types of cargo transported when controlling the movement of trains.

loading and unloading operations: non-compliance with technology when loading and unloading cargo; idle time of rolling stock.

4. Dangerous goods:

compliance with safety standards: non-compliance with the rules for transporting dangerous goods; Do not use labels or danger signs on carriages.

cargo condition monitoring: failure to check packaging and tightness of tanks and containers; failure to check the tightness and packaging of containers and tanks; failure to control the possibility of leakage or explosion.

supporting documents: incorrect execution of the waybill and instructions for working with it.

5. Human factor:

personnel qualifications: lack of knowledge among personnel on how to safely unload (load) and handle cargo from(to) freight trains.

loading and unloading teams: lack of instructions for working with certain types of cargo; lack of constant monitoring of compliance with the rules.

dispatch control: problems of coordination of work between the departure and arrival stations; inaccuracies in the traffic schedule.

6. Natural and external threats:

weather conditions: without taking into account precipitation, temperature and wind when transporting goods, especially bulk or liquid cargo; slowness of cargo protection from external influences.

external interference: lack of security systems at cargo transportation facilities; Insufficient work has been done to prevent theft and vandalism.

7. Economic and legal aspects:

security funding: do not allocate resources to modernize rolling stock and freight infrastructure.

Regulatory regulation: non-compliance with international and national shipping standards; lack of constant monitoring of compliance with cargo terminals and rolling stock.

From the above factors, we can conclude that to ensure the safety of transportation at cargo facilities, an integrated approach is required, including modernization of infrastructure, strict control over the condition of cars, the introduction of automated technologies, and ensuring a high level of professional training for employees.

In order to increase the level of train traffic safety, areas of action were developed to analyze the results and assess the factors influencing them (Fig. 1).

Measures to improve the level of train safety, that is, the main directions, were developed taking into account the principles of Hoshina-Kanri [9] (Fig. 3).

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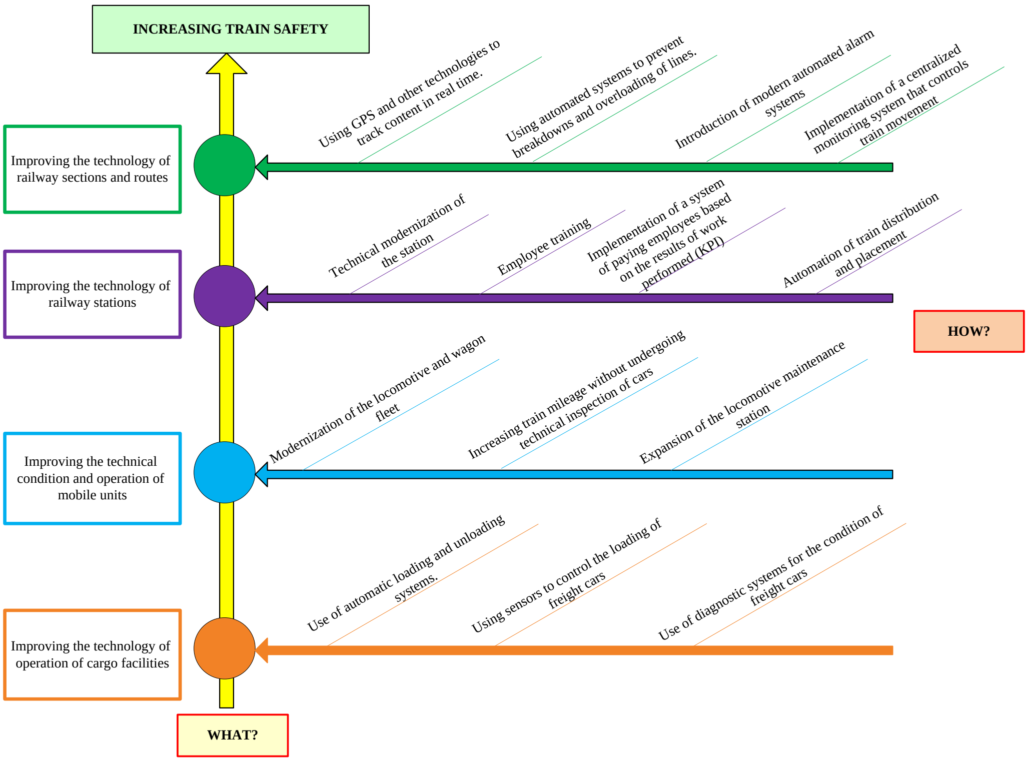

Fig. 3. Main directions for improving train safety along the route

Through this developed mechanism (Fig. 3), trains determine which measures should be implemented at each stage (train, station, freight facility, etc.) to improve traffic safety.

4. Conclusion

Ensuring the safety of train traffic at each stage determines the level of implementation of complex indicators of the quality of railway transport. Ensuring traffic safety significantly influences the performance of important indicators of railway transport and determines the position of the industry in the transport market.

Systematization of factors affecting the safety of trains along the route in the area of stations, stations and freight facilities, their systematic analysis, assessment and development of operational measures for their timely elimination, creates opportunities for effective assessment of the work of transport and the transport process of each of its participants.

The implementation of the proposed measures will lead to an increase in the productivity of railway transport and increase the attractiveness of the industry.

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Development of document management technology in the railway automation and telemechanics system

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Abstract: Traditional paper-based systems have given way to contemporary centralized electronic solutions in the development of document management technology in railway automation and telemechanics. The handwritten documentation used in railway operations was labor-intensive, prone to mistakes, and ineffective when managing massive amounts of data. These antiquated systems frequently resulted in misunderstandings, longer decision-making times, and higher functional risks.

By guaranteeing real-time data transmission, increased accuracy, and greater protection, the application of a new centralized electronic document operation system has completely transformed railway automation. By combining digital documents, electronic signatures, and automated methods, this process drastically cuts down on paperwork and the need for human intervention. Operational efficiency is increased by the centralized approach, which enables smooth coordination between control systems, dispatch centers, and railroad stations. The monitoring and regulate capabilities of contemporary telemechanics systems also improve maintenance scheduling and accident avoidance. In addition to improving railway management, this shift follows worldwide trends in digital transformation, making the railway network more reliable and cutting edge.

Keywords: Document management, digital documents, electronic document operation system, signaling and communications, project documentation

1. Introduction

A big step toward efficiency and contemporaneity is the switch from paper-based technologies to electronic document management. The importance of this change is maintained by the Law of the Republic of Uzbekistan “On electronic document management” which encourages the use of digital documentation to improve workflow automation, security, and accessibility. Organizations can increase data accuracy, expedite transmission and streamline methods by minimizing their dependence on paper.

The authenticity and legal acknowledgment of electronic documents are confirmed by this law, which creates a framework for their creation, storage, and exchange. In order to create a more open and effective administrative environment, it also elevates the use of secure information systems and digital signs. The change helps Uzbekistan become part of the contemporary digital economy and is in line with worldwide trends in digital transformation.

2. Research methodology

JSC “Uzbekistan Railways” signaling and communications department is responsible for organizing work interconnected to automation, telemechanics, and communications. There are eleven distances (SCD) in the signaling and communications department: ten for signaling, centralization, and blocking (SCB), and one for communication. In figure 1, the signaling and communications department’s detailed directorial construction is displayed. The territorial distribution feature, which is evident in figure 2, determines the signaling and communications department’s structure individually.

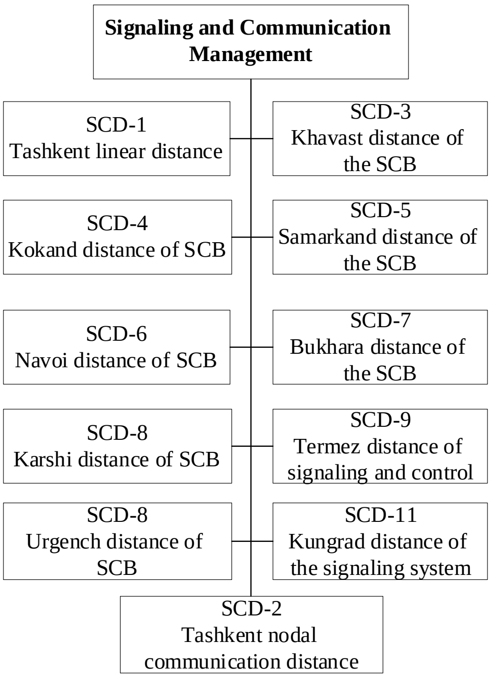

Fig. 1. JSC “Uzbekistan Railways” signaling and communication management structure

Instructions on technical documentation for signaling and interlocking devices and wired communications, as well as radio communications and recording of devices for rolling stock monitoring, closely restrict documents pertaining to automation and telemechanics installation (NSh-02) [3,6,7].

Priorities in the improvement of the aforementioned forms include: ensuring railway transport safety; introducing cutting-edge machinery and technologies; improving the

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technical and financial performance of railway rolling stock and infrastructure facilities; and raising the standard of services offered.

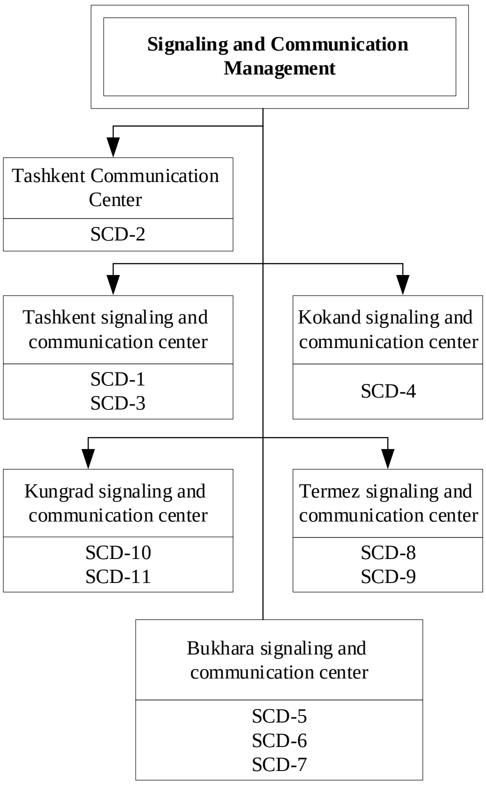

Fig. 2. Signaling and communication sector territorial division formation

All technical documentation is divided into three categories: design, operational, and archival, per the guidelines above. Figure 3 illustrates how technical documentation is organized [4-9].

Document flow is organized by design organizations, signaling and communications departments (SCD), signaling and communication departments, and building and installation organizations (Figure 4).

Projects are issued in five copies by the design organization. When the construction and installation train (SMP-406) receives a copy of the project, it is utilized for both commissioning and construction and installation. The project is sent to the signaling and communications department's technical documentation department in three copies. Two copies of these are moved to the appropriate signaling and communication distance, while one copy is kept in the archive. In turn, one copy is moved to the appropriate station, while the other copy is kept in the technical documentation group's archive (Figure 5).

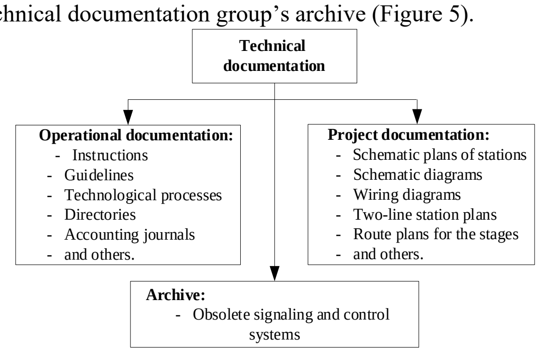

Fig. 3. Structure of technical documentation

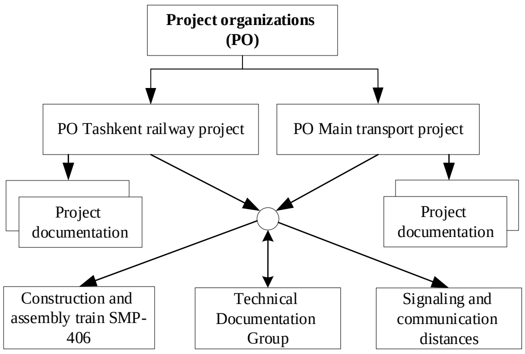

Fig. 4. Simplified structure of document flow

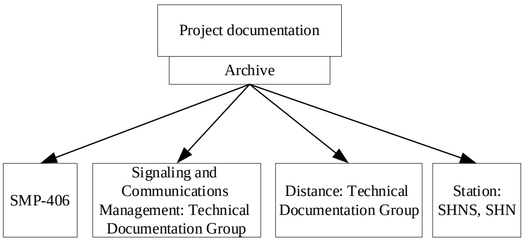

Fig. 5. Principle of distribution of design documentation

JSC "Uzbekistan Railways" occasionally has large quantities of technical documentation completed by several departments, which raises the cost of ineffective work and, as a result, operator errors. These tasks are entirely done by hand using paper material. Over 250 thousand copies of paper media are produced by each business. This technology's search speed and technical documentation accessibility are poor, and it does not allow multiple employees who are located far apart to examine the material at the same time [5,7,8].

When it comes to organizing and editing papers, paper technology is quite labor-intensive and complicated. These documents take up a lot of room when stored, are hard to account for, and cause loss and damage as well as confusion in the archive.

3. Conclusion

It is evident from an analysis of contemporary document management systems that automated electronic management systems are necessary. Electronic technical documentation maintenance technology will guarantee industrial competitiveness and boost overall transportation sector efficiency. It is necessary to create specialist software packages for developing information interchange and communication amongst railway design groups in order for electronic document management to function. It is necessary to update "Paper" technology by introducing contemporary computer systems with specialized software that will automate work environments and make it easier for employees who analyze technical documentation.

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Control and management of active and reactive power balance in a solar power supply system

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Abstract: This article discusses the development of a measurement and control system for monitoring and managing the balance of active and reactive power at power plants based on “Green” energy sources. Monitoring and management of the balance of active and reactive power based on a measurement and control system, calculated expressions are developed to solve the problem of reactive power compensation when transmitting electricity at power plants based on “green” energy sources. Reactive power is calculated based on measured active power, and combined reactive power sources generate the reactive power required by the network based on control signals. Schemes for connecting these reactive power sources to the network have been developed, and this diagram shows the installation of a measurement control device. The schematic block diagram of a measurement control device shows the sequence of the process of measuring and processing electrical data, as well as the generation of control signals. To study the operating principle and elements of a device created to monitor and manage reactive power consumption, a microcontroller, a signal converter and measuring transducers were selected. An algorithm for monitoring and managing the balance of active and reactive power has been developed for the device software. At the same time, equations for separating current, voltage and frequency signals in the phase section were developed.

Keywords: Green energy, active and reactive power, balance, monitoring and control, measurement and control system, microcontroller, signal converter, current, voltage, frequency, traditional power plant, solar and wind power plants, calibration factor, Arduino Uno, integrated circuit, Atmega328

1. Introduction

Today, power plants based on renewable energy sources are being built in the republic. Today, practical work is underway in Uzbekistan to build 22 solar and wind power plants with a capacity of 9 GW. In particular, a solar power plant with a total capacity of 900 MW has been built and commissioned in Samarkand, Jizzakh and Surkhandarya regions, while the Chinese company China Gezhouba Group has built and commissioned two solar power plants with a total capacity of 1,000 MW in Bukhara and Kashkadarya regions. At the same time, design and construction of wind power plants worth 650 million US dollars each have begun in the Peshku and Gijduvan districts of Bukhara region. The foreign company ACWA POWER from the Kingdom of Saudi Arabia is working on the creation of wind power plants with a capacity of 300-500 MW in the Peshku and Gijduvan districts. In general, by 2030, it is planned to build solar and wind power plants with a capacity of 27 GW based on "Green" energy sources in our Republic.

Based on the above, we can say that great attention is paid to providing the population with uninterrupted electricity in our republic.

This requires, along with the uninterrupted supply of electricity, ensuring the quality of electricity. In particular, along with active power consumers in the electricity network, there are also reactive consumers. This, in turn, requires paying attention to the issues of compensation for reactive power when transmitting electricity at power plants based on "Green" energy sources. There is still a lot of work to be done in this regard.

In this article, a measurement and control system has been developed to monitor and control the balance of active and reactive power when transmitting electricity to the network at power plants based on "Green" energy sources. Based on the measurement and control system for monitoring and controlling the balance of active and reactive power, a device installation scheme, a measurement and control system, a control and control device, and software were developed to control and control reactive power consumption in power plants based on "Green" energy sources.

2. Research methodology

In this work, the visualization of the energy performance of a solar power plant connected to the grid is considered. Usually, the visualization of the energy performance of a solar power plant is obtained using the Huawei online calculation program. When obtaining the visualization results of the energy performance of a solar power plant, climate and weather conditions, the angle of incidence of sunlight, and the pollution of the panels are important issues of the study. Inverters used in the electric power generation system have a significant impact on the quality of electric energy. Quality control when transmitting the generated active power to the grid has certain problems. It is known that in a power supply system, the active power balance is related to the network frequency, while the reactive power balance is a voltage-dependent quantity. The active power balance in a power supply system should be as follows [1-2]:

$$\sum P_{gen} = \sum P_{ist} = \sum P_{yuk} + \sum \Delta P$$

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if,

$\sum P_{gen} < \sum P_{ist}$ or $\sum P_{gen} > \sum P_{ist}$

If the frequency in the power supply system decreases or increases. For stable operation of the power supply system, the nominal permissible deviation of the frequency is set at ±0.2 GHz. [4].

The reactive power balance should look like this [3-5]:

$$\sum Q_{gen} = \sum Q_{ist} = \sum Q_{yuk} + \sum \Delta Q$$

if,

$\sum Q_{gen} < \sum Q_{ist}$ or $\sum Q_{gen} > \sum Q_{ist}$

If, the voltage of the power supply system decreases or increases.

It is known that the amount of reactive power generated by traditional power plants is insufficient for the power supply system, 2/3 of the reactive power required by consumers is covered by consumers, and 1/3 is taken from the power supply network. Therefore, in power supply systems with solar power plants, monitoring and controlling the transfer of active and reactive power to the power supply system network is an important issue.

Information on the amount of active and reactive power supplied to the power supply system by an 80 kW solar power plant during the day on March 15, 2024 is presented in Figure 1. It can be seen that the solar power plant generated 379.96 kW*h of active electricity during this period and transferred it to the power supply system network.

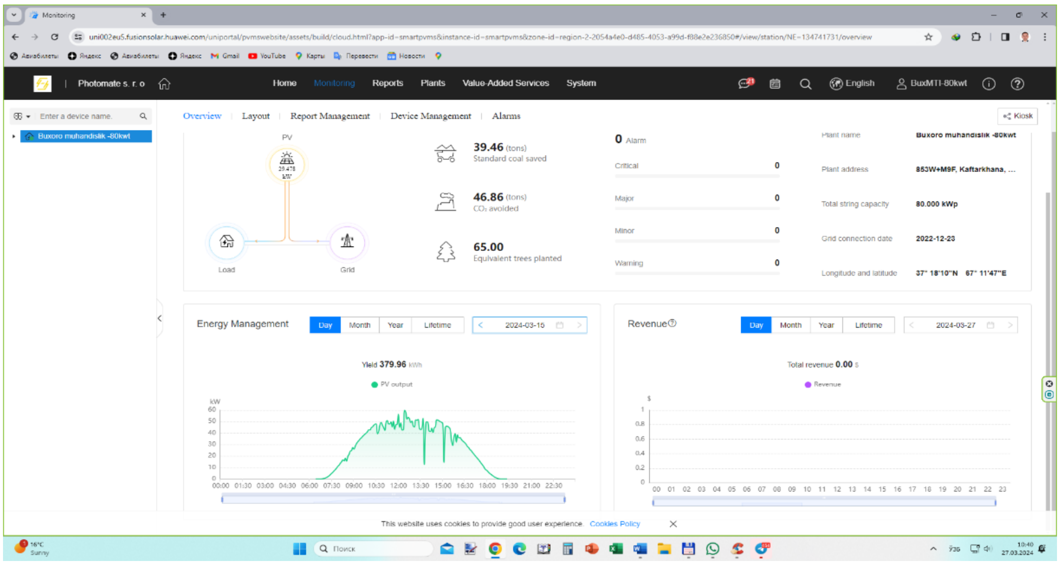


Fig. 1. Electricity generated by an 80 kW solar power plant

The solar power plant operates in parallel with the power supply system network in the electricity generation mode. In this process, an inverter is used to ensure the quality of the transmitted electricity. The reactive power balance is not considered in the described power supply system.

Developed schemes and equations. The results of the analysis and research have shown that the algorithm for monitoring and controlling the reactive power balance for a power supply system with a solar power plant, as well as the structural and electrical schemes for reactive power compensation, are important issues.

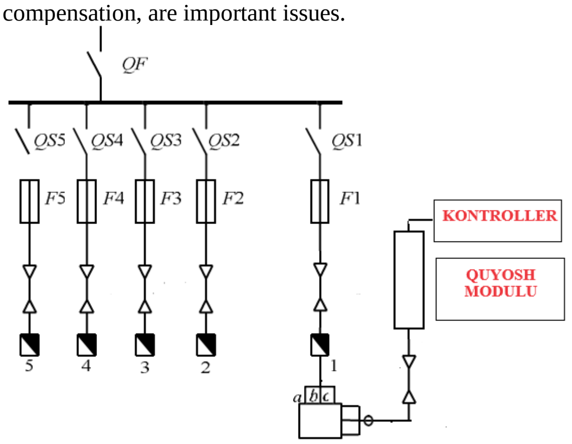


Fig. 2. Installation diagram of a device designed to control and manage reactive power consumption

Based on the installation diagram of a device designed to control and manage reactive power consumption, a measurement control system was developed to control and manage the balance of active and reactive power for a solar power plant power supply system. The measurement control system designed to control and manage the balance of active and reactive power in the power supply system is shown in Figure 3.

The measurement control system consists of three parts, the first part is the electrical part, the second part is the measurement-transformer part, and the third part is the software written in the microcontroller for processing the measurement results.

In the electrical part of the measurement control system, current signals are converted from the traditional power supply in the phase section by a special current transformer device and transmitted to the measurement-transformer unit. At the same time, a voltage signal is also supplied to the measuring and converting unit of the system. In the same way, current and voltage signals are obtained from the inverter of the solar power plant in the same order by phase.

In the measuring and converting unit, the current and voltage signals measured in the phase section are separated into current, voltage and frequency signals by phase and converted into a signal form and size that the microcontroller can read.

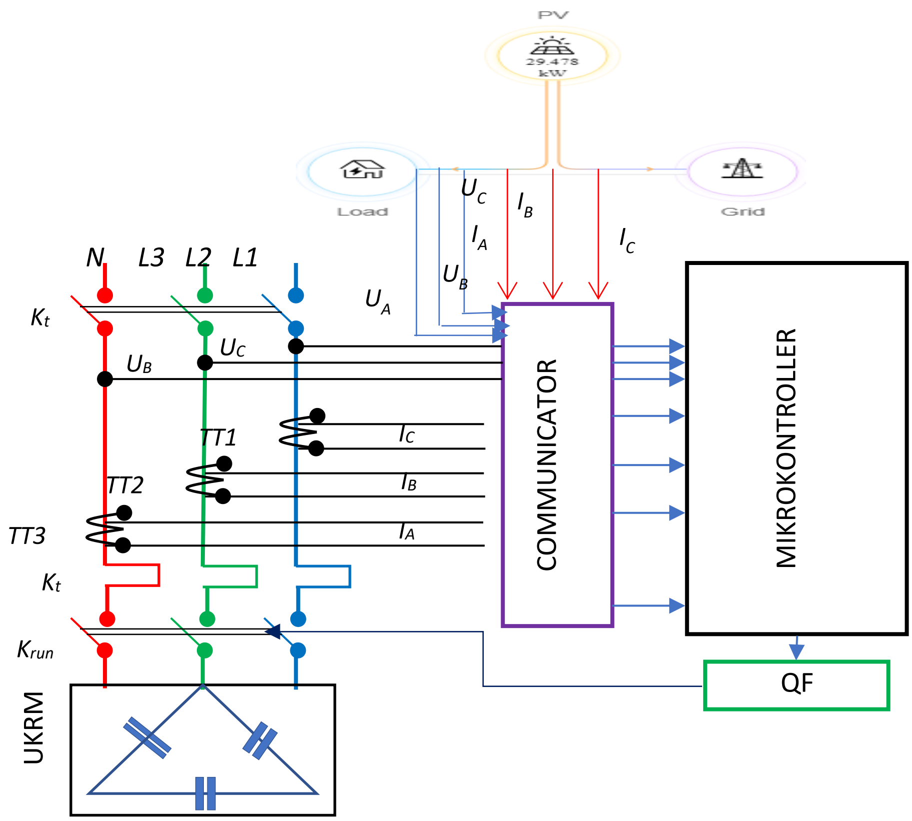


Fig. 3. Measurement and control system for monitoring and controlling the balance of active and reactive power

The microcontroller processes electrical quantities in the following sequence. Measuring electrical energy provides information about the change in power over time, and multiplies its signals in the form of voltage and current over time. If there is a difference between current and voltage, active power factor and phases, then active power is calculated as follows [2-3]:

$$p(t) = Ucos(wt) * Icos(wt + F), if\ F = 0$$

$$p(t) = \frac{UI}{2}(1 + cos2(wt))$$

$$if\ F \neq 0$$

$$p(t) = \frac{UI}{2}(1 + cos2(wt))$$

$$p(t) = Ucos(wt) * Icos(wt + F) =$$

$$= Ucos(wt) * [Icos(wt)\cos(F) + \sin(wt)\sin(F)$$

$$= \frac{UI}{2}(1 + cos(2wt)\cos(F)$$

$$+ UIcos(wt)\sin(\mathrm{wt})\sin(F)$$

$$= \frac{UI}{2}(1 + cos(2wt)\cos(F)$$

$$+ \frac{UI}{2}\sin(2\mathrm{wt})\sin(F)$$

The input voltage of the two channels of voltage and current is multiplied by the current and obtained through signal processing.

The active power data is converted to frequency, and in this process, the effective value of the voltage and the effective value of the current are calculated at the same time and converted to frequency. The effective values of the active power, voltage and current are outputted from the CF and CF1 channels, respectively, in a highly efficient manner.

The formula for calculating the frequency of the active power based on the output pulse is defined as follows [4]:

$$F_{CF} = 1721506 \frac{U(U) * U(I)}{U_{ref}^2}$$

where 1721506 is the calibration coefficient.

The voltage at the phase intersection is determined as follows [7]:

$$U_f = K_{kU} \frac{\sqrt{\sum_{i=1}^{n} U_i^2}}{n};$$

The current in the phase section is defined as follows[7]:

$$I_f = K_{kI} \frac{\sqrt{\sum_{i=1}^{n} I_i^2}}{n}$$

The active power and total active power in the phase section are defined as follows [7]:

$$P_f = K_{kU} \cdot K_{kI} \frac{\sqrt{\sum_{i=1}^{n} U_i I_i}}{n}; \qquad P_\Sigma = P_{fA} + P_{fB} + P_{fC}$$

The apparent power and total apparent power in the phase section are defined as follows [7]:

$$S_f = I_f \cdot U_f; \qquad S_\Sigma = I * U$$

The reactive power and total reactive power in the phase section are determined as follows: [7]:

$$Q_f = \sqrt{S_f^2 - P_f^2}; \qquad Q_\Sigma = Q_{fA} + Q_{fB} + Q_{fC}$$

The active power factor is defined as follows [7]:

$$\cos\varphi_{ABC} = \frac{P_{fABC}}{S_{fABC}}$$

Active and reactive electrical energy are defined as follows [7]:

$$W = P_\Sigma * t, \qquad Q = Q_\Sigma * t$$

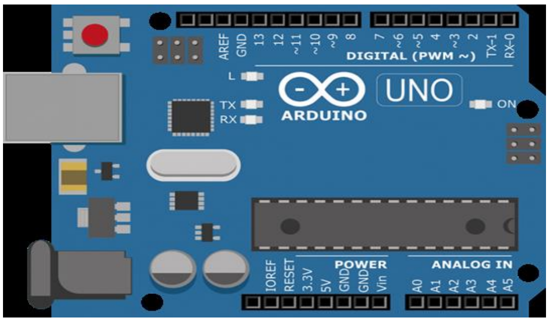
Based on the above mathematical expressions, the algorithm of the software for the operation of the measurement control system was formed, and this algorithm is a one-condition algorithm.

For the operation of the measurement control system, an Arduino microcontroller with an Atmega microprocessor was selected.

The basis of the Arduino Uno integrated circuit is the ATmega328 microcontroller. The characteristics of the Arduino Uno are given in Table 1 [4-5].

Table 1

Characteristics of the Arduino Uno microcontroller



Microcontroller type	ATmega328
Operating voltage	5 Volts
Supply voltage	7-12 Volts
Voltage range	6-20 Volts
Digital inputs and outputs	14, of which 6 are for PWM
Analog inputs and outputs	6
Specified current per output channel	40 mAmperes
Memory	32 kB, of which 0.5 kB is for programming
SRAM	2 kB
EEPROM	1 kB
Frequency	16 MHs

The connection diagram of the active and reactive power balance monitoring and control device and the Arduino Uno integrated circuit is shown in Figure 4.

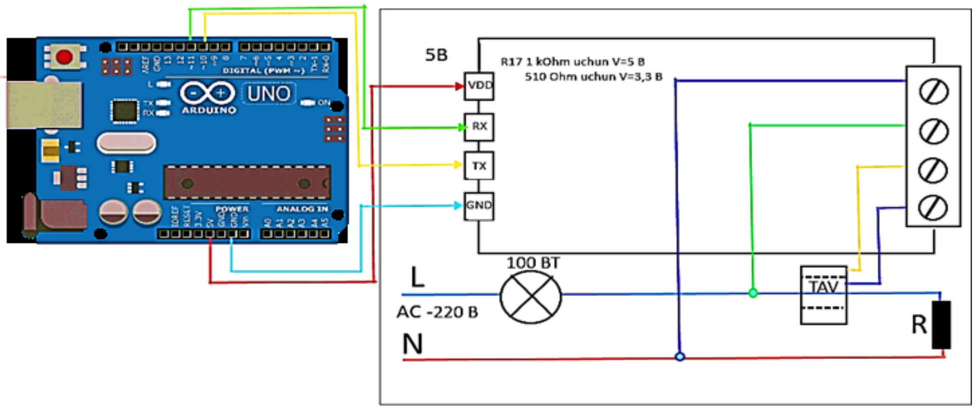


Fig. 4. Connection diagram of the active and reactive power balance control and management device and Arduino Uno integrated circuit

In the general scheme, the connection of the remaining phases of the electrical network is carried out in the same order as one phase is connected. The scheme presented in Figure 5 shows the connection of the active and reactive power balance control and management device and Arduino Uno integrated circuit.

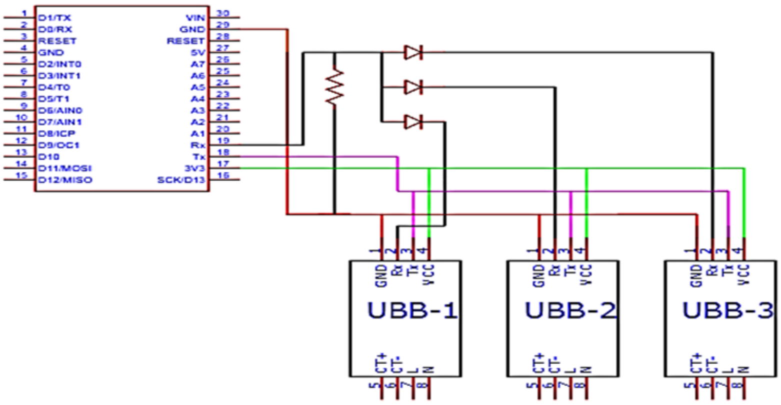


Fig. 5. Connection diagram of the three-phase active and reactive power balance control and control device and Arduino Uno integrated circuit

The measuring and control unit designed for the three-phase active and reactive power balance control and control is mainly assembled on the basis of the elements we have shown above, and its schematic diagram is shown in Figure 6.

The current and voltage signals at the output of the solar power plant inverter and the three-phase section of the traditional power grid are measured in the block for measuring data on the solar power plant and the power grid.

These measured signals are calculated in the block for processing the measurement results of the main electrical quantities of the power grid based on the equations given above [6-7].

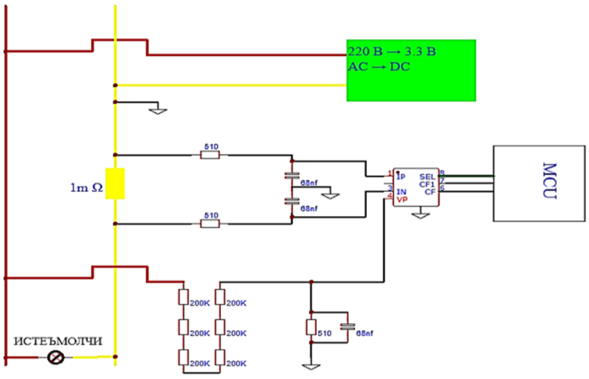


Fig. 6. Structural diagram of the measuring connection block

A control and control algorithm for the balance of active and reactive power was developed for the Arduino Uno selected for the three-phase active and reactive power control and management device. The control and control algorithm for the balance of active and reactive power is presented in Figure 4.

In order to compensate for the reactive power required by the power supply system network, the following additional reactive power amounts were determined for the minimum and maximum consumption modes and proposed for practical use [8]:

$$Q_{qop}^{min} = P_{o\prime rn} * (tg\varphi + tg\varphi_{tar}) = 43 * (3{,}792 + 0{,}38) = 179{,}392\ VAR$$

$$Q_{qop}^{max} = P_{o\prime rn} * (tg\varphi + tg\varphi_{tar}) = 43 * (0{,}505 + 0{,}38) = 38{,}055\ VAR$$

3. Conclusion

1. Ensuring the quality of electricity generated by solar power plants is one of the important tasks when transmitting electricity to the power supply system.

2. A solar power plant with a capacity of 80 kW installed in the educational laboratory building of the Bukhara Engineering and Technological Institute was taken as the object of research. By installing a measurement and control system created to monitor and control the reactive power consumption at the output of the solar power plant inverter, the reactive power to be compensated was calculated and reactive power sources were installed. According to the results of the research, it was justified that the reactive power consumption to be compensated with an installed average active power of the power supply system is 43 kW is as follows:

$$tg\varphi = tg\varphi(arccos\varphi) = tg\varphi(\arccos 0{,}255) = 0{,}3792$$

$$Q_{qop} = P_{o\prime rn} * tg\varphi = 43 * 3{,}792 = 16{,}31\ kVAR$$

3. The requirements for the power supply system indicate that consumers of electricity must be provided with high-quality active and reactive power in sufficient quantities. The results of the research have shown that one of the main factors affecting the quality indicators of active and reactive power of electricity is the automatic adjustment and compensation of reactive power in the power supply system based on the measurement and control system, since reactive power is an indicator of the efficiency of electricity.

4. The effective use of measurement and control systems in controlling the balance of active and reactive power in the power supply system with solar power plants allows you to control the minimum and maximum consumption of reactive power in real time, improve the quality of electricity, and also provides monitoring and digitization of the indicators of generated and consumed electricity.

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Comparative analysis of the degree of influence of factors on the speed of trains (using the example of Uzbek railways)

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Abstract: The main objective of the work is to conduct a comparative analysis of the impact of the main factors on train speeds on the normative and implemented train traffic schedule indicators. This was done using systematic, analytical, factor and tabular analyses. The train traffic speeds on the railway sections of the regional railway nodes of "UTY" JSC were systematically analyzed for the period 2011-2022, and as a result, the main factors that significantly negatively affect the actual implementation of the established normative speed values (replacement of train locomotives, the number of seasonal freight trains, stopping times at stations along the route, the number of seasonal passenger trains) were identified. The shares of the degree of influence of the identified main factors on the speed of freight trains on the railway sections were determined according to the criteria of weak, medium and strong. It was determined that the share of the main factors influencing the speed of freight trains on the railway sections under the jurisdiction of "UTY" JSC is weak - 32%, medium - 44% and strong - 24%. The method of systematic analysis of factors makes it possible to reasonably establish the values of train speeds in the production process and predict them on a daily, quarterly and annual basis.

Keywords: Train speed, factor, systematic analysis, comparative analysis, railway section

1. Introduction

One of the important tasks of the railway transport management system is the delivery of cargo and passengers in accordance with the established technical standards of the train traffic schedule (TTS) based on the daily planned performance indicators [1-4]. In this regard, the level of actual implementation of such indicators as technical equipment, movement speeds, type of traction supply, transportation and throughput capacity of railway sections attached to railway enterprises (regional railway nodes (RRN)) is of great importance [5, 6].

When standardizing the values of train speeds, the existing capacity of railway sections, the standard interval time, and the flow of freight and passenger trains are taken into account. However, the share of constant factors affecting the speed of movement during train movement is not taken into account. In particular, the number of high-speed passenger trains on railway sections, the traction force of locomotives, the variability of seasonal train flows, inefficient waiting of trains at stations, etc [1, 4, 7-9].

It is advisable to assess the values of train speeds for the next day, quarter and year by comparing the share of factors with the level of influence of established technical standards and the indicators actually achieved.

2. Research methodology

For comparative analysis of the speed indicators in the train movement graph, the following analytical methods are used: ((1)÷(3)- expressions) [1, 7]:

running speed

$$\vartheta_{run} = \frac{L_{sec}}{t_{run}} \qquad (1)$$

technical speed

$$\vartheta_{tech} = \frac{L_{sec}}{t_{run}+\sum t_{ac/sl}} \qquad (2)$$

section speed

$$\vartheta \frac{L_{sec}}{t_{run}+\sum t_{ac/sl}+\sum t_{in.st}}_{sec} \qquad (3)$$

here L_{uch} – length of specific railway sections, km;
t_{yur} – the time spent on trains moving at the set speed on the sections, hours;
$\sum t_{or.st}$ – time spent by freight trains on technological operations at intermediate stations and passing trains in the opposite direction, hours;
$\sum t_{t/s}$ – time spent by trains on acceleration and deceleration, hours;

These analytical expressions ((1)÷(3)) allow for the assessment of daily operational indicators on railway sections and planning for future periods. In particular, they allow for the comparison of daily operational indicators of the normative and implemented TTS, the determination of the reserve carrying capacity of sections, and the analysis of factors that negatively affect the established technical standards of movement speeds.

To stabilize transportation processes on the railway network, automated information systems have been developed and put into practice instead of information systems. These systems create opportunities for operational management of train movements on railway sections and assessment of their technical and economic efficiency [3]. For a comprehensive assessment of the TTS, a mathematical method has been developed for calculating the capacity of freight trains during periods when railway sections are devoid of passenger trains [8]

$$N_{fr}^{max\, min\left(\sum_{i=1}^{n\sum}\frac{\Delta t_{zon}^{i}}{T_{int}}()\right)} \qquad (4)$$

there
N_{fr}^{max} – The TTG has a maximum number of freight train movements during the period when the passenger is free of the train zone;

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Δt_{zon}^{i} – Time in the TMG in the freight train running zone, minutes.

T_{int} – interval time between trains, minutes;

1 – Extra train for fast TMG conversion.

In [9], a method for estimating the speed of a section was developed, taking into account factors that indicate the daily movement of freight trains.

$$\vartheta\left(1 - A\frac{T}{1440}\right)_{run_{sec}} \qquad (5)$$

here

A – correlation coefficient of factors affecting the movement of freight trains;

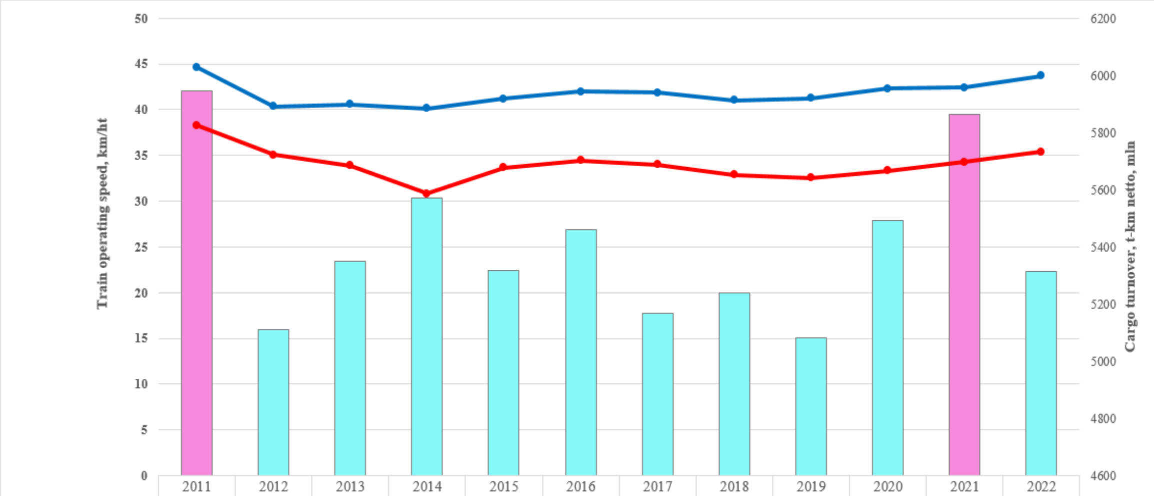
T – total travel time of freight trains on railway sections, minutes;

ϑ_{run} – speed of freight trains, km/h;

The author developed a method for analyzing and estimating section speed, taking into account random factors *(A)* affecting the movement of freight trains on railway sections, the speed of travel on sections, and the total time spent on the movement of freight trains during the day *(T)*.

3. Result and discussion

The impact of freight turnover on train speeds on railway sections within the regional railway hubs of “UTY” JSC was analyzed for the period 2011-2022 (Figure 1).



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
cargo turnover	5945,177	5110,539	5348,995	5572,463	5316,148	5461,527	5167,718	5240,92	5081,737	5492,225	5865,642	5313,071
plot speed	38,27	35,07	33,9	30,81	33,66	34,46	33,99	32,9	32,55	33,34	34,28	35,4
technical speed	44,64	40,35	40,58	40,14	41,18	41,98	41,84	41,05	41,28	42,31	42,42	43,7

Fig. 1. Dynamics of the degree of influence of the amount of cargo turnover on train speeds on railway sections within the regional railway nodes of JSC “UTY”

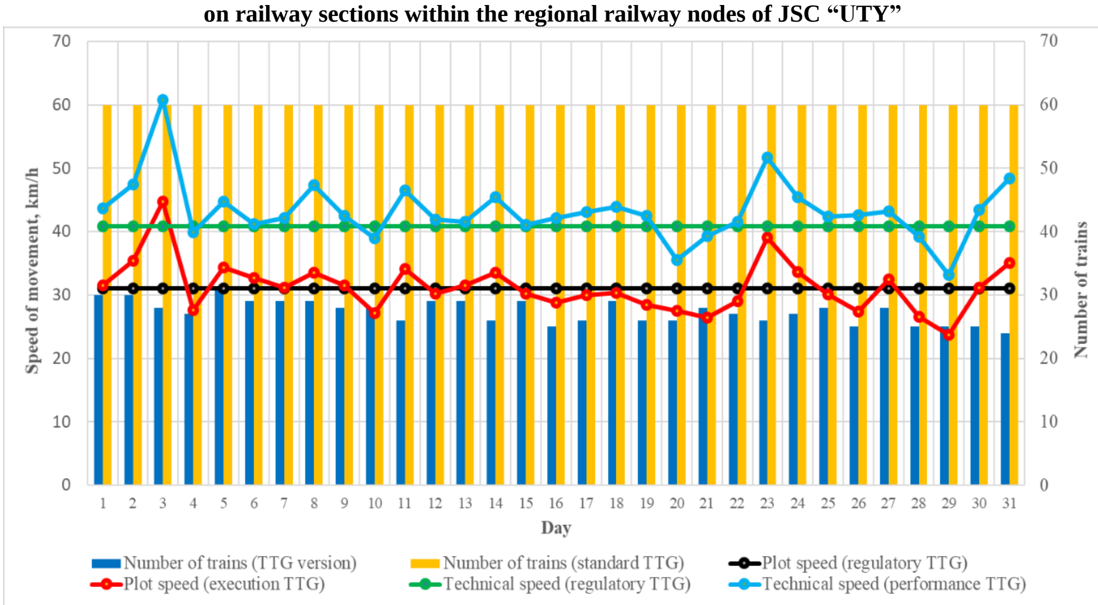


Fig. 2. Comparative analysis of the daily volume of freight trains in relation to technical and section speeds and the main indicators of the normative and implemented TTS (Uzbekistan-Khovos-Jizzakh)

The results of the analysis show that the dynamics of annual freight turnover (increase and decrease) does not significantly affect the speed of freight trains (SFT). Therefore, the factor of increase or decrease in the amount of freight turnover does not play a significant role in establishing the technical standards of SFT for specific sections and routes of “UTY” JSC.

Based on the statistical data of “UTY” JSC, a comparative analysis of the impact of the number of freight trains on the SFT (Uzbekistan-Khovos-Jizzakh) was carried out (Table 1). The comparative analysis was carried out for December, when the number of trains was the highest. Based on the data obtained from the analysis results, the impact of the change in the daily number of freight trains on the technical and section speeds and the main indicators of the normative and implemented SFT (Uzbekistan-Khovos-Jizzakh) was presented in the form of a diagram (Figure 2).

The technical and section speeds were determined as 41.8 and 32.95 km/h, respectively, when the average number of freight trains on the normative TTS was 21 pairs. The technical and section speeds were analyzed as 43.3 and 27.3 km/h, respectively, when the average number of freight trains on the operational PHG in December 2022 was 14 pairs. A comparative analysis of the main indicators of the normative and operational TTS showed that the number of freight trains was 7 pairs less, the technical speed was 1.5 km/h higher on average, and the section speed was 5.6 km/h lower.

In the analyzed month (Table 1), it can be seen that, in accordance with the change in the daily volume of freight trains, that is, on days when the number of trains increased, technical and section speeds decreased by more than 90% (for example, days 4 and 29), and in about 10% of cases, TTS indicators increased.

Table 1

Comparative analysis of the impact of the number of freight trains on the railway section "Uzbekistan-Khovos-Jizzakh" (December 2022)

Day	Distance traveled, km	Dwell times, hours	Time in motion, hours	Number of freight trains	Site speed, (average) km/h	Technical speed, (average) km/h
1	3351,4	29,51	76,74	30	31,54	43,67
2	3519,4	25,18	74,18	30	35,42	47,44
3	3930,7	23,13	64,72	28	44,74	60,73
4	2887,1	32,16	72,34	27	27,63	39,91
5	3304,1	22,56	73,78	31	34,30	44,78
6	3057,6	19,31	74,17	29	32,71	41,22
7	3074,3	25,78	72,89	29	31,16	42,18
8	3308,9	28,75	69,94	29	33,53	47,31
9	3080,6	25,14	72,48	28	31,56	42,50
10	3138,6	35,01	80,69	28	27,13	38,90
11	3002,9	23,55	64,51	26	34,10	46,55
12	3001,2	27,73	71,68	29	30,19	41,87
13	3151,4	23,97	75,89	29	31,56	41,53
14	2795,9	22,01	61,46	26	33,50	45,49
15	3128,6	27,27	76,08	29	30,27	41,12
16	2595,3	28,33	61,65	25	28,84	42,10
17	2699,9	27,26	62,71	26	30,01	43,05
18	3128,4	31,77	71,26	29	30,36	43,90
19	2758,5	32,12	65,01	26	28,40	42,43
20	2420,7	20,16	68,03	26	27,45	35,58
21	2659,5	33,02	67,71	28	26,40	39,28
22	2872,9	29,93	69,15	27	29,00	41,55
23	3086,8	19,42	59,66	26	39,03	51,74
24	2813,6	21,55	61,99	27	33,68	45,39
25	2679,6	25,83	63,19	28	30,10	42,41
26	2887,7	37,59	67,71	25	27,42	42,65
27	3079,3	23,47	71,31	28	32,49	43,18
28	2530,3	30,77	64,51	25	26,56	39,22
29	2921,7	35,15	88,14	25	23,70	33,15
30	2961,21	26,88	68,11	25	31,17	43,48
31	2833,93	22,38	58,53	24	35,03	48,42
General	**92662,04**	**836,69**	**2150,22**	**848**	**31,02**	**43,09**

It can be seen that the factors influencing the organization of train movement on the comparatively analyzed railway section have different effects on the level of fulfillment of the SFT normative values. In particular, it can be seen that the factors analyzed as the main factors (replacement of train locomotives, the number of seasonal freight trains, stopping times at stations along the route, the number of seasonal passenger trains) have high levels of influence.

Factors with high levels of influence have shown the feasibility of analyzing technical, technological, permanent and random factors affecting the RRT on railway sections not only in groups, but also in a comparative analysis of the main factors on specific sections [2, 10]. Therefore, the sections of the regional railway junction unitary enterprises (RRJUE) under the jurisdiction of UTY JSC (Tashkent RRN (Uzbekistan-Khovos-Jizzakh, Tashkent junction, Sergeli-Angren-Khojikent), Bukhara RRN (Khovos-Jizzakh-

Maroqand, Maroqand-Bukhara-Khojidavlat, Tinchlik-Uchkuduk 2-Misken, Bukhara-Misken), Kokand RRN (Kokand-Margilan Karasuv, Khovos-Kokand-Akhunboboyev, Pop-Angren), Karshi RRN (Bukhara-Karshi-Maroqand), Termez RRN (Tashguzar-Boysun-Kumqorgon, Karshi-Termez-Sarosiyo), Qongorod RRN (Qongorod-Taxiyatosh-Urgench-Misken-Nukus, a comparative analysis was carried out on the example of the main factors influencing the RRN on the Kungirat-Jaslyk-Qaraqalpak section.

The comparative analysis was carried out on the example of the following main factors:

- replacement of train locomotives;
- seasonal number of freight trains;
- stopping times at stations along the route;
- seasonal number of passenger trains.

In this case, the impact of the above factors on the reduction of the normative values of the SFT in the section of the RRN sections was analyzed comparatively based on the criteria of weak, medium and strong (Table 2).

Table 2

Results of assessment of the impact of the main factors on the level of safety of railway sections under the control of "UTY" JSC

Impact level criteria	RRJUE Tashkent			RRJUE Bukhara				RRJUE Kokand		RRJUE Karshi	RRJUE Termez		RRJUE Qongorod	
	Uzbekistan-Khovos-Jizzakh	Tashkent junction	Sergeli-Angren-Khojikent	Khovos-Jizzakh-Maroqand	Maroqand-Bukhara-Khojidavlat	Tinchlik-Uchkuduk 2-Misken	Bukhara-Misken	Kokand-Margilan Karasuv	Khovos-Kokand-Akhunboboyev	Bukhara-Karshi-Maroqand	Tashguzar-Boysun-Kumqorgon	Karshi-Termez-Sarosiyo	Qongorod-Taxiyatosh-Urgench-Misken-Nukus	Kungirat-Jaslyk-Qaraqalpak
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
replacement of train locomotives														
Weak			+			+			+					+
Average		+			+			+				+	+	
Strong	+			+			+			+	+			
seasonal number of freight trains														
Weak			+					+			+			+
Average		+			+	+	+		+	+		+	+	
Strong	+			+										
stopping times at stations along the route														
Weak			+				+				+		+	+
Average		+			+	+		+	+			+		
Strong	+			+						+				
seasonal number of passenger trainsr														
Weak							+		+			+	+	+
Average			+		+	+		+		+	+			
Strong	+	+		+										

From the results of the assessment of the degree of influence of factors on the SFT, it can be seen that, except for the factor of the number of seasonal freight trains of the Tashkent RRN (Table 2), the degree of influence of all types of factors on the SFT is the same, that is, from 33.3% (strong - 33.3%, weak - 33.3%, average - 33.3%).

Based on the results presented in Table 2, the share of the degree of influence of each factor (replacement of train locomotives, number of seasonal freight trains, stopping times at stations along the route, number of seasonal passenger trains) on the SFT was assessed in the RRN section (Figures 3÷6).

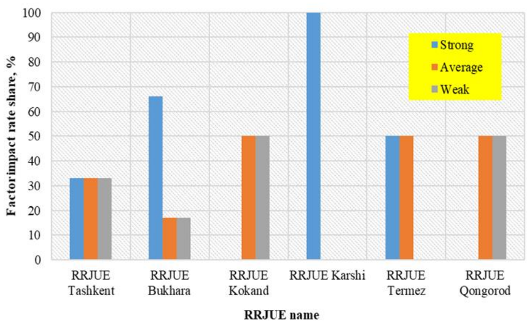


Fig. 3. The share of the impact of the locomotive replacement factor on the SFT of the RRJUEs under the jurisdiction of "UTY" JSC

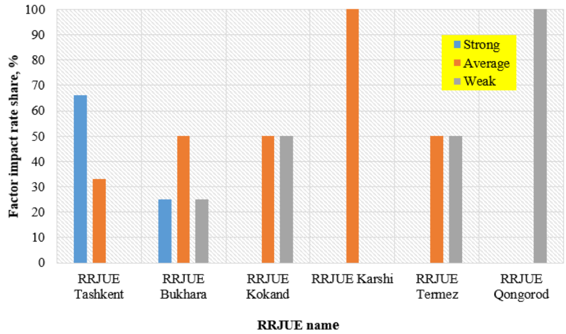


Fig. 4. The share of the impact of the seasonal freight train volume factor on the SFT for RRJUEs under the jurisdiction of "UTY" JSC

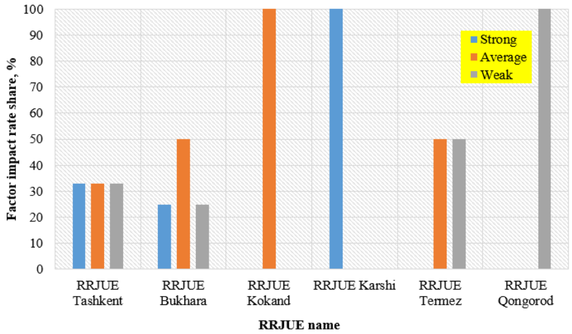


Fig. 5. The share of the impact of the factor of stopping times at stations along the route on the SFT for RRJUEs under the jurisdiction of "UTY" JSC

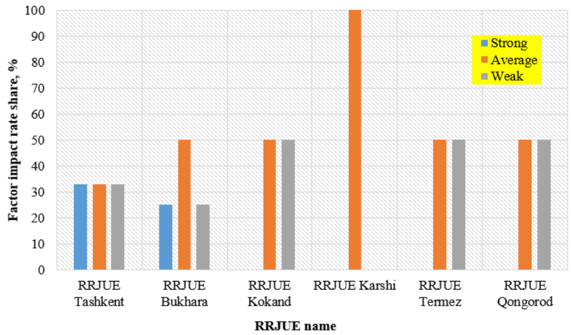


Fig. 6. The share of the impact of the seasonal passenger train volume factor on the SFT for RRJUEs under the jurisdiction of "UTY" JSC

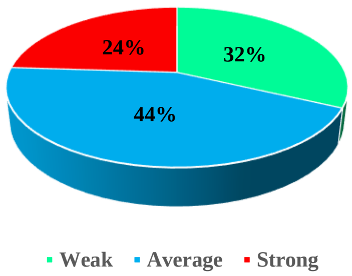


Fig. 7. The share of the main factors influencing the level of road safety on railway sections under the control of UTY JSC

The impact of factors that strongly influence the SFT is not significant. From the results presented in Figures 3÷6 and Table 1, it can be concluded that the negative impact of the main factors on the implementation of the SFT normative values is high. That is, the level of impact according to the strong and medium criteria is more than 60%. It can be seen that the negative impact of the main factors on the SFT on the railway sections under the control of "UTY" JSC is high (68% (strong - 24%, medium - 44%)) (Figure 7).

4. Conclusion

A comparative analysis of the degree of influence of the main factors on the speed of trains was conducted on the section of railway sections within the framework of the Tashkent State Railways and Transport Corporation under the jurisdiction of "UTY" JSC. The criteria for the degree of influence on the speed of trains (weak, medium, strong) on the sections of the railway sections of the RRN were assessed. As a result, it was possible to predict the daily, quarterly and annual indicators of the impact on the level of implementation of the established normative values of the RRN and the factors analyzed as the main indicators. A comparative comparative analysis of the main indicators of the normative and implemented speed of trains was carried out on the "Uzbekistan-Khovos-Jizzakh" railway section within the framework of the Tashkent State Railways and Transport Corporation under the jurisdiction of "UTY" JSC based on statistical and practical data.

The comparative analysis showed that despite the different number of freight trains in the implemented TTS during the days of December 2022, it was determined that the train speeds were at the lowest values on the 4th and 29th. Therefore, in the future, when establishing technical standards for the SFT on specific railway sections and routes under the jurisdiction of "UTY" JSC, it was proposed to establish TTS indicators based on the results of the comparative analysis.

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The use of modern composite materials and technologies in the design of Unmanned Aerial Vehicles

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Abstract: The integration of modern composite materials and advanced manufacturing technologies has revolutionized the design and performance of Unmanned Aerial Vehicles (UAVs). This study investigates the application of carbon fiber-reinforced polymers (CFRP), glass fiber-reinforced polymers (GFRP), and hybrid composites in UAV structures. Through experimental testing, computational modeling, and aerodynamic analysis, the research demonstrates significant improvements in weight reduction, structural integrity, and aerodynamic efficiency. The results indicate that composite materials enhance UAV performance by increasing payload capacity, extending flight duration, and improving overall durability. This paper underscores the critical role of composites in advancing UAV technology and provides a foundation for future innovations in aerial vehicle design.
Keywords: Composite Materials, Unmanned Aerial Vehicles (UAVs), UAV Design, Carbon Fiber-Reinforced Polymers (CFRP), Glass Fiber-Reinforced Polymers (GFRP), Hybrid Composites, Aerodynamic Efficiency, Structural Integrity, Lightweight Structures, Advanced Manufacturing Technologies

1. Introduction

Unmanned Aerial Vehicles (UAVs) have rapidly evolved to become essential tools across a myriad of industries, including surveillance, environmental monitoring, agriculture, and logistics. The versatility and operational efficiency of UAVs make them invaluable for tasks that range from real-time data collection to delivering critical supplies in remote or hazardous areas. As the demand for UAVs with enhanced performance metrics such as increased payload capacity, extended flight durations, and improved maneuverability continues to grow, the need for advanced materials and innovative design methodologies becomes paramount [1].

Traditionally, UAV structures have been fabricated using metallic materials like aluminum and titanium alloys. While these materials offer sufficient strength and durability, their relatively high densities impose significant weight burdens. This weight not only limits the payload capacity and flight endurance but also increases fuel consumption and operational costs. Consequently, there is a pressing need to explore alternative materials that can mitigate these limitations without compromising structural integrity or performance [2].

Composite materials, particularly Carbon Fiber-Reinforced Polymers (CFRP) and Glass Fiber-Reinforced Polymers (GFRP), have emerged as promising alternatives to traditional metals in UAV construction. These materials are celebrated for their exceptional strength-to-weight ratios, corrosion resistance, and design flexibility. CFRP, for instance, offers superior tensile strength and stiffness, making it ideal for critical structural components where performance and weight reduction are crucial.

GFRP, while slightly less robust than CFRP, provides a more cost-effective solution with adequate mechanical properties for less demanding applications. Additionally, hybrid composites that combine carbon and glass fibers are being investigated to balance performance and cost, offering tailored properties that meet specific design requirements [3].

Advancements in manufacturing technologies have further propelled the adoption of composite materials in UAV design. Techniques such as Automated Fiber Placement (AFP) and Resin Transfer Molding (RTM) enable the precise and efficient fabrication of complex geometries that are often challenging to achieve with traditional manufacturing methods. AFP allows for the meticulous placement of fibers, minimizing material waste and ensuring consistent quality across components. RTM facilitates the creation of intricate shapes with minimal voids, enhancing the structural integrity and aerodynamic performance of UAVs. Moreover, the integration of additive manufacturing, or 3D printing, into composite fabrication processes offers unprecedented flexibility in prototyping and customizing UAV components, accelerating the innovation cycle and reducing time-to-market [4].

This paper delves into the pivotal role of modern composite materials and manufacturing technologies in revolutionizing UAV design. By examining the mechanical performance, weight optimization, and aerodynamic efficiency of UAVs constructed with CFRP, GFRP, and hybrid composites, this study aims to elucidate the tangible benefits these materials offer over traditional metals. Through a combination of experimental testing, computational modeling, and aerodynamic analysis, the research provides a comprehensive evaluation of how composites enhance UAV performance. The findings underscore the transformative potential of composite integration in UAV structures, paving the way for future advancements in aerial vehicle technology.

2. Research methodology

The selection of appropriate materials is critical in the design and optimization of Unmanned Aerial Vehicles (UAVs). This study focuses on evaluating Carbon Fiber-

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Reinforced Polymers (CFRP), Glass Fiber-Reinforced Polymers (GFRP), and hybrid composites that integrate both carbon and glass fibers. The primary criteria for material selection include tensile strength, modulus of elasticity, density, fatigue resistance, and cost-effectiveness. These criteria ensure that the chosen materials not only enhance the structural performance of UAVs but also maintain economic feasibility for large-scale production.

CFRP is renowned for its exceptional tensile strength and stiffness, making it ideal for critical structural components that require high performance and weight reduction. The high strength-to-weight ratio of CFRP allows for significant weight savings without compromising structural integrity, which is essential for improving UAV payload capacity and flight endurance [5].

GFRP offers a more cost-effective alternative to CFRP while still providing adequate mechanical properties for less demanding applications. Although GFRP has a lower tensile strength and modulus of elasticity compared to CFRP, its versatility and ease of manufacturing make it suitable for various UAV components where extreme performance is not paramount [6].

Hybrid composites, which combine carbon and glass fibers, aim to balance performance and cost. By integrating both types of fibers, hybrid composites can be tailored to achieve specific mechanical properties required for different UAV sections. This approach allows for optimized material usage, where carbon fibers are utilized in high-stress areas and glass fibers are employed in regions where lower strength is acceptable [7].

Selection criteria:

– Determines the material's ability to withstand tensile forces without failure.
– Indicates the stiffness of the material, affecting the UAV's structural rigidity.
– Lower density contributes to weight reduction, enhancing payload capacity and flight duration.
– Ensures durability and longevity of UAV components under cyclic loading conditions.
– Balances material performance with economic viability for production scalability.

Table 1

Comparative material properties for UAV Structures

Material	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Density (g/cm³)	Cost ($/kg)
Aluminum	300	69	2.70	2.0
CFRP	600	150	1.60	15.0
GFRP	400	35	2.50	8.0
Hybrid	500	90	2.05	10.0

The materials were selected based on their ability to meet the performance requirements of modern UAVs. CFRP was chosen for its superior mechanical properties, making it suitable for high-stress areas such as the UAV frame and wings. GFRP was selected for components where cost savings are critical, and the mechanical demands are lower. Hybrid composites were incorporated to achieve a balance between performance and cost, allowing for strategic placement of different fiber types within the UAV structure.

To effectively utilize the selected composite materials, advanced manufacturing techniques were employed. These techniques enable the precise fabrication of complex UAV geometries, ensuring optimal material properties and structural performance.

– AFP technology allows for the accurate placement of fibers in predefined patterns, reducing material waste and ensuring consistent quality across UAV components. This method is particularly beneficial for creating lightweight and strong structures with minimal defects [8].
– RTM facilitates the production of complex shapes with minimal voids, enhancing the structural integrity and aerodynamic performance of UAVs. This technique involves injecting resin into a closed mold containing the fiber reinforcement, ensuring thorough impregnation and consolidation of the composite material [9].
– The integration of 3D printing enables rapid prototyping and customization of UAV components. Additive manufacturing allows for the creation of intricate designs with tailored mechanical properties, accelerating the development cycle and reducing time-to-market for innovative UAV solutions [10].

Comprehensive experimental testing was conducted to evaluate the mechanical and aerodynamic performance of UAV structures fabricated with the selected composite materials. The testing procedures included:

– Performed to determine the tensile strength and modulus of elasticity of CFRP, GFRP, and hybrid composites. Specimens were subjected to uniaxial tensile loading until failure, and stress-strain curves were generated to assess material performance [11].
– Conducted to assess the compressive strength and behavior of the composite materials under load. These tests help in understanding the material's ability to withstand compressive forces, which is crucial for maintaining structural integrity during flight [12].
– Evaluated the durability and lifespan of the composite materials under cyclic loading conditions. Fatigue testing simulates the repetitive stresses experienced by UAV components during operation, providing insights into the long-term reliability of the materials [13].
– Utilized a wind tunnel to measure drag coefficients and assess airflow characteristics around UAV prototypes with composite structures. Aerodynamic testing ensures that the composite integration contributes to reduced drag and enhanced flight stability [14].
– In addition to experimental testing, computational modeling techniques were employed to simulate and predict the behavior of composite UAV structures under various conditions.
– FEA was used to simulate the structural behavior of composite UAV components under different loading scenarios. This analysis helps in identifying stress concentrations, potential failure points, and optimizing the material distribution within the UAV structure [15].
– CFD simulations were performed to analyze the aerodynamic performance of UAVs with composite structures. These simulations focus on drag reduction, airflow stability, and overall aerodynamic efficiency, providing valuable data for design optimization [16].

3. Results and Discussion

The integration of modern composite materials in Unmanned Aerial Vehicles (UAVs) has demonstrated substantial improvements in various performance metrics. This section presents the findings from mechanical testing, weight optimization, aerodynamic analysis, and structural integrity evaluations of UAV structures fabricated using Carbon Fiber-Reinforced Polymer (CFRP), Glass Fiber-Reinforced Polymer (GFRP), hybrid composites, and traditional aluminum.

The mechanical performance of the selected materials was rigorously evaluated through tensile, compression, and fatigue tests. The results underscore the superior mechanical properties of CFRP and hybrid composites compared to traditional aluminum, highlighting their suitability for high-performance UAV applications.

Tensile testing was conducted to determine the tensile strength and modulus of elasticity for each material. The specimens were subjected to uniaxial tensile loading until failure, and the resulting stress-strain curves were analyzed.

– Exhibited the highest tensile strength at approximately 600 MPa and a modulus of elasticity of 150 GPa. The stress-strain curve for CFRP demonstrated linear elastic behavior up to failure, indicating excellent tensile properties and stiffness [17].
– Showed a tensile strength of 400 MPa and a modulus of elasticity of 35 GPa. While lower than CFRP, GFRP still offers substantial strength for applications where extreme performance is not critical [18].
– Achieved a tensile strength of 500 MPa and a modulus of elasticity of 90 GPa. The hybrid approach effectively balances the high strength of CFRP with the cost-effectiveness of GFRP, providing tailored mechanical properties suitable for diverse UAV components [19].
– Served as a baseline with a tensile strength of 300 MPa and a modulus of elasticity of 69 GPa.

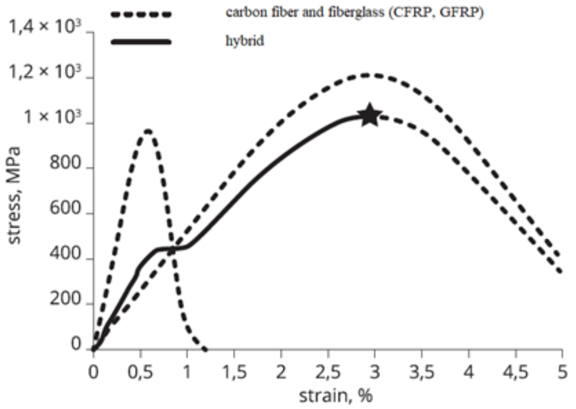

Fig. 1. Stress-strain curves of CFRP, GFRP, hybrid composites

The stress-strain analysis confirms that CFRP outperforms both GFRP and aluminum in terms of tensile strength and stiffness. Hybrid composites offer a middle ground, providing enhanced mechanical properties compared to GFRP while maintaining cost-effectiveness.

Compression testing assessed the ability of each material to withstand compressive forces. The results are summarized in Table 2.

Table 2

Compressive strength and behavior underload

Material	Compressive Strength (MPa)	Behavior Under Load
Aluminum	350	Exhibited plastic deformation before failure.
CFRP	550	Maintained structural integrity with minimal deformation.
GFRP	380	Showed some deformation but retained overall structure.
Hybrid	480	Balanced deformation with maintained integrity.

CFRP demonstrated superior compressive strength, closely followed by hybrid composites, making them ideal for load-bearing UAV components.

Fatigue testing evaluated the durability of the materials under cyclic loading conditions, simulating real-world operational stresses.

– Exhibited excellent fatigue resistance, with no significant degradation in mechanical properties after 105105 cycles.
– Showed moderate fatigue resistance, with a slight decrease in tensile strength after 105105 cycles.
– Demonstrated improved fatigue performance compared to GFRP, attributable to the reinforcing effect of carbon fibers.
– Experienced noticeable fatigue degradation, with a 20% reduction in tensile strength after 105105 cycles.

The fatigue performance results indicate that CFRP and hybrid composites offer enhanced durability and longevity for UAV structures, reducing the need for frequent maintenance and component replacements.

Weight reduction is a critical factor in UAV design, directly impacting payload capacity, flight duration, and overall performance. The incorporation of composite materials resulted in significant weight savings compared to traditional aluminum structures.

Table 3

Weight comparison of UAV structures

Material	Weight (kg)	Strength (MPa)	Cost ($/kg)
Aluminum	50	300	2.0
CFRP	35	600	15.0
GFRP	40	400	8.0
Hybrid	38	500	10.0

Table 3 illustrates a 30% reduction in weight when using CFRP compared to aluminum, with hybrid composites offering a balanced reduction of 24%.

The weight optimization results reveal that CFRP provides the most substantial weight savings, enabling UAVs to carry heavier payloads and achieve longer flight durations. Hybrid composites, while slightly heavier than CFRP, still offer significant weight reductions while maintaining cost-effectiveness.

Aerodynamic performance is paramount for UAVs, influencing speed, maneuverability, and fuel efficiency.

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Wind tunnel testing was conducted to assess the drag coefficients of UAV prototypes constructed with different materials.

Fig. 2. Aerodynamic drag comparison between composite and aluminum UAVs

The results indicate that UAVs with composite structures achieved a 15% reduction in aerodynamic drag compared to those constructed with aluminum. The smooth surface finish achievable through composite manufacturing techniques minimizes turbulence and enhances airflow stability, contributing to improved aerodynamic efficiency and flight performance.

$$C_d = \frac{2F_d}{pv^2A} \quad (1)$$

Where:

- C_d = Drag coefficient;
- F_d = Drag force;
- ρ_p = Air density;
- v = Velocity;
- A = Reference area.

The reduction in Cd*Cd* for composite UAVs translates to lower energy consumption and increased operational efficiency, making composites a superior choice for aerodynamic optimization.

Maintaining structural integrity under various loading conditions is essential for the reliability and safety of UAVs. Finite Element Analysis (FEA) simulations and experimental testing were employed to evaluate the structural performance of composite UAV components.

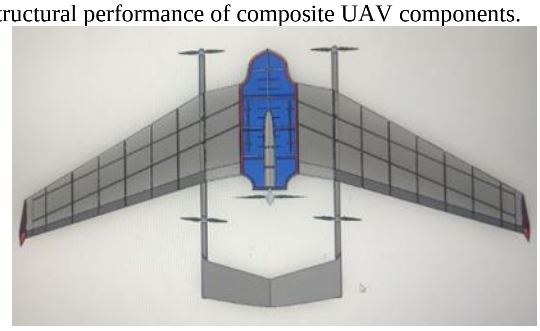

Fig. 3. Stress distribution in composite UAV structures under load

The FEA simulations revealed that composite UAV structures can withstand higher stress concentrations without deformation or failure. The anisotropic nature of composites allows for targeted reinforcement in critical areas, optimizing structural performance while minimizing material usage.

$$\sigma = \frac{A}{F} \quad (2)$$

Where:

– σ = Stress (MPa);

– F = Applied force (N);

– A = Cross-sectional area (mm²).

Experimental compression tests corroborated the FEA results, demonstrating that CFRP and hybrid composites maintain structural integrity under substantial loads, whereas aluminum structures exhibited deformation and potential failure points under similar conditions.

Fatigue testing confirmed that composites exhibit superior resistance to cyclic loading. CFRP, in particular, showed negligible fatigue degradation, while hybrid composites provided a balanced performance with enhanced durability over GFRP and aluminum [20]. This enhanced fatigue resistance contributes to the overall longevity and reliability of UAV components, reducing maintenance requirements and extending operational lifespan.

– Exceptional ability to withstand high stress concentrations and cyclic loading without significant deformation or failure.

– Balanced structural performance with targeted reinforcement, offering enhanced durability and reliability.

– Adequate structural integrity for less demanding applications but inferior to CFRP and hybrid composites.

– Susceptible to deformation and fatigue degradation under high stress and cyclic loading conditions.

The structural integrity results emphasize the advantages of composite materials in creating robust and reliable UAV structures, capable of performing under demanding operational conditions.

Integrating the findings from mechanical performance, weight optimization, aerodynamic efficiency, and structural integrity evaluations, it is evident that composite materials, particularly CFRP and hybrid composites, offer significant advantages over traditional aluminum in UAV design. The combined benefits of reduced weight, enhanced strength, improved aerodynamic properties, and superior durability position composites as the material of choice for next-generation UAVs.

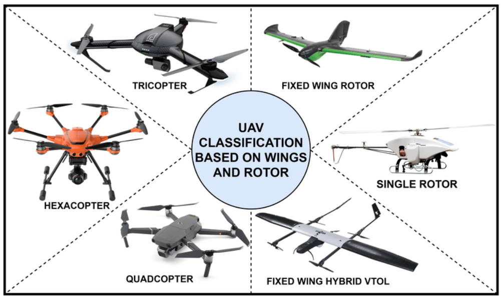

Fig. 4. Overall performance comparison of UAV structures

Figure 4 summarizes the comparative performance metrics, highlighting the comprehensive benefits of using composite materials in UAV structures.

4. Conclusion

The integration of modern composite materials and advanced manufacturing technologies has fundamentally transformed the design and performance of Unmanned Aerial Vehicles (UAVs). This study has systematically evaluated the application of Carbon Fiber-Reinforced Polymers (CFRP), Glass Fiber-Reinforced Polymers (GFRP), and hybrid composites in UAV structures, demonstrating their significant advantages over traditional metallic materials such as aluminum and titanium alloys.

– CFRP and hybrid composites exhibit superior tensile and compressive strengths compared to aluminum, enabling

UAV structures to endure higher stress concentrations and cyclic loading without substantial degradation. This enhanced mechanical robustness translates to increased durability and longer operational lifespans for UAV components.

– The use of composite materials, particularly CFRP, resulted in up to a 30% reduction in UAV weight. This weight optimization directly contributes to greater payload capacities, extended flight durations, and improved fuel efficiency, thereby enhancing the overall operational efficiency and versatility of UAVs.

– UAVs constructed with composite materials achieved a 15% reduction in aerodynamic drag compared to their aluminum counterparts. The superior surface finish and precise manufacturing capabilities of composites minimize turbulence and stabilize airflow, leading to enhanced speed, maneuverability, and energy efficiency.

– Finite Element Analysis (FEA) and experimental testing confirmed that composite UAV structures maintain structural integrity under substantial loads and complex stress distributions. The anisotropic properties of composites allow for strategic reinforcement in critical areas, optimizing material usage and ensuring robust performance under diverse operational conditions.

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Increasing the selective operation of microprocessor terminals

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Abstract: The article is devoted to a comprehensive study of microprocessor protection terminals for contact network feeders in terms of increasing the selectivity of its operation by reducing the number of outages for unknown reasons. The research is based on a method for visualizing, processing and storing information about the magnitudes and duration of currents and voltages (in the form of oscillograms) flowing in the contact network. An option for upgrading the existing terminal is proposed and the possibility of creating an individual template characterizing instantaneous operating parameters (setting) for various modifications of the train schedule (TS) is assessed.

Keywords: relay protection, selectivity, train schedule, oscillogram, spline interpolation, unified template, setting

1. Introduction

Relay protection (RP) is a set of devices designed for quick, automatic (in case of damage) identification and separation of damaged elements of this system from the electrical power system in emergency situations in order to ensure normal operation of the entire system

With the development of relay protection technology, its dimensions and self-consumption have decreased, its characteristics have improved, its performance, sensitivity and reliability have increased, and its operating algorithms have been improved. All this allows us to more confidently solve the main problem: a clear distinction between emergency and normal modes.

The purpose of relay protection and the requirements for it are that the devices must monitor the operation of electrical equipment, respond in a timely manner to changes in the operating mode, instantly disconnect the damaged section of the network and signal to personnel about an accident.

The following requirements apply to relay protection and automation systems:

1. Selectivity. In the event of an emergency, only the area in which an abnormal operating mode is detected should be switched off. All other electrical equipment must work.

2. Sensitivity. Relay protection must respond even to the most minimal values of emergency parameters (set by the response setting).

3. Performance. An equally important requirement for relay protection and automation, because The faster the relay operates, the less chance there is of damage to electrical equipment, as well as danger.

4. Reliability. Of course, the devices must perform their protective functions under the given operating conditions [4, 5].

Their use allows:

– implement fundamentally new possibilities for constructing protections;

– ensure the operation of protection in the presence of incomplete information;

– predict pre-emergency situations;

– implement self-diagnosis of protection;

– implement higher quality characteristics;

– process a large amount of information, incl. and from adjacent objects;

– implement self-adjusting (adaptive) systems.

The greatest effect of a microprocessor protection (MPP) system is realized when it is used in a complex manner, when not only the functions of relay protection and automation are performed, but also the location of damage is determined, digital oscillography is used to analyze the reasons that caused the protection to operate, etc. It is also possible to build multi-level automated control systems (ACS) based on MH units, thanks to the combination of protection functions with the functions of communication, data transfer, recording and displaying information (including about emergency situations) [1, 2].

However, there are many problems when using MPP systems:

– issues of operational reliability, etc.;

– problems with electromagnetic compatibility and noise immunity, especially in a situation of increasing danger of intentional remote impacts of powerful directed electromagnetic pulses;

– functional redundancy and complexity of settings for operation;

– relatively high cost;

– excessive sensitivity leading to false alarms;

– reliability is no higher than that of other types of relay protection, even with a built-in self-diagnosis capability.

The undoubted advantage of the MH system includes its design principles, namely: multiprocessing; modularity; decentralization; hierarchy; dynamic redistribution of functions; system development; complex design.

2. Research methodology

The object of further research is the microprocessor protection of AC railway contact network feeders.

This microprocessor protection has a modular-block design system, where current sensor modules (CSM) and voltage sensors (VSM), a measurement and protection controller module (MPCM) and an automation controller module (ACM) are located in a cassette manner (one after another) [3].

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Let's consider the process of operation of the MPP from a hardware and software point of view.

A simplified functional diagram of microprocessor relay protection is as follows (Fig. 1).

The input elements are intermediate voltage transformers IVT and current ICT, the output signals from which are fed to frequency filters (FF), which pass current and voltage components of 50 Hz and do not allow high-frequency harmonics (interference). Next, the analog signals must be converted into discrete ones using an analog-to-digital converter (ADC). The resulting discrete signals in the form of binary code are fed to the input of a programmable microprocessor system (MPS).

MPS functions as follows:

– food is supplied;

– the first command is loaded into the address register (AR);

– the first command transfers control to the control command;

– the control command tests the MPP (memory devices, external devices, etc.), rewrites the main program (MPr) into a random access memory device (RAM) and transfers control to it;

– the main program begins to work, performing the functions of the system in real time: the OPr enters into the OP the instantaneous values of the input signals, converted into digital form using an analog-to-digital converter;

– performs arithmetic and logical operations in accordance with the algorithm;

– compares the converted numbers with the setting of the starting element;

– if the trigger is triggered, the program starts working again.

The operation of microprocessor protection occurs as follows: controlled signals are continuously removed from current and voltage transformers and are fed to primary low-pass frequency filters, where higher harmonic components are cut off.

Next, the current and voltage signals are digitized for the purpose of subsequent discrete Fourier transform, which underlies the operation of digital filters.

The main task of digital filters implemented at the microprocessor software level is to isolate the first (fundamental) harmonic from the input non-sinusoidal signal.

The microprocessor analyzes and processes the parameters of the sinusoidal signal at the software level, issuing the appropriate control action through a digital-to-analog converter to the executive bodies (contact line feeder switches). In parallel, information about emergency modes is sent to the control panel of the operating personnel and stored in the memory module microprocessor protection digital automation protection.

The decision to trigger microprocessor protection is made mainly based on an assessment of the phase difference between the current and voltage vectors. Meanwhile, digital filters provide a large error in determining the phases if the signal frequency deviates from their nominal values.

Microprocessor protection is equipped with a display for current visual monitoring of parameters, but also with the ability to save information about cases of emergency shutdowns, false alarms, etc. Eighteen causes of emergency events are recorded and stored, which are stored in the EMERGENCIES menu and sixteen oscillograms of the last emergency shutdowns of the circuit breaker.

Oscillograms are recorded during recording with a sampling interval of 0.833 ms. The duration of the registration process is 1.2 s: - 0.5 s - accident background (before the accident); - 0.7 s - emergency process.

The contact network is a special case of a standard single-phase (multiphase) electrical network that does not have a reserve (although it belongs to the first category in terms of power supply reliability). Taking into account the specifics of the possible operating modes of the traction power supply system, a number of increased requirements and additional conditions are imposed on relay protection devices for AC contact network feeders.

Microprocessor protection) performs not only the functions of protection and automation, control and alarm, but also local and remote control of the traction network feeder.

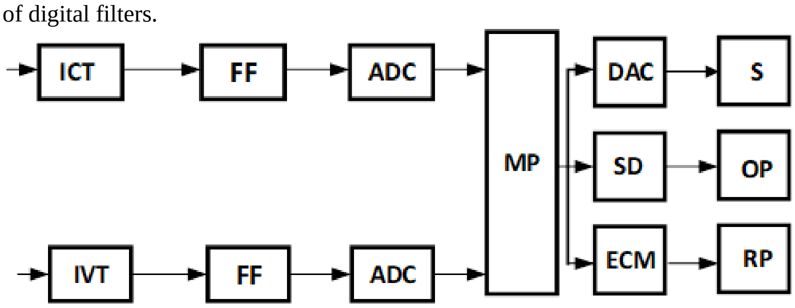

Fig. 1. Block diagram of microprocessor protection:
ICT – intermediate current transformer; IVT – intermediate voltage transformer; FF – frequency filters; ADC – analog-to-digital converter; MP – microprocessor; DAC – digital-to-analog converter; SD – signaling device; S – switch; OP – operational personnel; RP – relay personnel

Since microprocessor protection can be included in the automated control system of a traction substation as a lower-level subsystem, it provides two control modes:

- local control - by buttons located on the remote control unit;

- remote control carried out via a serial channel from an automated control system or through special discrete inputs from a traditional telemechanics rack.

One of the disadvantages in the operation of microprocessor protection is the inability to record into the device’s memory data on changes in currents and voltages flowing in the traction network in on-line mode (only a limited number of emergency oscillograms are recorded) and the ability to visualize them (on-line viewing) on the display control unit.

Investigating the possible reasons that led to such frequent (including) operation for unknown (unidentified)

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reasons, it can be assumed that rigidly introduced settings (which do not change with changes in the train situation and the operating mode of the traction power supply system) do not allow the relay protection device to recognize the modes , associated with a short-term increase in traction current and a change in the phase shift angle between current and voltage in normal operation when starting heavy trains, when resuming the power consumption mode after passing the neutral insert, when switching operating modes of electric locomotive engines, turning on recuperation modes, and trains entering coverage area of protection and exit from it during a batch traffic schedule, passage of heavy and double trains, etc.

3. Conclusion

As a result of a detailed study and analysis of the operation of existing and operated microprocessor relay protection of contact network feeders from the point of view of their modern level of automation, the following points were identified:

- there is no comprehensive approach to ensuring the reliability of the operating modes of the traction power supply system, including well-founded solutions in terms of hardware and software of devices and relay protection and automation systems, ensuring the survivability of objects of the traction power supply system;

- issues of organizing remote access and cybersecurity have not been fully resolved;

- the development of an automated relay protection system with active-adaptive algorithms is required;

- development of communication networks of information channels about the parameters of moving trains, track profile, train traffic modes, traffic schedules, etc.

The work proposes the following predicted changes in the general level of relay protection and automation systems:

- the use of microprocessor devices with significant computing capabilities;

- distributed hardware architecture - separation of functions between application functions of relay protection devices (formation of a database of settings templates, etc.) and control devices;

- development of communication networks of information channels about the parameters of moving trains, track profile, train movement modes, traffic schedules, etc.;

- use of modern communication means, mainly serial fiber-optic connections for new and modernized systems, duplication of communication ports;

- application of adaptive configuration, built-in damage assessment, improved algorithms for non-traditional instrument transformers;

- comprehensive monitoring of the energy system;

- use of modern automation tools.

The subject of this study is the standard algorithm for the operation of a device for digital protection and automation of a 27.5 kV overhead contact network feeder, which is proposed to be improved through the use of an analog-to-digital converter - an electronic USB oscilloscope, an additional (auxiliary) microcontroller and dedicated wired communication channels according to the “analog block” scheme. - digital converter – microcontroller unit – “GID” software – workplace of the duty personnel of the traction substation.”

The study was carried out using the conversion of instantaneous values of input signals into digital values, the fast Fourier transform method, the method of analytical representation of digitized signals using spline interpolation (first, second and third degrees with various options for gluing functions at their interface points), adaptation methods and joint storage of the received data from the auxiliary microprocessor and with a specialized software shell “GID” (graph of the executed movement) at the workplace of the duty personnel of the traction substation in the form of a database of unified settings templates

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Mathematical modeling of transient groundwater filtration in multilayered media with a low-permeability barrier

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Abstract: The article numerical models and computational algorithms for pressure and pressureless filtration processes in single-layer porous media were analyzed, and numerical models for pressure-pressureless filtration problems in dynamically coupled, low-permeable double-layer porous media based on the laws of fluid motion were developed, and software was created to solve groundwater filtration problems based on mathematical models and computational algorithms in the Matlab software tool.
The model and software they create are used to predict groundwater movement, assess environmental safety, or manage water resources.

Keywords: Filtration processes, mathematical models, groundwater filtration issues, software interface

1. Introduction

In our republic, research on filtration theory is of particular interest for accurately predicting groundwater level changes during irrigation, as well as assessing the impact of artificial and natural drainage structures on groundwater fluctuations. These studies are also of great importance for hydrogeology, land reclamation, and soil science.

Numerous hydrogeological cross-section studies have shown that, in most cases, the main aquifer, from which water is extracted, is overlain by a low-permeability cover layer and confined at the bottom by a weakly permeable barrier. This barrier facilitates the connection with underlying aquifers.

The problem of hydrogeological calculations for aquifers, oil, and gas fields remains unresolved. The mathematical challenges encountered in this field have forced researchers to simplify and schematize the physical picture of water movement in stratified conditions. However, the demand for scientifically grounded filtration theory predictions continues to grow.

The selection of optimal mathematical models for the studied process is impossible without a thorough quantitative analysis of various natural and artificial factors influencing the process. This analysis is best conducted through computational experiments using electronic computers. The process consists of several stages: problem formulation, mathematical modeling, computational algorithm development, programming, result analysis, and verification of the model's adequacy.

One of the most important aspects of comprehensive research is mathematical modeling of aquifers using various filtration theory models. The most effective and efficient methods for solving filtration theory problems involve numerical and computer modeling.

Since it is impossible to study water filtration processes in deep underground layers under natural conditions, mathematical, numerical, and computer modeling methods are employed. Through modeling, we can study, analyze, and predict filtration processes and groundwater movement in deep layers of the Earth.

The primary method of cultivating agricultural crops in Central Asia is artificial irrigation. The development of irrigated agriculture is constrained by water resources, making the extensive use of groundwater—an internal reserve—particularly important. The construction of hydraulic and reclamation structures, along with the utilization of groundwater for water supply and irrigation, affects the balance and regime of groundwater. These changes can lead either to the depletion of reserves or to groundwater rise, resulting in soil salinization. Therefore, the dynamic assessment of exploitable groundwater reserves must be based on comprehensive studies that consider climatic conditions, hydraulic engineering, land reclamation, and water supply.

A comprehensive study of hydrodynamic processes occurring in aquifers is becoming increasingly important due to the development of automated groundwater management systems.

The book by Davydov L.K. and others [1], which has long served as a textbook on general hydrology for university students, presents the fundamentals of hydrology, describes the interconnections between the waters of the Earth, and explains the general laws governing hydrological processes in oceans, seas, rivers, groundwater, lakes, reservoirs, swamps, and glaciers.

According to this book, the total amount of water on Earth that is not chemically or physically bound to the Earth's crust and mantle is approximately 1.5 billion km^3. About 94% (1.37 billion km^3) of this volume is contained in oceans and seas. The volume of water in the atmosphere is relatively small, amounting to about 14,000 km^3.

The volume of free gravitational water within the five-kilometer-thick continental crust is estimated at 60 million km^3, which is four times greater than the volume of surface water. In the Earth's mantle, there is at least 13–15 billion km^3 of chemically bound water—approximately 13 to 15 times the amount found in the world's oceans and on land.

Groundwater, located within the Earth's crust, exists in a zone where water is not the primary component of matter but is instead an integral part of it. The study of groundwater falls under the domain of hydrology—a branch of geology. One of the key properties of water as a liquid is its mobility. The study of the laws governing the motion and equilibrium

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of liquids is the task of hydromechanics and its applied branch—hydraulics. Hydraulics focuses on developing methods to apply general principles of liquid motion and equilibrium to solving practical problems under specific natural and human-made conditions.

This book is particularly useful as it provides a comprehensive list of the thermophysical properties of water in its three aggregate states, as well as details on the Earth's water cycle.

Book [2] is dedicated to the analytical theory of heat and mass transfer phenomena in gas mixtures, dispersed systems, and capillary-porous bodies. The development of mathematical models for filtration processes is based on fundamental physical laws, specifically Fick's law for mass transfer, Newton's law for momentum transfer, and Fourier's law for heat transfer.

Fick's law assumes a linear relationship between the substance flux and the gradient of the substance concentration within the studied field. However, practical observations show that this law does not always accurately describe filtration processes. To account for anomalous effects, an inertial term—representing the time derivative of the flux density—is sometimes included in Fick's law. This leads to hyperbolic equations for mass transfer, which possess the property of finite propagation speed for concentration profiles, resulting in the formation of concentration waves.

Macroscopic modeling has demonstrated that the relaxation time of mass flux density is very small. The study [3] shows that, depending on the differentiation of various parameters, different transport laws can be derived, each with distinct characteristics of concentration wave propagation.

Fractional derivatives have been widely used in numerous studies on filtration processes [4, 5, 6, 7]. One such study is the dissertation [8], which focuses on the further development of filtration theory for heterogeneous fluids in various porous media using the mathematical framework of fractional derivatives. It presents a comprehensive analysis of filtration in both homogeneous and heterogeneous media, employing fractional-order derivatives and their computation methods based on Riemann-Liouville, Grünwald-Letnikov, and Caputo definitions.

The key outcome of this research is the development and testing of new modifications of mathematical models for filtration processes. The study provides a qualitative analysis of the results obtained by applying these models to specific problems and highlights variations in modifications that differ from classical results in terms of process intensity over time and spatial distribution.

Study [9] examines the filtration process in a fractured-porous medium, modeled using fractal geometry. Due to the complex structure of fractures and pore blocks, the trajectory of suspended particles follows an intricate path. This study presents one of the first models of mass transport in such media. Within the framework of the bicontinuum approach, convective transport equations containing fractional derivatives are analytically derived for fractured-porous media.

Study [10] investigates hydrodynamic filtration models of heterogeneous fluids in porous media, considering diffusion, hydrodynamic dispersion, convection, adsorption, the heterogeneity of pore volume in terms of filling degree, and internal diffusive mass exchange.

This study provides key information on the adsorption of substances during convective-diffusive transport in porous media. It offers a detailed review of models and methods for solving mass transport problems in porous media. The research addresses mass transport problems in porous media saturated with both stationary and mobile fluids, under various adsorption and internal mass exchange laws (linear, nonlinear, equilibrium, and non-equilibrium). These problems are solved numerically, and concentration profiles of substances in mobile fluid zones, adsorbed substances, and mass exchange between zones are determined for different initial parameter values.

Additionally, the study explores a two-site adsorption model, where the total adsorption surface is divided into two parts—one undergoing equilibrium adsorption and the other non-equilibrium adsorption. The influence of this dual-site adsorption on mass transport characteristics is evaluated. A problem involving mass transport in a porous medium with a wetting front condition is also solved, with differences highlighted between this setting and the semi-infinite reservoir case.

Furthermore, a two-dimensional mass transport problem in a heterogeneous medium is considered, where the fluid remains immobile in certain inclusions but undergoes diffusion transport. The effects of stationary liquid zones and adsorption phenomena on mass transport characteristics in both regions are analyzed. The study also examines salt transport and dissolution processes in porous media and provides solutions for convective-diffusive transport of dissolved salts under wetting front conditions, considering a piecewise-homogeneous initial salinity field.

Maintaining reservoir pressure in oil and gas fields is a pressing issue, as it helps reduce the energy consumption of hydrocarbon extraction. Various injection methods have been proposed [11], including water injection, the disposal of industrial waste containing surface-active agents [12], dry gas injection, in-situ combustion of gas components, high-frequency reservoir stimulation, and other filling techniques.

The dissertation [13] is dedicated to the development of mathematical and numerical modeling methods for filtration processes in single-phase and two-phase media within single-layer and multilayer porous environments.

The review chapter of the study presents key concepts and methods for the development of oil and gas fields under various geological conditions. It also provides an overview of research on modeling unsteady filtration processes of liquids and gases in porous media, as well as an analysis of the main stages of mathematical modeling and computational experiments for oil and gas field development.

Numerical simulations have been conducted to model filtration processes related to the displacement of target products in porous media under water drive conditions. The study discusses the characteristics of field development under water drive mechanisms, considering different types of water flooding: intra-contour and extra-contour flooding in various configurations (well row flooding, areal flooding, selective flooding, localized flooding, frontal flooding, and barrier flooding). The dissertation presents both mathematical and numerical models, along with a computational algorithm for solving two-dimensional filtration problems involving multiphase media. These models account for the moving boundary between oil and water, as well as gas and water. One of the key achievements of this work is the development of a differential finite-difference method that utilizes the advantages of the longitudinal-transverse sweep technique.

The dissertation by U.J. Saidullaev [14] focuses on studying the peculiarities of filtration processes in conditions where a cake layer forms. The main contributions of this work include:

- The enhancement of a mathematical model describing the filtration of heterogeneous liquids with sediment formation on filter surfaces, based on exponential and nonlinear consolidation laws.
- The refinement of a mathematical model for suspension filtration with cake layer formation on filter surfaces, considering convective transport.
- The development of a mathematical model for filtration and suspension filtration with sediment formation on filter surfaces, using a generalized relaxation-based Darcy law.
- The formulation of a system of differential equations for relaxation-based filtration of suspensions with cake layer formation under constant filtrate flow conditions. This system was numerically solved for different relaxation time values.

Cake layer formation occurs naturally. At the same time, various methods and materials are used to suppress the filtration process. In particular, study [15] proposes using bentonite from various deposits in the Republic of Uzbekistan to reduce filtration processes. Based on extensive experimental data, optimal bentonite concentrations and layer thicknesses were determined for earthen dams, considering the physico-mechanical properties of both the soil and bentonite.

Study [16] focuses on problems related to mass transport in aggregated porous media with specific geometries, considering adsorption phenomena and the heterogeneous distribution of filtration velocity fields. The dissertation analyzes challenges in modeling mass transport processes in heterogeneous porous media and investigates the impact of adsorption phenomena on filtration.

A numerical solution has been formulated for the movement of fluids and mass transport in a cylindrical two-layer medium, where the inner cylindrical region represents a macropore, and the outer cylindrical region represents a micropore. The study examines fluid flow and mass transport in a dual-zone cylindrical porous medium, taking into account the non-uniform distribution of filtration velocity fields. Additionally, inverse problems for mass transport have been formulated and solved to determine the mass transfer coefficient, both with and without the consideration of adsorption effects.

2. Research methodology

The mathematical model of the two-dimensional problem of confined-unconfined filtration is reduced to the integration of a quasi-linear system of partial differential equations of the parabolic type:

$$\left.\begin{aligned} &\frac{\mu_1}{x}\frac{\partial H}{\partial t}=\frac{\partial}{\partial x}\left[(H-b)\frac{\partial H}{\partial x}\right]+\frac{\partial}{\partial y}\left[(H-b)\frac{\partial H}{\partial x}\right]+\frac{f_1}{k_1},\\ &\frac{\mu_2}{k_2}\frac{\partial Z}{\partial t}=\frac{\partial}{\partial x}\left[(Z-b)\frac{\partial Z}{\partial x}\right]+\frac{\partial}{\partial y}\left[(Z-b)\frac{\partial Z}{\partial y}\right]+\frac{f_2}{k_2}-(1-\frac{h}{Z-b}),\\ &\frac{\mu_3}{T}\frac{\partial h}{\partial t}=\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}+\frac{k_2}{T}(1-\frac{h}{Z-b}) \end{aligned}\right\}$$
(1)

with the corresponding boundary conditions:

$$H(x,y,0)=F_1(x,y),(0\le x,y\le L_1);\ (2)$$

$$\left.\begin{aligned}Z(x,y,0)=F_2(x,y),\\ h(x,y,0)=F_3(x,y),\end{aligned}\right\};(0\le x,y\le L_2);\ (3)$$

$$k_1(H-b)\frac{\partial H}{\partial x}\Big|_{x=0}=Q_1(t); \quad (4)$$

$$T\frac{\partial h}{\partial x}\Big|_{x=L_2}=Q_2(t);\frac{\partial Z}{\partial x}\Big|_{x=L_2}=0; \quad (5)$$

$$k_1(H-b)\frac{\partial H}{\partial x}=k_2(Z-b)\frac{\partial Z}{\partial x}+T\frac{\partial h}{\partial x};x=L_1;\ (6)$$

Where $H(x,0)=\phi_1(x),0\le x\le l_1$; - groundwater level, impermeable layer, filtration coefficients, specific yield, and infiltration in the single-layer filtration zone, respectively.

$Z(x,t),b(x),k_2,\mu_2,f_2$- the same for the covering thickness of the layered filtration zone;

$h(x,t),T,\mu_3$- pressure, coefficients of water conductivity and elastic water yield in the pressure horizon of the layered filtration zone;

Q_1 and Q_2 – lateral inflows into the filtration zone;

L_1- zone separation boundary;

L_2- filtration area length;

$F_1(x),F_2(x),F_3(x)$ - specified functions.

3. Computational experiment

A program was developed in MATLAB for the proposed algorithm. Using this program, the influence of filtration parameters of aquifers on the dynamics of groundwater level and head distribution in the transition zone from a single-layer to a layered filtration zone was studied.

In particular, the influence of the filtration coefficients k_1 and k_2 on changes in levels and pressures was assessed. The remaining geofiltration parameters are considered constant. The obtained forecast calculations for the second and fifth years after the start of irrigation are given in Table 1.

Table 1

The obtained forecast calculations

№	Filtration coefficient, m/day.		Forecast levels at the transition boundary (in meters)	
	Single layer zone k_1	Layered zone k_2	for 2 years	for 5 years
1	5	0,5	431,958	441,026
2	2,5	0,5	427,506	433,689
3	0,5	0,5	421342	422,961
4	0,5	2,5	418,752	418,343

Table 2

The results of the numerical experiment

№	Gravity drainage		Elastic water yield of the layered zone μ^*	Forecast levels at the transition boundary (in meters)	
	Single layer zone μ_1	Layered zone μ_2		for 2 years	for 5 years
1	0,15	0,10	0,08	422,342	423,961
2	0,15	0,10	0,003	419,803	422,417
3	0,15	0,15	0,15	421,318	422,920
4	0,10	0,35	0,08	423,698	425,218

From Table 2 it is evident that the greater the difference in the values of the filtration coefficients of the single-layer

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and layered zones, the greater the height of the rise in the groundwater level at the transition boundary (the initial level is 421.00).

Next, the effect of changing the capacitive properties of μ_1,μ_2 and μ^* on changing the groundwater level at the transition boundary is considered. The remaining geofiltration parameters remain unchanged. The results of the numerical experiment are given in Table 2.

The analysis of the obtained results shows that, as in the previous case, the greater the difference in the capacitive properties of the two zones, the higher the predicted level at the transition boundary. This leads to the accumulation of groundwater reserves in the single-layer unconfined zone.

Currently, we are studying even more complex mathematical models of aquifers, where two highly permeable heterogeneous aquifers, connected by a weakly permeable layer, interact with groundwater flows in the covering thickness through a partition. In this case, infiltration, evaporation, and the operation of drainage structures are taken into account.

Thus, a thorough analysis of various aquifer models and groundwater flow theories has allowed us to effectively apply the developed algorithms and programs for calculating many real-world objects and to provide practical recommendations for improving the reclamation conditions of old irrigated and newly developed areas in arid zones.

The algorithms described in the previous chapters are implemented as universal programs written in the Matlab algorithmic language. Using these programs, various options for predicting problems of pressure and gravity waters for a single-layer model of aquifers are solved, taking into account all natural and artificial factors that affect the filtration process.

The initial information for the programs is prepared as follows. The grid filtration area is supplemented to a rectangle with fictitious nodes. The input procedure must ensure the input of levels (pressures) and filtration coefficients (water conductivity) into two-dimensional arrays with the identifier HN, (TN) (the values of these functions in fictitious nodes are arbitrary).

All collected information about the initial conditions of the filtration area, i.e. about the position of the groundwater level, boundary conditions, design parameters and others constitute an information array that is constantly increasing, expanding and supplemented with more detailed and accurate new data. Therefore, along with the correct collection of information, it is necessary to ensure the most rational forms of storage in the form of technical media convenient for prompt input into a computer.

Development of stable computational schemes, universal and effective algorithms and software that allow for solving problems of pressure and gravity filtration significantly increases the reliability of the resulting numerical calculations and their visualization in the graphical form of the object.

Therefore, in order to improve the efficiency of using modern computers, it is necessary to create software for conducting a computational experiment with interaction with computer specialists. This is necessary for making final or intermediate decisions in the process of analysis and monitoring.

Based on the mathematical model and calculation algorithm on the Matlab software tool, software has been developed for solving groundwater filtration problems. The interface of the software for solving pressure filtration problems is shown in Fig. 3.1.

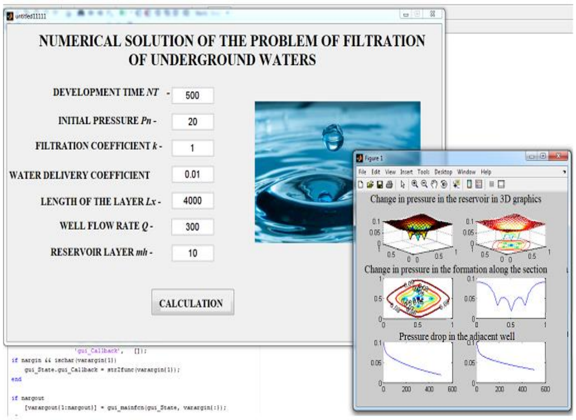

Fig. 1. Program for solving problems of groundwater filtration and visualization of numerical calculations of the computational experiment

The calculation results for the problem of pressure filtration in a single-layer zone are displayed as follows (Fig.1):

- Change in pressure in the formation in a 3D graph in various forms;
- Change in pressure in the formation in a contour graph;
- Change in pressure in graphs in the x-section;
- Drop in pressure in wells in graphs.

The following initial data are used to solve the problem:

n=21- the number of points in the grid area along x and y;

nt=500 - the total time for calculation;

dt=1 - the time step (per day);

pn1=200 - the initial pressure in the reservoir;

k=1 - the filtration coefficient;

μ - the free water loss coefficient;

Lx=4000 - the length of the filtration area along the x and y directions;

Q=300 - the well flow rates;

h=10 - power layer.

4. Conclusion

The software can be used for various similar two-dimensional problems, which mathematical model is described in the form of a differential equation of parabolic type.

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Evaluating the impact of elevations between concrete pavement slabs on road surface smoothness

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Abstract: This article investigates the formation of elevations between cement-concrete pavement slabs on the 228-581 km section of the A-380 "Guzar-Bukhara-Nukus-Beyneu" highway and the reasons for their impact on road surface smoothness. Experimental studies were conducted using the "TRASSA" mobile road laboratory. Based on the obtained results, the elevations in the expansion joints between concrete pavement slabs and their negative impact on road surface smoothness were evaluated. The study also considered the operating conditions of cement-concrete pavements and the influence of moving loads on the expansion joints between the slabs. The article analyzes how these elevations between slabs negatively affect road safety and the long-term performance of the road for vehicular traffic.
The obtained results serve to identify problems that arise in the production and operation of cement-concrete pavements and to develop practical recommendations for their elimination. The study also demonstrates the necessity of applying advanced technologies in road construction to enhance the quality of roads and improve their effective management.
Keywords: Evenness, protrusions, joints, IRI, dowel, anchor, cracks, structure, deformation, expansion joint, slab

1. Introduction

The formation of elevations between slabs on cement-concrete paved roads significantly affects the smoothness of the road surface. These elevations cause deformations on the road surface, which complicates vehicle movement and reduces safety. The elevations create unsmoothness of varying degrees (cracks and rises) on the road surface. This situation complicates the movement of vehicles, especially at high speeds, potentially leading to dangerous situations for drivers due to the elevations on the road surface. The irregularities and deformations deteriorate the road's smoothness, which leads to vehicles slowing down and, consequently, decreases the overall operational efficiency of the road [1,4].

If the smoothness of the road deteriorates due to uplifts and deformations, this, in turn, increases repair and maintenance costs. Deformed sections of concrete require repair or replacement, which shortens the road's service life and leads to additional expenses.

If elevations and deformations occur frequently, the road requires regular maintenance and renovation. This affects the continuous and safe movement of vehicles.

The key quality indicators of road surfaces are their durability and smoothness, which significantly influence traffic flow speed, ease of movement, transport safety, and load-bearing capacity. When certain road sections have low durability and smoothness, it necessitates the allocation of additional resources for their repair, leads to deterioration of vehicle traffic conditions, reduces the efficiency of automobile transport, and increases transportation costs (including fuel consumption and wear of spare parts and tires).

The importance of the highway, the conditions for ensuring convenient movement, and the calculated speed requirements are presented in QR 06.03-23 (Table 1) according to the international IRI (International Roughness Index) indicator and the established standards [3,6,8].

1-table

Requirements for the International Roughness Index (IRI)

№	The Significance of the Path	Road Classification	Types of coatings	Based on various assessments of road smoothness, its values according to the international IRI (International Roughness Index), (m/km)				
				Excellent	Very good	Good	Satisfactory	Unsatisfactory
1	International	I (Ia and Ib)	Hot asphalt concrete Cement concrete	up to 2,1	2,1-2,5	2,5-3,1	3,1-3,9	greater than 3,9
2	State	II	Hot asphalt concrete Sementbeton	up to 2,8	2,8-3,3	3,3-4,0	4,0-4,9	greater than 4,9
		III	Hot asphalt concrete	up to 3,2	3,2-3,8	3,8-4,7	4,7-5,8	greater than 5,8
			Cold asphalt concrete	up to 3,5	3,5-4,2	4,2-5,1	5,1-6,2	greater than 6,2
			Cold asphalt concrete	up to 4,4	4,4-4,9	4,9-5,6	5,6-6,5	greater than 6,5

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3	Local	IV	Black crushed stone Stone materials processed with binders	up to 4,7	4,7-5,3	5,3-6,1	6,1-7,2	greater than 7,2
		V	Black crushed stone Stone materials processed with binders	up to 6,1	6,1-7,1	7,1-8,5	8,5-10,1	greater than 10,1
			Crushed stone or stone aggregates	up to 6,5	6,5-7,6	7,6-8,9	8,9-10,6	greater than 10,6

As evident from the experience of developed countries, the smoothness of road surfaces is evaluated using the International Roughness Index (IRI). It is known that the formation of bumps on cement-concrete paved roads significantly deteriorates the smoothness of the road surface.

2. Research methodology

The Guide for Mechanistic-Empirical Design of New and Reconstructed Pavements - GMED-2003 (USA) contains a model for predicting pavement smoothness. Using this model, calculations are performed to evaluate the impact of elevation on pavement smoothness [2,9,10]:

$$\mathrm{IRI} = \mathrm{IRI}_0 + 0{,}013 \cdot C + 0{,}007 \cdot J + 0{,}0015 \cdot H + 0{,}4 \cdot S \qquad (1)$$

Here:

IRI_0 – initial roughness index, m/km;

C– Number of plates with transverse and angled cracks, %;

J – percentage of deteriorated (damaged) seams, %;

N- final value of the rise per 1 km of road, in mm;

S- The construction factor is calculated as follows:

$$\mathrm{S} = (\mathrm{T} \cdot (1 + \mathrm{I}) \cdot (1 + P_{0{,}075})) \cdot 10^{-6} \qquad (2)$$

Here:

T – age of the surface layer, in years;

I– cold hardiness index, °C days;

$R_{0,075}$- the percentage of particles smaller than 0.075 mm in the road subgrade soil.

3. Analysis and Results

We calculate the international roughness index for the studied sections of the road and adopt it as the initial smoothness measurement. In recent years, requirements for road surface smoothness have become more stringent. In this context, in foreign countries, the issue of ensuring the required pavement smoothness throughout its entire design life is addressed at the stage of determining and calculating the pavement structure. When calculating road surfaces, particularly rigid pavements, using modern methods, in addition to determining the main parameters of the structure, the probability of crack formation is assessed, taking into account the potential changes in road and environmental conditions.

We determined the longitudinal smoothness values for sections 228-581 km of the A-380 "Guzar-Bukhara-Nukus-Beyneu" highway using the "TRASSA" mobile road laboratory (Figure 1). The results obtained from measuring the longitudinal smoothness were processed and converted into graphical representations (Figures 2-6).

Fig. 1. "TRASSA" mobile road laboratory vehicle

Fig. 2. Smoothness indicators of the cement-concrete pavement on the 228-315 km section of the A 380 highway

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Fig. 3. Smoothness indicators of the cement-concrete pavement on the 315-355 km section of the A 380 highway

Fig. 4. Smoothness indicators of the cement-concrete pavement on the 355-440 km section of the A 380 highway

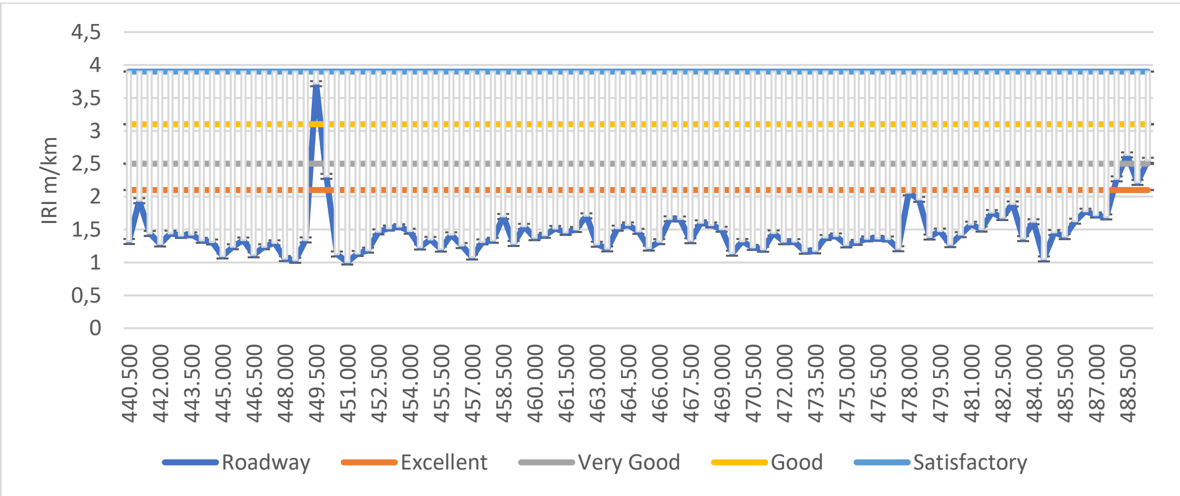


Fig. 5. Smoothness indicators of the cement-concrete pavement on the 440-490 km section of highway A 380

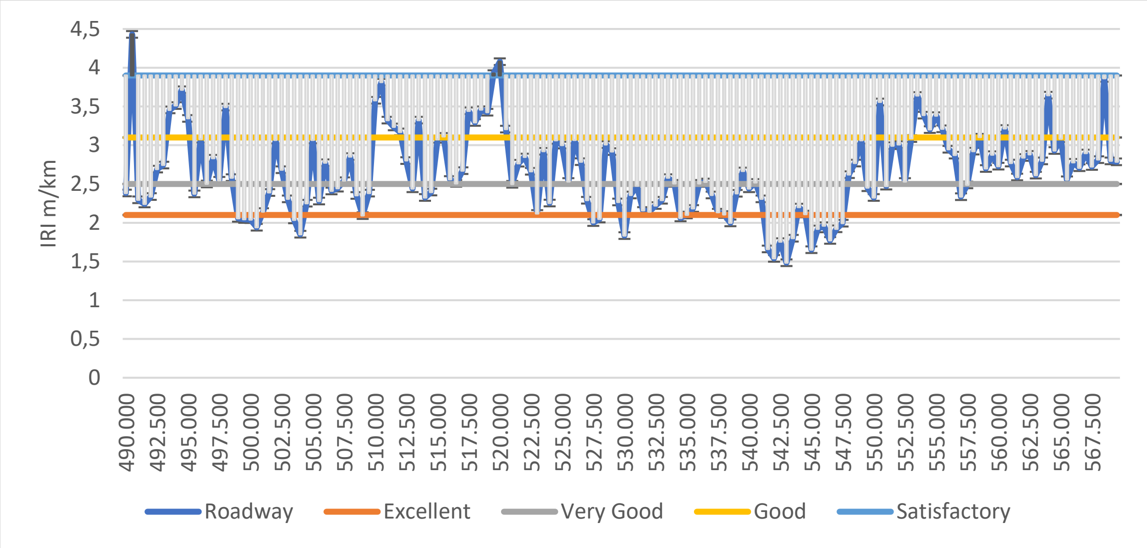
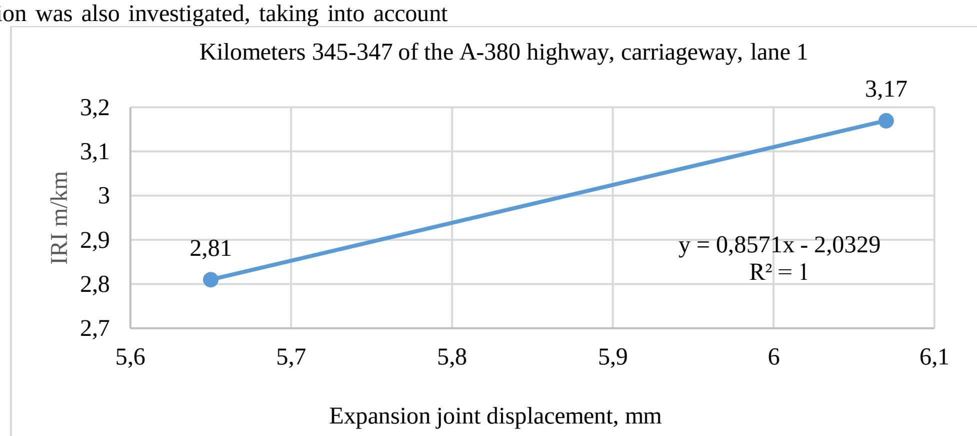


Fig. 6. Smoothness indicators of the cement-concrete pavement on the 490-581 km section of A 380 highway

In recent years, requirements for road surface smoothness have become more stringent. Consequently, in other countries, the issue of ensuring the required pavement smoothness throughout its entire design life has been addressed at the stage of determining and calculating the road surface structure [5,7,8].

In modern methods of calculating road pavements, particularly rigid pavements, not only were the main parameters of the structure determined, but the probability of crack formation was also investigated, taking into account the likelihood of changes in road and natural pavement conditions.

The calculation of the road surface concludes with determining the predicted condition of the pavement during road operation. Graphs and tables showing the relationship between changes in roadway smoothness and the spaces between concrete slabs for sections 345-347 km, 370-373 km, and 425-430 km of the A-380 "Guzar-Bukhara-Nukus-Beyneu" highway are presented below.

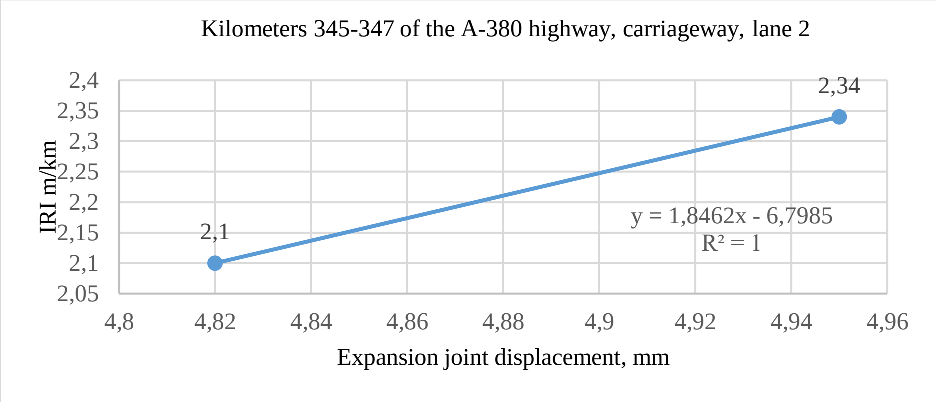


Graph 1. Relationship between IRI and elevation differences between slabs

Table 2

Dependence of pavement smoothness on changes between plates

№	Highway A-380, second lane of the roadway, km	Change in spacing between plates, mm	IRI, m/km
1	345-346	5.65	2.81
2	346-347	6.07	3.17

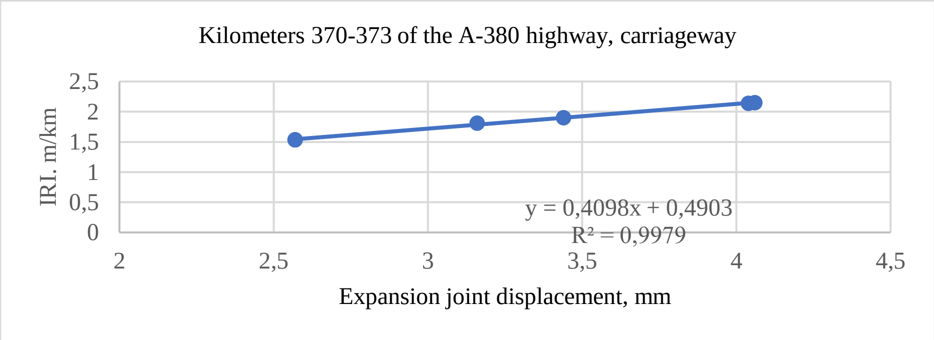


Graph 2. Relationship between IRI and elevation differences between slabs

Table 3

Dependence of pavement smoothness on changes between plates

№	Highway A-380, second lane of the roadway, km	Change in spacing between plates, mm	IRI, m/km
1	345-346	4.82	2.1
2	346-347	4.95	2.34

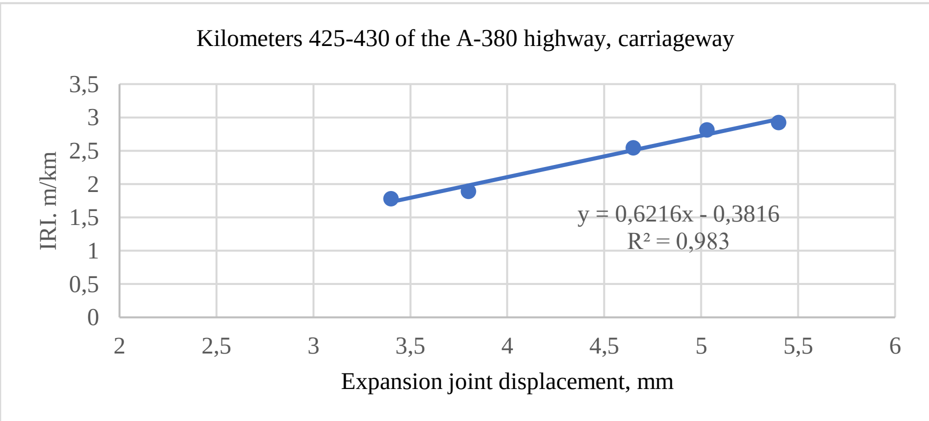


Graph 3. Relationship between IRI and elevations between slabs

Table 4

Dependence of pavement smoothness on changes between plates

№	Highway A-380, second lane of the roadway, km	Change in spacing between plates, mm	IRI, m/km
1	370,0-370,5	2.57	1.53
2	370,5-371,0	2.57	1.53
3	371,0-371,5	3.16	1.81
4	371,5-372,0	3.44	1,90
5	372,0-372,5	4.06	2.15
6	372,5-373,0	4.04	2.14



Graph 4. Relationship between IRI and elevations between slabs

Table 5

Dependence of pavement smoothness on changes between plates

№	Highway A-380, second lane of the roadway, km	Change in spacing between plates, mm	IRI, m/km
1	425-426	3.4	1.78
2	426-427	5.03	2.81
3	427-428	4.65	2.54
4	428-429	5.4	2.92
5	429-430	3.8	1.89

4. Conclusion

It is expected that the smoothness of roads with cement-concrete pavement complies with the requirements of QR 06.03-23.. In the conducted research work, negative elevations between the slabs were identified on the A-380 "Guzar-Bukhara-Nukus-Beyneu" highway at sections 345-347 km, 370-373 km, and 425-430 km. As a result of testing the pavement smoothness using the "TRASSA" mobile road laboratory equipment, indicators in the range of 1.53-3.17 m/km were determined. Through a graph showing the relationship between the state of elevations in the transverse expansion joints and the pavement smoothness, it was established that the elevations on the slabs directly affect the smoothness.

After the construction of roads with cement-concrete pavement, transverse expansion joints, vertical and horizontal displacements of cement-concrete slabs, impacts from vehicle wheels, and slab tilting result in the normalization of transverse and longitudinal joints. Their regulatory and legal activities in the field of road construction ensure.

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Single-phase to six-phase voltage converter

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Abstract:

This paper presents a novel circuit for converting a single-phase power supply into a stabilized six-phase voltage system. The proposed converter is based on a three-limb transformer with six secondary windings connected in a hexagonal configuration and two primary windings connected in series opposition. Each primary winding is shunted by a capacitor, forming two ferroresonant circuits that ensure voltage stabilization and precise phase shifting.

Key features of the design include:

- **Simplified construction** – Reduced number of windings and optimized connection scheme.
- **Improved conversion quality** – Stabilized output voltages and maintained phase shifts (60° between adjacent phases).
- **High efficiency** – Use of an amorphous alloy core minimizes losses and reduces overall size.

The converter operates by exciting ferroresonant oscillations in the primary circuits, which saturate the outer transformer limbs while keeping the middle limb (with double cross-section) unsaturated. This ensures stable magnetic fluxes (Φ_1, Φ_2, and their sum Φ_3), inducing balanced six-phase voltages in the secondary windings. By adjusting the capacitive reactance, a 120° phase shift between Φ_1 and Φ_2 is achieved, resulting in a symmetrical six-phase output.

Potential applications include:

- Household appliances (enabling three-phase motor operation from single-phase supply).
- Industrial and transportation systems (where single-phase input is preferred).
- Power electronics and automation devices requiring multi-phase voltage.

The proposed design offers a cost-effective and reliable solution for generating high-quality six-phase power from a standard single-phase source.

Keywords: phase converter, six-phase system, ferroresonant circuit, voltage stabilization, amorphous core

1. Introduction

A circuit for converting a single-phase voltage system into a multiphase system, specifically a six-phase system, is considered. Such converters can be applied in household appliances, where their use combines the advantages of three-phase electric motors with frequency control and the availability of only a single-phase network. In particular, the use of such devices eliminates voltage dips caused by the starting currents of asynchronous motors. These converters are also used in electrified transport systems, such as shop floor, mining, and mainline transportation, where a single-phase voltage system is preferable due to the reduced number of conductors. Additionally, they are employed in protection and automation devices for power transmission lines [1,2].

2. Research methodology

In the stabilized single-phase to six-phase voltage converter under consideration (Fig. 1), which includes a three-core transformer with six secondary windings connected in opposition and arranged in pairs on each core, and two primary windings located on the outer cores with terminals for network connection, the three-core transformer is designed with a doubled cross-section for the middle core.

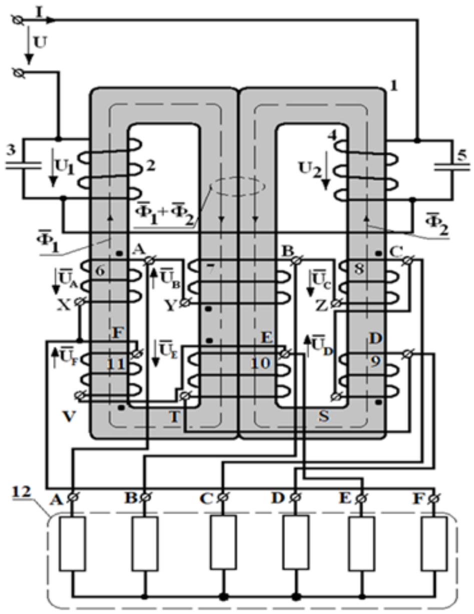

Fig. 1. Stabilized single-phase to six-phase voltage converter

The secondary windings are connected in a hexagonal configuration, while the primary windings are connected in a series-opposed arrangement and are shunted by capacitors, forming two ferroresonant circuits. This design simplifies the device by reducing the number of windings and simplifying their connection scheme while also improving

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conversion quality by stabilizing the voltage in the artificially generated phases and maintaining the required phase shifts. The use of a magnetically soft amorphous material as the transformer core enhances the efficiency of the converter and reduces its overall size [3,4].

The proposed stabilized phase number converter (Fig. 1) consists of a three-core transformer 1 of the core-shell system, where the middle core is designed with double the cross-sectional area compared to the outer cores. It includes two primary windings 2 and 3, connected in a series-opposed configuration and placed on the outer cores of the magnetic core. The winding 2, shunted by capacitor 4, forms the first ferroresonant oscillatory circuit, serving as the stabilizing element, while winding 3, shunted by capacitor 5, forms the second ferroresonant oscillatory circuit, acting as the stabilized ballast element. The secondary windings 6, 7, 8, 9, 10, and 11, where A, B, C, D, E, F are the start points of the phase windings, and X, Y, Z, S, T, V are the end points of the phase windings, located on the outer and middle cores of the magnetic core and connected in a hexagonal configuration, are used to generate an artificial six-phase voltage system that powers the load 12. The stabilized phase number converter operates as follows. When alternating input voltage U is applied to the device, ferroresonant oscillations are excited in the first and second ferroresonant circuits, formed by winding 2 and capacitor 4, and winding 3 and capacitor 5, respectively. The magnetic fluxes Φ1 and Φ2, induced by currents in windings 2 and 4, saturate the outer cores of transformer 1. Their magnitude remains almost unchanged, which results in the stabilization of voltages U1 and U2 across windings 2 and 4. Due to the opposing connection of windings 2 and 4, the magnetic flux in the middle core of the magnetic core, equal to the sum of the stable fluxes Φ1 and Φ2, is also stabilized, despite the fact that saturation does not occur in the middle core due to its doubled cross-sectional area.

The magnetic fluxes of the left and right cores Φ1 and Φ2, as well as the magnetic flux of the middle core, equal to the sum of Φ1 and Φ2, induce voltages UA, UB, UC, UD, UE, UF in the corresponding secondary windings 6, 7, 8, 9, 10, 11. The stability of these voltages is ensured by the minimal variation of the magnetic fluxes *Φ1* and *Φ2* when the outer magnetic cores of transformer 1 reach saturation. The phase shifts between the magnetic fluxes *Φ1* and *Φ2* allow for the generation of an artificial six-phase voltage system, including phase voltages U_A, U_B, U_C, U_D, U_E, U_F, or line voltages U_{AB}, U_{BC}, U_{CD}, U_{DE}, U_{EF}, U_{FA}, which power the six-phase load 9. The connection of the secondary windings 6, 7, 8, 9, 10, 11 in a hexagonal configuration improves the harmonic composition of the phase and line voltages of the artificial phases by eliminating higher harmonics that are multiples of three.

Figure 2 shows the vector diagrams of the magnetic fluxes $\bar{\Phi}_1$ and $\bar{\Phi}_2$ in the magnetic core rods, the phase voltages $\bar{U}_A, \bar{U}_B$ $\bar{U}_C, \bar{U}_D, \bar{U}_E, \bar{U}_F$, and the line voltages $\bar{U}_{AB}, \bar{U}_{BC}, \bar{U}_{CD}$ $\bar{U}_{DE}, \bar{U}_{EF}, \bar{U}_{FA}$ of the secondary windings, explaining the process of artificial phase conversion.

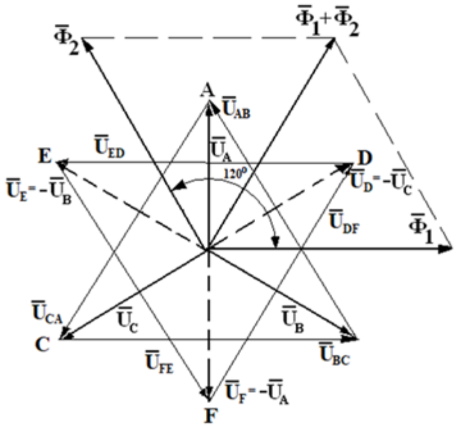

Fig. 2. Vector diagrams of the phase number converter

When autopraramentric oscillations are excited in the first (winding 2 and capacitor 3) and second (winding 4 and capacitor 5) ferroresonant circuits, the phase shift between the magnetic flux vectors $\bar{\Phi}_1$ and $\bar{\Phi}_2$ in the outer rods of the magnetic core can theoretically range from 90° to 180°. By varying the capacitance of capacitor 5 and thereby adjusting the capacitive reactance of the second oscillatory circuit, it is possible to achieve a phase shift of 120°. In this case, the magnitude of the magnetic flux vector in the central core $\bar{\Phi}_3$, which is equal to the sum of the vectors $\bar{\Phi}_1$+$\bar{\Phi}_2$, will be the same as the magnitudes of the vectors $\bar{\Phi}_1$ and $\bar{\Phi}_2$. Consequently, the amplitudes of the phase voltages $\bar{U}_A, \bar{U}_B$,$\bar{U}_C, \bar{U}_D, \bar{U}_E, \bar{U}_F$, induced by these magnetic fluxes in the secondary windings 6, 7, 8, 9, 10, and 11, as well as the amplitudes of the line voltages $\bar{U}_{AB}, \bar{U}_{BC}, \bar{U}_{CD}, \bar{U}_{DE}, \bar{U}_{EF}$ and $\bar{U}_{FA}$, will also be equal. The beginnings of the windings, marked with dots in Fig. 3, should be on the same side for the windings of the outer cores (6, 11 and 8, 9), while for the winding of the central core (7 and 10), they should be on the opposite side. As a result, the voltage vectors of winding 7 and$\bar{U}_E$ winding 10 are rotated by 180°, which ensures the required phase shift of 60° between the secondary voltage vectors $\bar{U}_A, \bar{U}_B$ $\bar{U}_C, \bar{U}_D, \bar{U}_E, \bar{U}_F$.

3. Conclusion

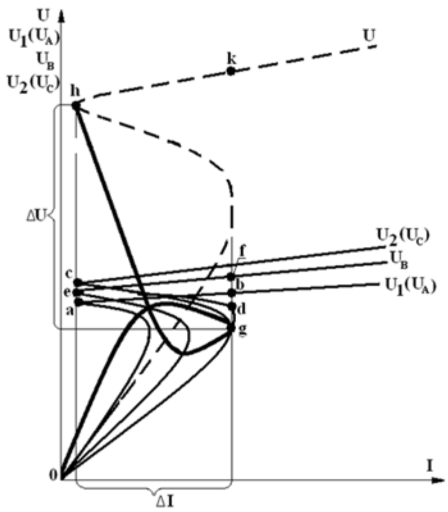

Fig. 3. Volt-ampere characteristics of the phase number converter

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Fig. 3 shows the volt-ampere characteristics of the components of the phase number converter, illustrating the principle of stabilization of phase and line voltages of the artificial phases. The curve U represents the overall volt-ampere characteristic of the entire circuit, $U=f(I)$. The curve $U_1(U_A)$ represents the volt-ampere characteristic of the first ferroresonant circuit, $U_1=f(I)$, or, considering the transformation ratio, the volt-ampere characteristic of phases A and F, i.e., $U_A=f(I)$ and $U_F=f(I)$. The curve $U_2(U_C)$ represents the volt-ampere characteristic of the second ferroresonant circuit, $U_2=f(I)$, or, considering the transformation ratio, the volt-ampere characteristic of phases C and D, i.e., $U_C=f(I)$ and $U_D=f(I)$. The curve U_B represents the volt-ampere characteristic of phases B and E, i.e., $U_B=f(I)$ and $U_E=f(I)$. When an alternating input voltage U, whose value is within the range ΔU (or when the supply current I varies within the range ΔI), is applied to the device, ferroresonant autoparametric oscillations occur in the first and second ferroresonant circuits. These oscillations are characterized by energy exchange not only within the circuits but also between them. This ensures the stability of the device's operation, where the first ferroresonant circuit operates inductively with a lower resonance voltage (segment a − b of the curve $U_1(U_A)$), and the second ferroresonant circuit operates capacitively with a higher resonance voltage (segment c − d of the curve $U_2(U_C)$). For any operating mode of the circuit, the expression for voltage vectors is valid $\bar{U} = \bar{U}_1 + \bar{U}_2$. Considering that the voltages U1 and U2 of the first and second ferroresonant circuits, operating in inductive and capacitive modes respectively, are nearly in antiphase, the volt-ampere characteristic of the entire circuit is determined not as the arithmetic sum of the voltages U_1 and U_2 across the circuits (dashed curve U on segment 0 – h – k), but as the vector difference between the voltage U_1 in the inductive segment and U_2 in the capacitive segment (bold curve U on segment 0 – g – h – k). From the graphs, it is evident that in the zone of ferroresonant autoparametric oscillations (segment g – h of curve U), when the supply voltage changes within ΔU, the voltages $U_1(U_A)$ (segment a – b) and $U_2(U_C)$ (segment c − d) vary insignificantly. Meanwhile, the phase voltage U_B, equal to the vector sum of U_A and U_C with the opposite sign (segment e − f of curve UB), remains virtually unchanged. Thus, the device is simplified by reducing the number of windings, while the conversion quality is improved through the stabilization of voltages in the artificially generated phases.

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