ENGINEER

international scientific journal

ISSUE
4, 2024 Vol. 2
ISSN
3030-3893

A bridge between science and innovation

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Tashkent state transport university

ENGINEER

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ISSN 3030-3893

VOLUME 2, ISSUE 4

DECEMBER, 2024

engineer.tstu.uz

TASHKENT STATE TRANSPORT UNIVERSITY

ENGINEER

INTERNATIONAL SCIENTIFIC JOURNAL
VOLUME 2, ISSUE 4 DECEMBER, 2024

Founder of the international scientific journal "Engineer" – Tashkent State Transport University, 100167, Republic of Uzbekistan, Tashkent, Temiryo'lchilar str., 1, office: 465, e-mail: publication@tstu.uz.

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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Tashkent State Transport University had the opportunity to publish the international scientific journal "Engineer" based on the **Certificate No. 1183** of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. **ISSN 3030-3893.** Articles in the journal are published in English language.

ENGINEER

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VOLUME 2, ISSUE 4 DECEMBER, 2024

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CONTEXT / MUNDARIJA

Enhancing energy efficiency in industrial pump units: the role of asynchronous motors with frequency converters

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Abstract: This research investigates the enhancement of energy efficiency in industrial water supply systems through the implementation of asynchronous motors equipped with frequency converters. With the global increase in energy demand and the critical need for energy-saving solutions, this study focuses on optimizing the performance of centrifugal pumps, which are integral to water management in industrial settings. Utilizing a Variable Frequency Drive (VFD) system, the study demonstrates significant energy savings by controlling motor speed and reducing power consumption. The methodology involves a comprehensive simulation using the Simulink package to model the VFD's impact on pump performance. Key findings indicate that VFDs not only decrease energy usage but also provide precise control over motor speed and torque, thereby enhancing system stability and reducing mechanical wear. These results suggest that adopting VFD technology can lead to substantial cost savings and operational efficiency in industrial water systems. The practical implications of this research are vast, offering a pathway for industries to achieve sustainability and improved energy management. Conclusively, the study underscores the importance of integrating advanced control systems to optimize the energy efficiency and reliability of industrial water supply operations.

Keywords: Energy efficiency, industrial water systems, asynchronous motors, frequency converters, variable frequency drive (VFD), centrifugal pumps, motor speed control, energy savings, pump performance optimization

1. Introduction

Taking into account the annual decrease of energy resources in the world and the increase in demand for energy, the creation of effective and economical processes and solutions in the use of energy is an urgent topic for the field of science. If we analyze the consumption of energy resources by sectors, the energy consumed in industrial enterprises is in developed and industrialized countries, for example, 42% in the USA, 50% in Germany, 70% in China, and 44% in India. In developing countries, this indicator is gradually increasing in accordance with the level of industrialization. It can be seen from the analysis that in all countries, energy consumption values in industrial enterprises occupy dominant positions compared to other sectors. The policy of energy saving and efficiency implemented in industrial enterprises can give positive results when implemented using new technology and methods. Achieving energy efficiency with the introduction of new technologies and methods is being put into practice thanks to the possibilities of scientific achievements, such as high-speed computing machines with semiconductor technologies achieved at the end of the 20th century. At this point, it is necessary to take into account the types of energy consumers in their divisions and shops when applying the energy saving policy to industrial enterprises. In this scientific work, we will consider energy saving in the energy consumption of the water supply system available in every industrial enterprise and the introduction of modern scientific achievements in it.

The water supply system of industrial enterprises consists of the following units, which are electrical, mechanical and hydraulic in nature. Electric units - a control cabinet consisting of a three-phase voltage network and its control and protection elements, an electric motor that converts electrical energy into mechanical energy and its control part, mechanical units - a common shaft or other type of transmission with an electric drive and the working wheel of pumps, and a hydraulic unit – primary water source, suction pipe system, pump unit, pressure pipe system and reservoir or tank capacity. The water supply system of industrial enterprises is a critical infrastructure that ensures the availability of water for various production processes, cooling systems, sanitation facilities, and other operational needs. It encompasses a comprehensive network of units and components designed to source, treat, distribute, and manage water within the industrial facility. The design and configuration of the water supply system are tailored to the specific requirements of the enterprise, taking into account factors such as water quality standards, production demands, environmental regulations, and energy efficiency considerations.

Water Sourcing and Intake: The water supply system begins with the sourcing and intake of water from external or internal water sources. External sources may include municipal water supplies, rivers, lakes, wells, or reservoirs, depending on the location and availability of water resources. Industrial enterprises may also have their own on-site water sources, such as groundwater wells or surface water sources. The intake process involves screening and filtration to remove debris, sediment, and other impurities before the water enters the treatment system.

Water Treatment Units: Once water is sourced, it undergoes treatment to meet the quality standards required

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for industrial processes and other applications. Treatment processes may include:

Filtration: Removal of suspended solids and particulate matter through physical filtration methods.

Chemical Treatment: Addition of chemicals such as coagulants, flocculants, disinfectants, and pH adjusters to remove contaminants, control microbial growth, and adjust water chemistry.

Biological Treatment: Utilization of biological processes such as activated sludge, biofilters, or constructed wetlands to remove organic pollutants and nutrients.

Membrane Processes: Deployment of membrane filtration technologies such as reverse osmosis, ultrafiltration, or nanofiltration for the removal of dissolved solids, ions, and microorganisms.

These treatment units are often arranged in a sequence or combination to achieve the desired water quality objectives, which may vary depending on the specific industrial processes and regulatory requirements.

Water Distribution Network: The treated water is then distributed throughout the industrial facility via a network of pipes, pumps, valves, and storage tanks. The distribution system is designed to deliver water to various points of use efficiently and reliably, ensuring adequate flow rates and pressure levels to meet production demands. Control systems may be employed to monitor and regulate water distribution, optimizing flow patterns and minimizing energy consumption.

Cooling Systems: Industrial enterprises often require large quantities of water for cooling purposes, such as heat exchange in manufacturing processes, equipment cooling, and HVAC systems. Cooling water systems may utilize open-loop or closed-loop configurations, depending on factors such as water availability, environmental considerations, and process requirements. Cooling towers, heat exchangers, chillers, and circulation pumps are integral components of these systems, contributing to the overall energy consumption of the water supply system.

Wastewater Treatment: As industrial processes generate wastewater containing pollutants, the water supply system includes wastewater treatment units to treat and discharge or reuse the effluent safely. Wastewater treatment processes may include physical, chemical, and biological treatment methods to remove contaminants and pollutants, ensuring compliance with regulatory discharge standards and environmental regulations.

The energy consumption of the water supply system in industrial enterprises varies depending on factors such as the scale of operations, the efficiency of equipment and processes, the source and treatment methods of water, and the specific requirements of production processes. Energy-intensive components such as pumps, motors, aerators, and treatment systems contribute to the overall energy consumption of the system. Therefore, optimizing the design, operation, and maintenance of the water supply system is essential for reducing energy consumption, minimizing environmental impact, and enhancing the overall sustainability of industrial operations.

2. Methods

In industrial water systems, pumps are essential components utilized for the transfer, circulation, and management of water. The selection of an appropriate motor type for these pumps is critical, as it directly impacts the efficiency, reliability, and overall performance of the system. Several motor types are commonly employed in such applications, each offering unique characteristics tailored to specific operational requirements. The most prevalent motor types used in pump units for industrial water systems include induction motors, synchronous motors, and permanent magnet motors.

Induction motors are the most commonly used type in industrial water systems due to their reliability, ruggedness, and cost-effectiveness. These motors operate on the principle of electromagnetic induction, where a rotating magnetic field is induced in the motor's stator coils, causing the rotor to rotate due to electromagnetic interaction. Induction motors are known for their robust construction, high starting torque, and ability to operate in various environmental conditions. They are well-suited for applications requiring continuous operation, such as water circulation in cooling systems, wastewater treatment plants, and irrigation systems. Induction motors offer a wide range of power ratings and speeds, making them versatile for different pump sizes and flow rates.

Synchronous motors are characterized by their synchronous speed, where the rotor rotates at the same speed as the rotating magnetic field in the stator. Unlike induction motors, synchronous motors require an external power source, such as a DC excitation or an electronic controller, to establish synchronism between the stator and rotor fields. Synchronous motors exhibit precise speed control, high efficiency, and power factor correction capabilities, making them suitable for applications demanding constant speed operation and stringent control requirements. In industrial water systems, synchronous motors are often utilized in high-performance pumps, such as those used in water supply networks, hydroelectric power plants, and large-scale water treatment facilities. Their ability to maintain constant speed and synchronize with grid frequency makes them ideal for applications where stability and reliability are paramount.

Permanent magnet motors utilize permanent magnets embedded in the rotor to generate the magnetic field, eliminating the need for separate excitation sources or rotor windings. These motors offer higher power density, improved efficiency, and reduced maintenance compared to induction and synchronous motors. Permanent magnet motors are particularly advantageous in applications where space constraints, energy efficiency, and dynamic performance are critical factors. In industrial water systems, they are commonly employed in compact and energy-efficient pumps, such as those used in HVAC (heating, ventilation, and air conditioning) systems, booster pumps, and smaller-scale water distribution networks. Their compact design and high torque-to-inertia ratio make them well-suited for applications requiring rapid acceleration and deceleration, as well as precise speed control.

Each motor type has its unique advantages and limitations, and the selection process involves careful consideration of factors such as operating conditions, system requirements, energy efficiency, and lifecycle costs. While induction motors offer reliability and cost-effectiveness, synchronous motors provide precise speed control and efficiency, and permanent magnet motors deliver compactness and energy savings. By understanding the characteristics and capabilities of each motor type, engineers can design and optimize industrial water systems to meet specific performance objectives while ensuring reliability, efficiency, and sustainability.

Pumps are essential devices used across various industries to move fluids by mechanical action. They can be categorized into two primary types: dynamic and positive displacement pumps. Each type has distinct mechanisms, advantages, and applications, suited to specific requirements in various sectors.

Dynamic pumps, also known as kinetic pumps, operate by imparting velocity to the fluid, which is then converted into pressure. The main subtypes include centrifugal and axial flow pumps.

Centrifugal Pumps: These pumps use a rotating impeller to add velocity to the fluid. The kinetic energy is then transformed into pressure energy. They are widely used for water supply, chemical processing, and wastewater treatment due to their ability to handle high flow rates at low pressures. Centrifugal pumps can be further categorized into:

Axial Flow Pumps: Suitable for high flow and low head applications, commonly used in flood dewatering and irrigation.

Radial Flow Pumps: Often employed in water supply systems, offering moderate head and flow capabilities [1].

Mixed Flow Pumps: These combine features of axial and radial flow pumps, used in applications requiring both significant flow and head.

Axial Flow Pumps: These pumps move fluid parallel to the pump shaft. They are typically used in applications that require high flow rates and low pressures, such as in power plants and flood control systems.

Positive displacement pumps move fluid by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe. They are typically used for high-pressure, low-flow applications.

Reciprocating Pumps: These pumps use a piston or plunger to displace the fluid. They are suitable for applications requiring precise flow control, such as in hydraulic systems and chemical injection. Reciprocating pumps are categorized into piston, plunger, and diaphragm pumps. They are commonly used in high-pressure applications like oil drilling and steam generation [2].

Rotary Pumps: These pumps move fluid using the rotation of gears, screws, or vanes. They are well-suited for pumping viscous fluids and are widely used in lubrication systems, chemical processing, and food industries. Examples include gear pumps, screw pumps, and lobe pumps [3].

Diaphragm Pumps: These are a type of positive displacement pump where a diaphragm moves back and forth to displace the fluid. They are ideal for applications where the fluid must be isolated from the moving parts, such as in chemical processing and pharmaceuticals [4].

Water Supply and Wastewater Management: Centrifugal pumps are predominantly used due to their efficiency in handling large volumes of water at relatively low pressures. Submersible pumps and vertical turbine pumps are often used for deep well water extraction and municipal water supply [5].

Fire Protection: Dynamic pumps, especially centrifugal pumps, are essential in fire protection systems for their ability to maintain steady water flow. Positive displacement pumps like rotary and reciprocating pumps are used to supply additives to enhance firefighting efforts [6].

Chemical Processing: The chemical industry relies heavily on various pump types to handle different chemicals and process fluids. Diaphragm pumps are favored for their ability to handle corrosive fluids without leakage, while metering pumps are used for precise chemical dosing [2].

Oil and Gas Industry: Reciprocating pumps are used for high-pressure applications such as oil drilling and hydraulic fracturing. Rotary pumps, including gear and screw pumps, are used for transferring viscous fluids like crude oil and lubricants [4].

HVAC Systems: Centrifugal pumps are commonly used in heating, ventilation, and air conditioning (HVAC) systems to circulate water and other fluids. These pumps are crucial for maintaining the desired environmental conditions in buildings [2].

Pumps are vital components in numerous industrial applications, with each type offering specific benefits tailored to particular needs. Understanding the differences between dynamic and positive displacement pumps, along with their subtypes and applications, is crucial for selecting the right pump for any given task. Whether it's for water supply, fire protection, chemical processing, or HVAC systems, the appropriate pump selection ensures efficiency, reliability, and cost-effectiveness in fluid handling operations [7].

Optimizing Industrial Water Systems: Frequency Converters for Centrifugal Pumps

In industrial water systems, centrifugal pumps are the workhorses, responsible for moving fluids across vast distances and overcoming pressure differences. However, traditional control methods often lead to wasted energy and imprecise flow and pressure regulation. This is where frequency converters (also known as variable frequency drives or VFDs) come into play. By electronically adjusting the motor's operating frequency, VFDs offer a powerful solution for optimizing pump performance and achieving significant energy savings [8].

The Affinity Laws and Energy Consumption

Centrifugal pumps operate according to the Affinity Laws, a set of fundamental relationships between flow rate (Q), head (H), rotational speed (n), and power consumption (P):

$$\frac{Q_{var}}{Q_{nom}} = \frac{n_{var}}{n_{nom}}$$

Flow rate is proportional to rotational speed.

$$\frac{H_{var}}{H_{nom}} = \left(\frac{n_{var}}{n_{nom}}\right)^2$$

Head is proportional to the square of rotational speed.

$$\frac{P_{var}}{P_{nom}} = \left(\frac{n_{var}}{n_{nom}}\right)^3$$

Power consumption is proportional to the cube of rotational speed.

These laws highlight a crucial fact: a small reduction in pump speed (n) can lead to a significant decrease in power consumption (P) without compromising flow rate (Q) to a great extent. This is the essence of the energy-saving potential of frequency converters.

Traditional Throttling vs. VFD Control:

In the past, throttling valves were used to regulate flow and pressure in centrifugal pumps. However, this method has inherent drawbacks:

- Energy Waste: Throttling dissipates energy as heat, essentially consuming power without achieving useful work.

- Inaccurate Control: Throttling valves offer limited control granularity, leading to imprecise flow and pressure regulation.

VFDs and Efficient Pump Operation:

Frequency converters offer a superior alternative by directly controlling the motor's rotational speed. By adjusting the frequency (f) of the power supply to the motor, VFDs can precisely regulate the pump's speed according to the relationship:

$$n = \frac{60 \cdot f}{p}$$

(where p is the number of poles in the motor design)

This allows for:

- Reducing Energy Consumption: By operating the pump at the optimal speed required for the desired flow rate, VFDs significantly reduce energy consumption according to the cube law relationship (P ∝n^3). Studies show potential energy savings of up to 50% compared to throttling control.
- Precise Flow and Pressure Regulation: VFDs offer a wider range of control and faster response times compared to valves. This allows for precise matching of flow and pressure requirements (as described by the Affinity Laws), leading to improved system efficiency.
- Beyond Energy Savings: Additional Benefits of VFDs
- The advantages of VFDs extend beyond energy savings:
- Reduced Wear and Tear: Lower operating speeds translate to less stress on the pump components (bearings, shaft), leading to extended equipment life and reduced maintenance costs.
- Soft Starts and Stops: VFDs provide smooth motor starts and stops by controlling the rate of change of frequency (df/dt), minimizing mechanical stress on the pump and piping system.
- Improved System Stability: Precise flow and pressure control contribute to a more stable and predictable system operation, reducing pressure fluctuations and improving overall system performance [9].

VFD Operation: Inside the Drive

A VFD functions by manipulating the power supply delivered to the AC induction motor. Here's a breakdown of the key components:

- Rectifier: Converts incoming AC power to DC voltage. Described by the formula:
- $V_{dc} = V_m \cdot \sqrt{2}$
- (where *Vdc* is the DC output voltage, *Vm* is the phase voltage of the AC input)
- DC Bus: Stores the rectified DC voltage.
- Inverter: Converts the DC voltage back to AC voltage, but with variable frequency and voltage.
- Control Unit: Analyzes system parameters (flow, pressure) and user commands to adjust the inverter's output frequency and voltage.
- By controlling the output frequency of the inverter, the VFD regulates the speed of the motor. Additionally, the VFD may adjust the output voltage (*V*) to maintain a constant motor voltage/frequency (*V/f*) ratio at varying speeds, ensuring proper motor torque and efficient operation. This relationship can be expressed as:
- *V/f* = constant (adjusted based on motor characteristics)

Practical Considerations for Implementing VFDs

While VFDs offer numerous benefits, successful implementation requires careful planning and consideration of several factors:

- System Analysis: A thorough analysis of the pump system is crucial. This includes:
- Flow Rate and Pressure Requirements: Understanding the desired operating range for flow (*Q*) and pressure (*H*) is essential for selecting the appropriate VFD and configuring its settings.
- Pump Selection: The pump's design curve and efficiency characteristics should be evaluated to ensure compatibility with the VFD's operating range. Affinity Laws provide a mathematical framework for relating these parameters: (Motor Compatibility: The existing motor's voltage, power rating, and control type need to be compatible with the chosen VFD) We already established these formulas earlier [10].
- VFD Selection: Selecting the right VFD requires considering:

Horsepower Rating: The VFD's horsepower rating should match or exceed the motor's rating to ensure it can handle the required load.

Input and Output Voltage: The VFD's input voltage should match the system's supply voltage, and the output voltage should be compatible with the motor's voltage rating for proper operation.

- Control Features: Different VFDs offer varying functionalities like:

Programmable logic controllers (PLCs) for advanced control and automation, allowing for integration with existing control systems.

Sensor inputs for monitoring parameters like flow, pressure, and temperature, enabling real-time feedback and adjustments.

Installation and Commissioning: Proper installation of the VFD is essential, following manufacturer's recommendations for wiring, grounding, and safety precautions. Commissioning involves configuring the VFD parameters based on the system analysis and pump characteristics. This may involve setting:

- Ramp Rates: Setting acceleration and deceleration times (t) for smooth motor starts and stops to minimize mechanical stress. These ramp rates can be calculated based on the inertia (J) of the rotating components and the desired torque (T):

$$t = \frac{(J \cdot \Delta n)}{T},$$

- Maximum Frequency: Limiting the motor's speed (*n*) to stay within the pump's safe operating range according to the pump's design curve to prevent damage.
- Control Modes: Selecting the appropriate control mode (e.g., pressure control, flow control) based on system requirements. VFDs can be programmed to maintain a constant pressure output (*H*) by adjusting the pump speed (n) based on real-time pressure sensor readings. Similarly, flow control modes can be implemented to regulate flow rate (*Q*).
- Monitoring and Maintenance: Regularly monitoring VFD performance parameters like output frequency, motor current, and fault codes is crucial for preventive maintenance. This ensures optimal operation and early detection of potential issues like failing bearings or overheating, allowing for timely corrective actions and avoiding costly downtime.

By leveraging the scientific principles of the Affinity Laws and the technological prowess of VFDs, industrial water systems can achieve significant energy savings (up to 50% compared to throttling control), improved flow and pressure control, and extended equipment life. A thorough understanding of VFD operation, careful system analysis that considers pump characteristics and desired operating points, and proper implementation are key factors for reaping these benefits. As industries strive for sustainability and operational efficiency, VFDs will continue to be a powerful tool for optimizing the performance of centrifugal pumps in water systems [11].

To analyze this system, we will create a model in the Simulink package.

Model Components:

- Three-Phase Voltage Source: This block represents the AC power supply for the VFD. You'll need to specify the voltage (e.g., 480V) and frequency (e.g., 60 Hz) based on your system.
- Frequency Converter (VFD): This block can be a pre-built library block from Simulink (e.g., Voltage Source PWM) or a custom block you create using power electronics components like rectifiers, inverters, and control logic. The control logic should adjust the inverter's output frequency based on a reference signal.
- Centrifugal Pump: This block can be a simple model relating pump speed (*RPM*) to flow rate (m^3/s) and head (pressure, meters) based on the Affinity Laws. You can define this relationship using mathematical equations or lookup tables based on a specific pump model's performance data.
- Inertia Block: This block represents the inertia of the rotating parts (motor and pump impeller) and helps simulate the dynamic behavior of the system during speed changes.
- Control System (Optional): You can add a control system block to regulate the pump's operating point (flow and pressure) by providing a reference signal to the VFD. This could involve a PI (Proportional-Integral) controller that compares the measured pressure (from a pressure sensor block) with the desired pressure and adjusts the VFD's reference frequency accordingly.
- Measurement Blocks: Include blocks to measure relevant parameters like motor speed (*RPM*), flow rate (m^3/s), and pressure (meters) at desired locations in the model.
- Analysis Considerations:
- Steady-State Analysis: Run simulations at different VFD reference frequencies to observe the corresponding changes in pump speed, flow rate, and pressure. This helps verify the implementation of the Affinity Laws in the model.
- Transient Analysis: Simulate scenarios with varying flow demands or pressure disturbances. Observe how the control system (if implemented) reacts to these changes and how the pump speed adjusts to maintain the desired operating point. Analyze the rise and fall times of the pump speed to assess the impact on the system dynamics.
- Energy Consumption Analysis: Include a block to calculate the motor's power consumption based on motor speed and efficiency data. Compare the power consumption at different operating points to evaluate the potential energy savings achieved by using a VFD for speed control compared to a throttling valve [12].

Simulink Model Development:

While I cannot create the complete Simulink model here due to software limitations, the above description provides a roadmap for building it. Each block can be configured with its specific parameters, and connections can be established between them to represent the physical system. You can utilize built-in Simulink functionalities like scopes and data logging to visualize and analyze the simulation results [13].

Additional Considerations:

- The complexity of the model can be adjusted based on the desired level of detail. Simpler models may focus on steady-state analysis, while more complex models can incorporate detailed motor and pump dynamics for transient analysis.
- Real-world pump data, motor efficiency curves, and control system algorithms can be integrated into the model for a more accurate representation of the actual system.

By building and analyzing a Simulink model of a VFD-controlled centrifugal pump system, you can gain valuable insights into the system's behavior, optimize control strategies, and evaluate the potential benefits of using VFDs for energy savings and improved flow and pressure control in industrial water systems [14].

The provided Simulink models represent a comprehensive Variable Frequency Drive (VFD) system. A VFD is an essential component in industrial applications, providing precise control of motor speed and torque by varying the frequency and voltage supplied to an electric motor. This analysis aims to dissect and explain the components and operation of the depicted VFD models.

Model Breakdown

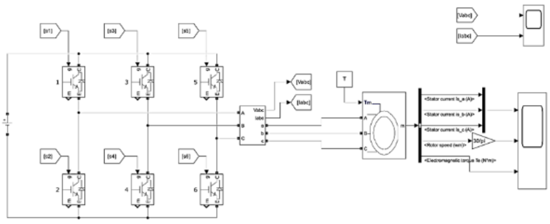

Figure 1. Inverter and Motor Control

1. Inverter Module:
   o The first figure showcases the inverter module, which consists of six Insulated Gate Bipolar Transistors (IGBTs) labeled *S1* through *S6*. These transistors are arranged in a three-phase bridge configuration.
   o Each IGBT is connected to a free-wheeling diode, allowing for current flow in the opposite direction when the IGBT is off, thereby protecting the transistors from voltage spikes.
2. Gate Signals:
   o Gate signals for the IGBTs (*S1-S6*) are provided by a control circuit. The timing of these signals is crucial as it determines the output voltage and frequency supplied to the motor.
3. Three-Phase Output:
   o The inverter outputs three-phase voltages (V_{abc}) and currents (I_{abc}) to the motor. These are labeled as *A*, *B*, and *C* phases.
4. Motor Model:
   o The motor model takes in these three-phase inputs and provides outputs such as stator currents (*is_a, is_b, is_c*), rotor speed (w_m), and electromagnetic torque (T_e). These parameters are essential for monitoring and control purposes.

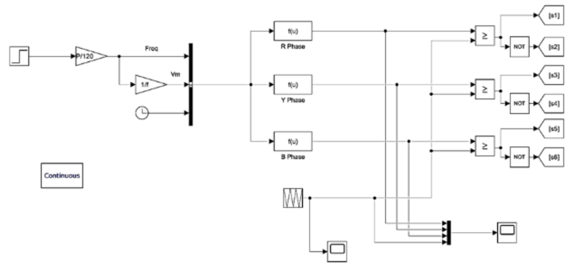

Figure 2. Control Circuit

1. Frequency and Voltage Control:

o The second figure depicts the control circuit, which determines the frequency (*Freq*) and magnitude (V_m) of the output voltage.

o A reference signal is divided by 120 to provide the base frequency, and another block calculates the inverse of this frequency to control the voltage.

2. Phase Generation:

o The control system generates three phase signals (*R Phase, Y Phase, B Phase*) which correspond to the reference voltage (V_{abc}) and current (I_{abc}) inputs. These phases are used to generate the PWM (Pulse Width Modulation) signals required for controlling the IGBT gates.

3. PWM Generation and Logic:

o Each phase is passed through a function block (*f(u)*), which calculates the necessary PWM signals.

o The NOT gates are used to ensure that complementary signals are generated for each pair of IGBTs in a phase leg (e.g., S1 and S2, S3 and S4, S5 and S6). This complementary operation ensures that when one IGBT is on, the other is off, and vice versa.

4. Pulse Generator and Power GUI:

o A pulse generator block sets the switching frequency for the PWM signals.

o The powergui block is used for simulation purposes, enabling the model to run continuous or discrete simulations based on the control strategy.

Functional Analysis

Inverter Operation

The inverter converts DC voltage from a source into a three-phase AC output. The gate signals to the IGBTs are modulated to produce a sinusoidal output at the desired frequency and voltage. This is achieved using PWM techniques, where the width of the pulses is varied to control the effective voltage and frequency.

Motor Control

The motor model simulates the behavior of an AC motor under varying conditions of voltage and frequency. By adjusting the frequency and voltage supplied to the motor, the speed and torque can be precisely controlled. This is particularly useful in applications requiring variable speed control, such as conveyors, fans, and pumps.

Feedback and Monitoring

The feedback signals (stator currents, rotor speed, and torque) are critical for closed-loop control. These signals can be used to adjust the PWM signals dynamically to maintain desired motor performance. For instance, if the rotor speed deviates from the setpoint, the control system can adjust the frequency to bring the speed back to the desired value.

Applications

VFDs are widely used in various industrial and commercial applications, including:

- HVAC Systems: Controlling the speed of fans and pumps to save energy and maintain desired environmental conditions.
- Manufacturing: Providing precise motor control for machinery and automation systems.
- Renewable Energy: Integrating with wind turbines and solar panels to optimize energy conversion and storage.
- Transportation: Used in electric vehicles and railway systems to control motor speed and improve efficiency.

The Simulink models presented provide a detailed and functional representation of a Variable Frequency Drive system. By controlling the frequency and voltage supplied to an AC motor, the VFD achieves precise control of motor speed and torque, which is essential for a wide range of industrial applications. The combination of inverter circuitry, control logic, and feedback mechanisms ensures efficient and reliable motor operation, making VFDs a vital component in modern automation and control systems.

3. Results and Discussion

The simulation results from the Simulink model provide a detailed analysis of the performance and efficiency of the Variable Frequency Drive (VFD) system applied to industrial water pumps. Below is a summary of the key findings illustrated by the provided figures.

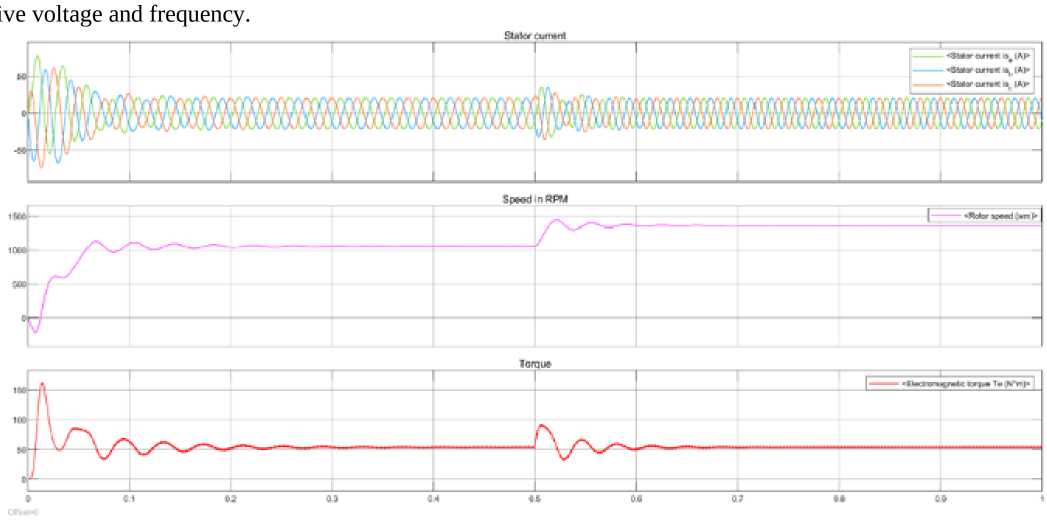

Figure 3. Motor currents, speed and torque

The simulation displays the motor's stator currents, rotor speed, and electromagnetic torque.

Stator Currents: The currents in the stator windings demonstrate a sinusoidal pattern, indicating smooth operation under the control of the VFD.

Rotor Speed: The rotor speed plot shows a steady increase to the desired operating speed, which is maintained throughout the simulation. This illustrates the VFD's ability to achieve and hold precise motor speed control.

Electromagnetic Torque: The torque plot highlights the motor's response to load variations. The VFD provides smooth torque control, reducing mechanical stress on the system.

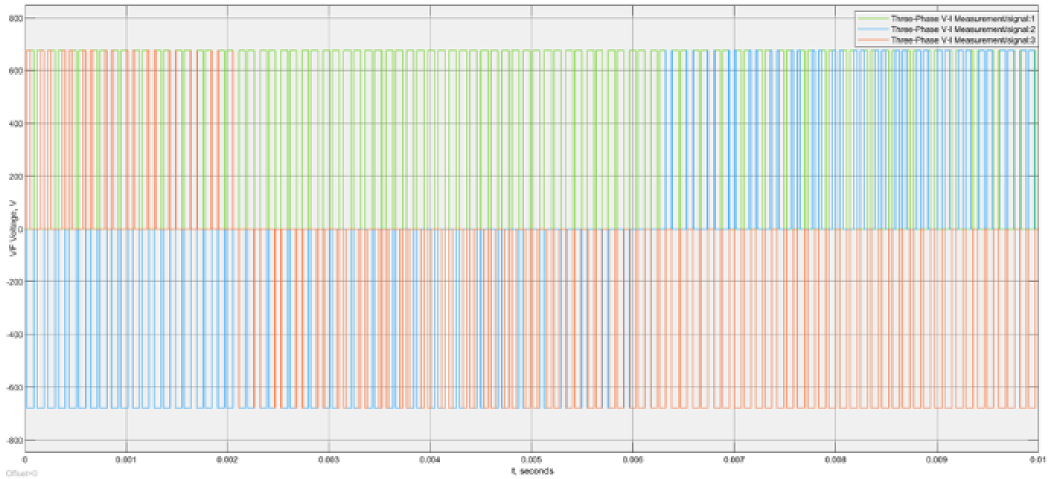

Figure 4. Three phase voltage from variable frequency

This figure shows the output voltages from the VFD to the motor:

Voltage Waveforms: The waveforms are sinusoidal, confirming the VFD's effective modulation of the input DC voltage into three-phase AC voltages.

Frequency Control: The frequency of these waveforms is varied according to the desired motor speed, demonstrating the VFD's capability to adjust frequency in real-time for precise control.

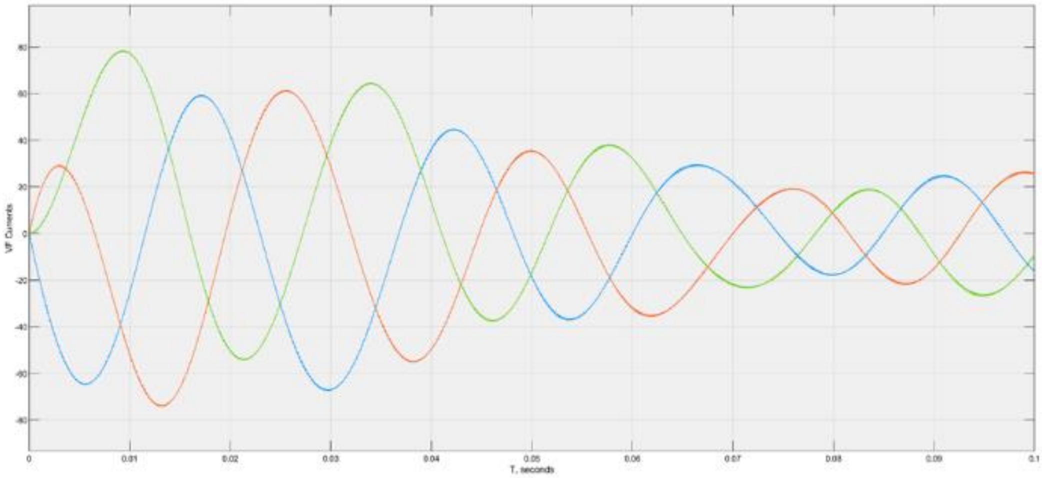

Figure 5. Variable frequency circuit currents

The currents in the variable frequency circuit reflect the behavior of the VFD components:

Current Modulation: The figure illustrates how the VFD adjusts the current supplied to the motor to match the required load conditions.

Energy Efficiency: The reduction in current at lower frequencies indicates decreased power consumption, validating the energy-saving potential of VFDs as theorized by the Affinity Laws.

The results from the Simulink model confirm the theoretical benefits of implementing VFDs in industrial water pump systems.

Energy Efficiency: The simulation shows that VFDs significantly reduce energy consumption by controlling motor speed and thereby reducing power usage. This aligns with the cube law relationship ($P \propto N^3$) of the Affinity Laws, which predicts substantial energy savings with even small reductions in speed.

Precise Control: The VFD provides precise control over motor speed and torque. This precise regulation is crucial for maintaining optimal performance in industrial water systems, ensuring that pumps operate efficiently under varying load conditions.

Reduced Mechanical Stress: The smooth start-up and shutdown capabilities of VFDs, as demonstrated in the torque and speed plots, reduce mechanical wear and tear on pumps, leading to longer equipment life and lower maintenance costs.

System Stability: The VFD enhances system stability by minimizing pressure fluctuations and ensuring a consistent flow rate, which is vital for industrial processes that rely on steady water supply.

Cost-Effectiveness: While the initial investment in VFD technology can be high, the long-term savings in energy costs and maintenance justify the expenditure. The simulation results highlight the potential for significant operational cost reductions through improved energy efficiency and equipment longevity.

4. Conclusion

The application of VFDs in industrial pump systems offers substantial benefits in terms of energy efficiency, precise control, reduced mechanical stress, and system stability. The simulation results validate the theoretical advantages, showcasing the potential for significant improvements in operational efficiency and cost-effectiveness.

By leveraging VFD technology, industrial enterprises can achieve greater sustainability and competitiveness in their operations. The adoption of such advanced control systems represents a pivotal step towards optimizing energy usage and enhancing the overall performance of industrial water supply systems.

For future research, it would be beneficial to explore the long-term impacts of VFDs on pump durability and to conduct field trials to further validate the simulation results under real-world conditions. Additionally, integrating advanced control algorithms and real-time monitoring systems could further enhance the efficiency and reliability of VFD-equipped pump systems.

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Functions of the Operation of Continuous Automatic Locomotive Signaling in Rail Transport (ALSN)

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Abstract: Automatic locomotive signaling continuous type of action - a system of traffic safety on railway transport, performing continuous data about signal indication traffic light standing in front of train in form of coded signals from ground devices of automation and telemechanic to control post of rolling stock.The continuous automatic locomotive signalling system (ALSN) is a type of cab signalling systems that provides track status information to the train cab and uses the rails as a continuous communication channel between track and train.

Keywords: rail transportation, computational modeling, signalling system, signal disturbances, function blocks, simulation, MATLAB&Simulink

1. Introduction

ALSN is used on almost 100 thousand kilometres in the countries of former Soviet Union or more than 10 percent of the world's railways. This system is installed on main lines but applied basically as additional equipment which supplements, and not replaces trackside signals in most cases[1]. If there is a disagreement between trackside and cab signals, the driver has to obey the trackside signal. Systems such as auto-blocking, electrical centralization of arrows and signals, and dispatch centralization use information received from rail circuits to determine whether sections of track can be used in the train route [2]. Automatic locomotive signaling is a means of regulating the movement of trains using locomotive traffic lights that reflect the train situation in the block section located in front. Automatic locomotive signaling devices transmit to the driver's cabin the readings of the passing and station traffic lights that the train is approaching. Automatic locomotive signaling is complemented by hitchhiking with devices for checking the driver's vigilance and controlling the speed of the train. Automatic locomotive signalling with hitchhiking is a combination of track and locomotive devices. ALS track devices are equipped not only with the transfer routes, but also all the main tracks at the stations, as well as the receiving and sending routes along which non-stop passage of trains is provided. Continuous type ALS devices (ALSN) ensure the transmission of signal readings of floor-mounted auto-locking traffic lights continuously when the train is moving along the stage and station. The ALSN system is used in areas equipped with single- or double-track auto-blocking[3].

2. Research Methodology

Automatic locomotive signaling is characterized by the quantity and quality of signal readings transmitted from the track to the locomotive. Along with the signal indications of the locomotive traffic light, high-speed (digital) signaling is also used in newly developed systems, which increases the functionality of the train traffic control system using ALS. Along with signaling and speed readings, locomotive signaling systems are complemented by means of monitoring the set and actual speeds of movement, as well as devices for monitoring the vigilance of the driver. The driver's vigilance is checked once or periodically[4]. The driver confirms his vigilance by pressing the vigilance handle in response to the warning whistle of the electropneumatic valve (EPC). If, in necessary cases (when it is necessary for the driver to take measures to exclude the passage of a forbidding signal), the vigilance handle is not pressed within 7 seconds after the whistle warning, then this is regarded by the devices as a loss of the driver's ability to drive the train and the train brakes and stops.

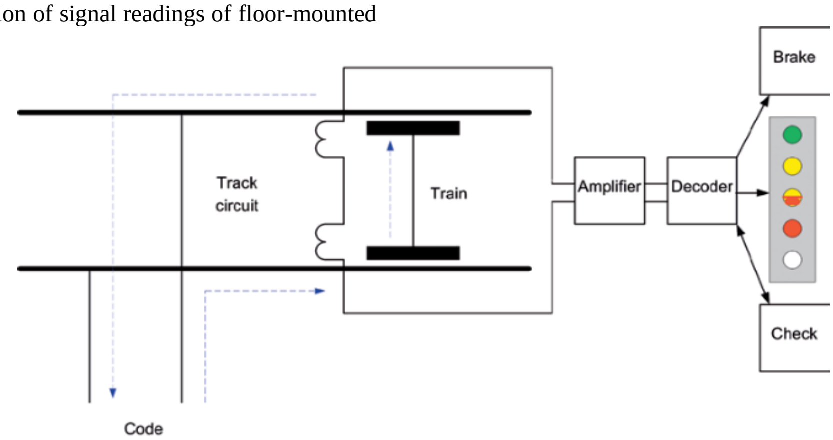

Figure 1. Code transmission from track circuits to the locomotive equipment

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There are three codes displayed in the cab signal corresponding with the aspect of the trackside signal ahead. In case of three-aspect-signalling these codes are

(figure 1):

– red signal ahead (results in cab signal red-yellow)

– yellow signal ahead (results in cab signal yellow)

– green signal ahead (results in cab signal green)

The section beyond a signal at Stop is not coded, therefore the train will be emergency stopped (cab signal red). This is in accordance with the fail-safe-principle. Passage of a Stop signal can be authorised with driver's special action at the maximum speed 20 km/h (figure 2).

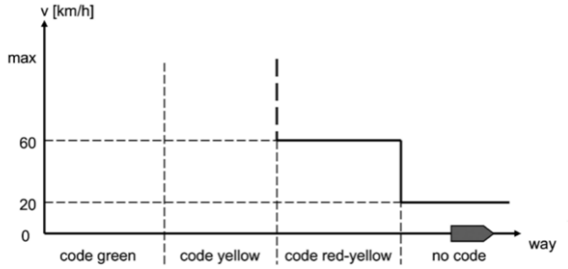

Figure 2. Braking supervision in ALSN

As the number of signal aspects in and near stations is usually higher than three, there is a simple rule[5]. If the train approximates a signal indicating the diverging route (the speed restriction for which can be between 25 and 80 km/h depending on the geometry of movable track elements) or to a yellow signal (straight route, but only one block section is clear, the speed restriction after the signal is 60 km/h), the train receives the code yellow and driver has to select the proper speed according to the trackside signal[6]. If two or more block sections are clear and the first section has the straight route, the train receives the code green. If the following signal is red or an auxiliary signal, the train receives the code red-yellow[7].

3. Analysis and Results

In the ALSN numerical code system, coding equipment is installed at the automatic blocking traffic light in the form of a KPT code waypoint transmitter and a transmitter relay T (Fig. 2.1). The signal code is selected depending on the traffic light reading by an encoding scheme: in DC autoblocking using linear relay contacts L, and in AC autoblocking using signal contacts relay G and 3. The transmitter relay Operates in the mode of the code currently generated by the KPT transmitter, depending on the indication of the passing traffic light[8]. By switching the contact in the circuit of the CT code transformer, the relay T transmits a numerical signal code in the form of alternating current pulses to the rail circuit.

The period of the code transmitted by the track circuit is 1.60 or 1.86 seconds (figure 3). The carrier frequency depends on traction power supply and is 50 Hz or 25 Hz. As external influences with low frequency often occur, the reaction time of the system is three code periods[9]. This means that the new cab signal becomes effective five seconds after a code change.

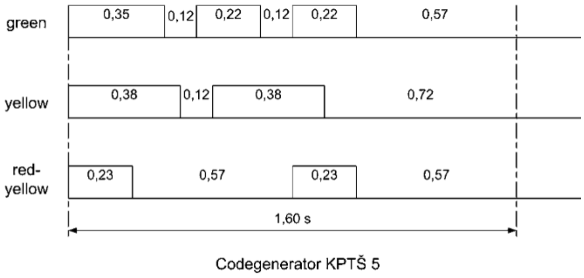

Figure 3. Code generator

System ALSN itself (without the additional systems) cannot transmit information about distance to the signal ahead[10]. The distance between signals varies from 1000 to 2600 meters depending on local conditions. Therefore the supervision curve in system ALSN (without any additional transmission) is only staircase, but the frequency of driver's acknowledgement check by the codes yellow and red-yellow depends on train speed. Moreover, the change of a cab signal to lower speed is accompanied by a bell and the driver is obliged to confirm this by an acknowledgement[11]. If the train receives the code red-yellow, its speed is limited to 60 km/h.

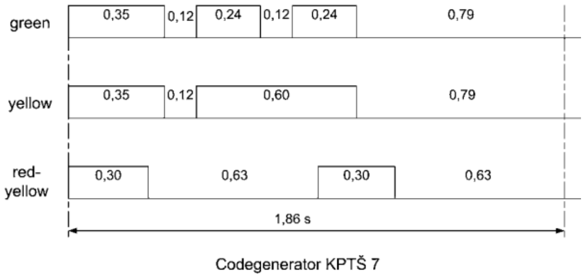

Figure 4. Code generator

4. Conclusion

According to new technical requirements, stations and open lines will have high frequency track circuits. This implies new functions for ALSN. When the track section is clear, the track circuit carries no code and serves for track clear detection only[12]. Only in these sections where a train is detected or expected soon, the code is applied. On open lines, jointless track circuits, whose areas of efficacy overlap by some tens of metres, are used. When the train is in this overlapping area, the coding is shifted from one track circuit to the next. Therefore, only one track circuit carries the coding at any given time. But in stations, insulated rail joints are still applied and track circuits do not overlap. To transfer the coding upon entering a new track could cause failures due to inertia of the detectors and transmitters. Therefore in stations the codes are given in two track circuits at the same time: the one which is currently occupied and the one ahead. As soon as the train occupied a new section, the coding in the previous section is switched off. Likewise generally in ALSN, only these station tracks which are provided for non-stop train passage are coded.

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Features of the effect of increased reverse traction currents on rail circuits and continuous automatic locomotive signaling

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Abstract: The features of the influence of increased reverse traction currents on rail circuits and continuous automatic locomotive signaling are considered. It is shown that the current norms for the relative magnitude of the asymmetry of the traction current in the rail strands of the rail line were calculated for maximum reverse traction currents. When moving heavy-duty trains, especially in mountainous areas, reverse alternating traction currents can be significantly greater, so their effect on the ALS channels remains unclear.

Keywords: reverse alternating traction current, rail circuits, grounding resistances, choke transformer, reinforced concrete supports, track receivers of the DSSh-16 type

1. Introduction

As shown by the analysis of theoretical and experimental studies of electrical circuits with nonlinear choke transformers, inductors, their nonlinear properties are most strongly manifested at high currents flowing through their windings. At the same time, numerical data are known only for some points of the nonlinear dependence of the resistance of the main winding of choke transformers at variable traction magnetizing currents not exceeding the upper value of the permissible magnetization current.

The experience of running heavy trains on the road shows that up to three heavy trains can be on the stages at the same time with intervals of 12... 15 minutes between them. In this case, the greatest current load on the elements of the reverse traction network is obtained, as well as the greatest interference from the traction current on the RC and on the continuous automatic locomotive signaling (ALSN) devices. As a result, it has already been noted that the auto-lock signals overlap before the first train of the train pack. In such a train situation, the intensity of ALSN failures increases.

2. Methodology

Interference from the reverse traction current in the rails appears in the ALSN locomotive channel and in the equipment of the supply and relay ends of the RC with asymmetry of traction currents. The level of these interferences is directly proportional to the absolute value of the difference in traction currents in the rail lashes.

According to current standards, the relative value of this difference should be no more than 4% with the value of the reverse alternating traction current equal to 300A. The absolute value of the considered traction current difference should not exceed 15A [1,2,3]. The difference in traction currents in rail threads is directly proportional to the magnitude of the longitudinal and transverse asymmetry of the electrical resistance of the rail line and the magnitude of the traction current [4,5,6].

Longitudinal asymmetry of the resistance of the rail line RL) occurs when the resistances of the rail threads are unequal, when the sum of the resistances of the prefabricated conductive joints of the threads within the RC, limited by insulating joints or within the stretch with non-jointed RC, are not the same.

Transverse asymmetry appears when the resistance of the specified rail threads differs with respect to the ground. And if longitudinal asymmetry can be eliminated in principle, then transverse asymmetry on electrified sections of railways is always present where grounding circuits of contact network supports and other structures are connected to the right-hand rail thread on double-track sections [7,8,9,10,11,6].

The resistance of the outer rail thread with respect to the ground on electric traction runs is always less than such resistance of the inner rail thread. This is determined by the fact that grounding circuits of various structures located along the railway track are connected to the external rail.

The most widespread are the grounding circuits of the contact supports. To exclude the negative effect of these earths on the operation of RC and ALSN, their individual resistance is normalized at a level not lower than 100 ohms [12, 13].

The actual resistance of these circuits is usually lower for metal supports and structures, in which it varies between 0.5...200 ohms. On the railway network, about 40% of the considered earths have a resistance of up to 10 ohms, 70% – up to 20 ohms and over 90% – up to 50 ohms [14]. The grounding resistance depends on the size, structure and its type, depth of occurrence in the ground, type of foundation, degree of humidity and chemical composition of the soil, the service life of the structure.

Reinforced concrete supports have a grounding resistance (in the circuit between the console and the rail) in the range from 10 to 40,000 ohms, and about 40% of the supports have a resistance up to 1600 ohms [14]. The grounding resistance of reinforced concrete structures depends on the conductivity of concrete in the layer between the clamp and the reinforcement, the presence of electrical insulating coatings on the foundation and embedded parts.

3. Results

Artificial structures have the following limits of grounding resistance: bridges – 0.2...1000 ohms; overpasses – 0.15...40 ohms; pedestrian bridges and viaducts -0.4... 20

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ohms. The grounding resistance of relay cabinets and traffic light masts is 20...30 ohms.

Metal supports of the contact network are used on a number of railway sections. An analysis of the numerical values of the resistance of their grounding circuits showed that the absolute majority of metal supports do not meet current requirements. These resistances usually do not exceed 30-40 ohms, the resistance of some supports does not exceed 5-10 ohms. Moreover, these supports stand on transshipment sites, where increased traction currents and the use of recovery significantly complicate the task of ensuring electromagnetic compatibility of ALSN devices with traction currents.

According to current requirements, structures with a ground circuit resistance below 100 ohms must be connected to the rail through spark gaps [12,13]. However, this requirement is not always fulfilled on the railway, which is one of the main reasons for the appearance of traction currents of asymmetry in rail threads, and therefore one of the main reasons for the insufficient stability of the ALSN operation. It remains unclear what is the degree of negative influence of grounding circuits with low resistance on the stability of the ALSN locomotive equipment.

On mountainous sections of the railway, cases of overlapping of entrance traffic lights at stations with traction substations and phase-sensitive RC with track receivers of the DSSh-16 type were recorded. One of the reasons for blocking the traffic light protecting a given route may be the false employment of one or more RC included in the route.

False employment with the serviceability of the RC equipment may occur when the protection devices of the RC equipment are triggered as a result of exposure to increased interference from the traction current. To protect the path receiver of a phase-sensitive RC with a DSSh-16 relay from traction current interference, a protective block filter of the ZB-DSSh type is used, consisting of a serial LC circuit tuned to the frequency of the first harmonic of the traction current, which is switched on in parallel with the track winding of the DSSH16 relay. Thus, harmonics of the traction current can enter the input of the track winding of the DSSh-16 relay, which in turn can reduce the amount of torque of its sector. This may be the reason for the false release of the relay sector.

The dependence of the magnetic flux in the core of the DT-1-150 and DT-1-300 type choke transformers on the current flowing through the main winding is nonlinear, which determines the nonlinearity of their characteristics.This non-linearity is confirmed by the manufacturer. When magnetizing choke transformers of these types, manufactured before 1995, with a voltage of 5 V with a frequency of 50 Hz applied to the main winding, the total resistance of the main winding to alternating current with a frequency of 25 Hz and a voltage of 4 V on the main winding increases by 40% (from 0.5 to 0.7 ohms) [2, 6].

For the choke transformers DT-1-150 and DT- 1-300, manufactured after 1995, the same total resistance of the main winding at a voltage of 4 V with a frequency of 25 Hz is obtained when it is magnetized by an alternating current of 50 Hz with a power of 4 A (across the entire winding), that is, at a voltage of 4 V.

The manufacturer does not explain why new modifications of throttle transformers have become more sensitive to the magnetization of their cores by alternating current of industrial frequency.

The total resistance of the main winding of the choke transformers of the specified type, in the absence of magnetization, should be equal to 0.5 ohms at a frequency of 25 Hz at a voltage of 0.3 V at a frequency of 25 Hz, that is, it is measured in a different mode. The resistance of the main winding to direct current at a temperature of + 200 should be no more than (3.5 ± 0.35) mOhm of the latest modifications of types DT-1-150 and 2DT-1-150, and for choke transformers of types DT-1-300 and 2DT-1-300 no more than (1.6±0.16) mOhm.

Magnetization of the core of a choke transformer by direct current leads to a decrease in the resistance of its main winding [15]. The resistance of the main winding of the choke transformer is halved at a constant magnetization current of 2A, which corresponds to a magnetization voltage of 7 mV applied to the entire winding.

4. Discussion

In the absence of core magnetization and a sinusoidal voltage between the terminals of the coil, the magnetic flux in the core is also sinusoidal and does not depend on the properties of the ferromagnetic material. In the presence of core saturation, the sinusoidal magnetic flux contains, first of all, a significant third harmonic component [15].If the magnetizing current remains sinusoidal, the non-sinusoidal trapezoidal shape is assumed by the magnetic flux. Consequently, a nonlinear choke transformer, when it is magnetized, becomes a generator of higher voltage harmonics in its windings.

The nonlinear characteristic of the choke transformer is symmetrical. If a voltage is applied to such an element in the form of two components K, the frequencies of which are correlated as 1:2, then in the current passing through the choke transformer, despite the absence of rectifiers, a constant component equal to K. Such a fact of the occurrence of a constant component in the conditions under consideration is called selective rectification [15]. Selective rectification is called because it occurs not at any frequency ratios of two voltages, but at a well-defined one.

The appearance of a constant component in the current flowing through the main winding of the choke transformer causes the appearance of even harmonics of sinusoidal currents flowing through this winding. The phase of even harmonics depends on the sign of the constant component [17].

Thus, the non-linearity of the characteristics of choke transformers of types DT-1-150, 2DT-1-150, DT-1-300 and 2DT-1-300 leads to the appearance of harmonics of traction current and signal frequency in rail circuits, and selective rectification causes the appearance of direct current, which additionally magnetizes the core of choke transformers.

The signal current of the ALSN with a frequency of 25 Hz at the beginning of a 2.5 km long code stage rail circuit varies from 5,l to 16 A, and in station phase–sensitive rail circuits with a frequency of 25 Hz with a 1.2 km long DCSH relay - in the range from 2.3 to 7 A, that is, these currents have the same order as and traction currents of asymmetry in the main windings of the choke transformer [18]. Since frequency converters are powered from phase C, and voltage is supplied to the contact network from phase A or B, there is always a phase shift between the signal and traction voltage in the main winding of the choke transformer[19]. Consequently, choke transformers have all the necessary conditions for the appearance of selectively rectified current in their main windings.

5. Conclusion

Measurements in rail circuits with a frequency of 25 Hz on electrified sections of the railway confirmed the appearance in some cases of a constant voltage component on the main winding of the DT-1-150 choke transformers, reaching a value of 0.005 V. Consequently, the constant magnetizing current at the same time exceeded 1.4 A, which leads to a decrease in the resistance of the main winding of the choke transformer by about 40%.

Thus, the magnetization of the core of the choke transformer by traction currents of industrial frequency asymmetry while simultaneously applying a signal current with a frequency of 25 Hz to it causes an increase in the resistance of the main winding. As a result of selective rectification, a constant component appears in the current of the main winding, which in turn causes the appearance of even harmonics of sinusoidal currents passing through the winding. These harmonics also cause selective rectification of currents, although the DC current that appears in this case will have a smaller value due to the fact that the amplitude of the harmonics is less than the amplitude of the signals of the main frequencies of 25 and 50 Hz.

Thus, the current norms for the relative magnitude of the asymmetry of the traction current in the rail strands of the rail line were calculated for maximum reverse traction currents of 300 A. This asymmetry determines the requirements for the longitudinal and transverse asymmetry of rail lines, as well as for the characteristics of nonlinear elements in the RC and ALSN equipment. When moving heavy-duty trains, especially in mountainous areas, reverse alternating traction currents can be significantly greater, so their effect on the ALS channels remains unclear.

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The influence of the chemical composition, including harmful and undesirable impurities, on the properties of spring steels

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Abstract: The role of various alloying elements in improving the mechanical properties of steels used for the manufacture of springs and springs is considered. The influence of carbon, silicon, manganese, chromium, nickel and vanadium on the elasticity, strength and resistance to relaxation of spring steels is investigated. The correct selection of alloying elements and heat treatment makes it possible to increase the yield strength and elasticity, resistance to small plastic deformations and wear resistance of steels. Special attention is paid to the role of silicon, manganese and vanadium, which, along with other elements, contribute to improving hardenability, prevent decarburization and provide resistance to cracking during deformation.

Keywords: hardenability, alloying elements, silicon, chromium, vanadium

1. Introduction

The steels used for the manufacture of springs must have high resistance to small plastic deformations, endurance limit and resistance to relaxation, while providing sufficient ductility and viscosity. To achieve these properties, steel must contain more than 0.5% carbon and undergo heat treatment such as quenching and tempering, or deformation hardening.

Alloying of steels allows to increase the tempering temperature, which helps to avoid the development of irreversible tempering brittleness. This, in turn, contributes to the combination of high resistance to small plastic deformations with good ductility and viscosity [1]. Alloy steels containing 1.5–2.8% silicon, 0.6–1.2% manganese, 0.2–1.2% chromium, 0.1–0.25% vanadium, 0.8–1.2% tungsten and 1.4–1.7% nickel are often used for the manufacture of springs and springs. These elements improve the hardenability, increase the resistance to relaxation and the elastic limit of steel [1]. Alloying elements also affect the decarbonization process by changing the rate of carbon diffusion and the thickness of the decarbonized layer, as well as affect the temperature of alpha-gamma transformation and carbon activity [2].

2. Research Methodology

2.1. Influence of chemical composition

In industry, siliceous steels such as 50Si2, 55Si2, 60Si2, 60Si2CrV, 65Si2V are most often used. ***Silicon*** in the composition of these steels increases hardenability, slows down the decay of martensite during tempering and significantly strengthens ferrite. Due to this, steels 50Si2, 55Si2 and 60Si2 have high yield strength and elasticity, which provides excellent performance properties. However, siliceous steels are prone to graphitization at a silicon content above 2.5% and to decarburization during hot processing, which can reduce the endurance limit [3, 4]. Additional alloying of siliceous steels with elements such as chromium, manganese, tungsten and nickel increases calcination and reduces the tendency to decarbonization, graphitization and grain growth when heated [1].

Carbon, which is the main alloying element in steel, dissolves in the crystal lattice, although its solubility in the iron matrix is low. In the ferritic matrix, carbon saturation is achieved with a minimum content of alloying elements. Dissolved carbon reduces the modulus of elasticity of steel as the content of alloying elements increases [5]. If the carbon concentration exceeds the saturation level, excess carbon precipitates in the form of cementite, whose modulus of elasticity is about 170 GPa [6].

The effect of dissolved alloying elements such as *rhenium, cobalt, chromium, iridium, ruthenium, silicon, manganese, nickel, rhodium* and *platinum* on the modulus of elasticity of steel is illustrated in Figure 1 [7]. A slight increase in the modulus of elasticity is observed with an increase in the content of rhenium, cobalt or chromium.

The alloying mechanism, which affects the modulus of elasticity of steel, operates in two directions. First, the inclusion of atoms of alloying elements with radii different from the radius of iron in the iron (Fe) crystal lattice changes the interatomic distances. This, in turn, affects the modulus of elasticity, since it is defined as the second derivative of potential energy with respect to interatomic distances. Secondly, doping changes the distribution of electrons in the material, which also affects the modulus of elasticity. These two mechanisms can either enhance or compensate each other, depending on the properties of the alloying element and its position in the periodic table of elements [8].

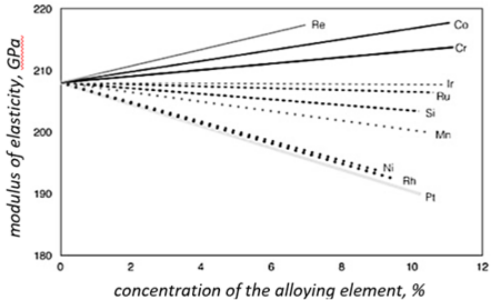

Fig. 1. The effect of alloying elements on the modulus of elasticity of steel [8]

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Manganese (Mn) plays an important role in stabilizing the γ-Fe (austenite) phase, increasing the stability of austenite and reducing the critical quenching rate. In the ferritic phase, manganese increases the tensile strength and yield strength, especially at a carbon content of 0.1 to 0.5%. However, it reduces the ductility and toughness of steel. Manganese also improves wear resistance and elasticity, which makes it an important element for alloying structural, spring-spring and wear-resistant steels. In some cases, manganese is used as a more affordable and inexpensive substitute for nickel [9].

Studies conducted by Wada and his colleagues [10-12] have shown that manganese reduces the carbon activity coefficient in austenite, which slows down carbon diffusion. Unlike manganese, silicon (Si) has the opposite effect, increasing the carbon diffusion coefficient in austenite [13].

Alloying steel with manganese, like many other elements, leads to improved technological and operational characteristics only in combination with proper heat treatment. Without heat treatment, alloying does not bring significant improvements, and the cost of the process may not be justified [9].

Chromium (Cr) is one of the most common alloying elements. It increases the strength, hardness and corrosion resistance of steel, although it may slightly reduce its ductility. The high chromium content makes the steel stainless and keeps its magnetic properties stable. Chromium also affects the rate of scale formation and reduces the tendency to decarburization by reducing the rate of carbon diffusion [9].

Vanadium (V) is added to steel to improve its mechanical properties and increase wear resistance. By forming carbides and nitrides, vanadium promotes grain grinding and increases the hardness and toughness of steel [9].

Vanadium is one of the key alloying elements used in spring-loaded steels to ensure a homogeneous and finely dispersed grain structure. Its addition significantly affects a number of processes occurring during the heat treatment of steel. Firstly, vanadium contributes to the grinding of microstructure grains, which significantly improves the mechanical properties of steel, including strength and toughness.

One of the important effects of vanadium is its ability to control processes in the lower part of the austenitic region. It slows down the growth of austenite grains, stabilizes the structure of steel during thermomechanical processing and increases the recrystallization temperature. The effect of vanadium on γ-α transformations provides a more stable microstructure and increases the mechanical characteristics of steel.

From the point of view of the electronic structure, vanadium does not possess p electrons, but has unfilled d orbitals, which leads to a decrease in the thermodynamic activity of carbon during alloying of steel. This change contributes to the formation of highly dispersed vanadium compounds such as carbides, nitrides and carbonitrides. These compounds, having a rounded shape, are evenly distributed along the grain boundaries, preventing their growth and contributing to the hardening of steel [14].

With a vanadium content ranging from 0.001% to 0.10%, it effectively reduces the size of steel grains, delaying their growth during recrystallization at high temperatures. This makes vanadium a valuable element in the composition of steels used for springs and springs, where high strength, wear resistance and stability of mechanical properties are important.

Additional alloying of steel with *chromium, vanadium* and *nickel* has a complex positive effect on its properties. Firstly, such alloying reduces the critical cooling rate, which improves the hardenability of steel, ensuring a more uniform formation of a solid and durable structure throughout the entire volume of the material.

Carbide-forming elements such as ***chromium*** and ***vanadium*** play an important role in preventing decarbonization of springs when heated before quenching, which is especially important for maintaining the surface properties and overall strength of the product. Vanadium, in turn, additionally contributes to an increase in the strength of steel due to the formation of fine carbide particles of the MS type based on VC. These carbides are formed during the decomposition of martensite during tempering and effectively harden steel, increasing its endurance and relaxation resistance.

Nickel has a positive effect on carbon activity and accelerates its diffusion in austenite, which improves the processes associated with heat treatment of steel. Although nickel has virtually no effect on the rate of scale formation, it contributes to the rapid formation of strong metal intermediate layers, which protects the steel from further oxidation.

In addition, nickel reduces the temperature of α–γ transformation, which reduces the tendency of steel to decarbonize, especially during high-temperature processing. It is important to note that the addition of nickel in an amount of 0.05–0.30% neutralizes the negative effects of copper, which is present as an impurity that can cause cracks to form on the surface of steel during hot rolling. Nickel also helps to absorb gases such as hydrogen, which prevents the formation of gas bubbles in ingots and reduces the likelihood of cracks along grain boundaries in the case of coarse-grained steel structure.

2.2. The effect of harmful and undesirable impurities

The high ***sulfur*** content in steel (up to 0.035%) has a negative effect on the crack resistance of finished springs. This is due to the formation of sulfide nonmetallic inclusions along grain boundaries. During hot deformation in the temperature range from 950°C to 1200°C, they contribute to the formation of cracks and ruptures. Therefore, the sulfur content in steels for highly loaded springs is limited to 0.025% [15]. Sulfur also globulates sulfide inclusions and participates in the formation of the plasticity level of steel, contributing to the formation of chips during machining [14].

Phosphorus is an unavoidable impurity in steel that settles along grain boundaries, reducing impact strength and leading to brittle fracture due to weakening of intergranular bonds. Therefore, the phosphorus content is limited to 0.025 wt.% [16]. During quenching and tempering, phosphorus forms junctions with elements such as chromium or manganese along the boundaries of former austenitic grains. This leads to a decrease in adhesion along grain boundaries and intercrystalline embrittlement, which has an extremely negative effect on strength and resistance to fatigue load in air. These effects have an even more negative effect on achieving high tensile strength and hardness. In order to simultaneously achieve high tensile strength, high hardness, as well as good air fatigue strength and corrosion resistance, the phosphorus content in spring steel should be as low as possible, not exceeding 0.015%, preferably 0.010%.

Microalloying with ***copper*** is based on its ability to crystallize last and concentrate along grain boundaries, reducing the likelihood of overheating and increasing the ductility of steel. In addition, copper increases corrosion resistance, although its effect becomes noticeable only at concentrations above 0.15%. However, if the copper content exceeds 0.20%, brittle copper phases can lead to cracking of grain boundaries during deformation. Copper is a hardening element in the form of a solid solution that can be added to steel along with other elements that increase its strength and hardness. Since copper does not combine with carbon, it strengthens steel without forming large and hard carbides, which can reduce fatigue strength in air [17].

The ***oxygen*** content should be from trace amounts to 0.0020%. Oxygen is an unavoidable impurity in steels, which, in combination with deoxidizers, can form large, solid and irregularly shaped inclusions or smaller but longer accumulations that negatively affect the fatigue strength in air. These effects, in particular, reduce tensile strength and hardness. To achieve a balance between high tensile strength, hardness and fatigue strength both in air and in aggressive environments, the oxygen content in steel should not exceed 0.0020%.

The ***nitrogen*** content should be in the range from 0.0020 to 0.0110%. Regulation of the nitrogen content within these limits is necessary for the formation of fine nitrides, carbides or submicroscopic carbonitrides in interaction with titanium, niobium, aluminum or vanadium, which contributes to grain grinding. The minimum nitrogen content should be 0.0020%, and the upper limit should not exceed 0.0110%, in order to avoid the formation of large solid nitrides or titanium carbonitrides larger than 20 microns, which can form at a depth of 1.5 ± 0.5 mm from the surface of the rods intended for the manufacture of springs. This depth is crucial in terms of fatigue stresses. A large number of nitrides or carbonitrides can significantly reduce the fatigue strength of steel at high strength and hardness values.

3. Conclusion

Based on theoretical studies, it has been shown that alloying elements such as carbon, manganese, silicon, chromium, vanadium and nickel play a key role in improving the strength, elasticity and other performance properties of spring steels. Heat treatment, as well as alloying, significantly affects the final properties of materials, especially their hardenability and resistance to decarbonization. The introduction of such elements helps to improve the mechanical properties, increase the wear resistance and durability of spring products.

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Analysis of existing methods for measurement of air pollution in road areas

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Abstract: The problem of air pollution in roadside areas is relevant due to the increase in traffic flow and urbanization. Air pollution has a significant impact on public health, especially in urban areas. The purpose of this study is to analyze existing methods and instruments for measuring air pollution in roadside areas. Objectives include a review of existing methods and an evaluation of their effectiveness.

Keywords: Exhaust gases, vehicle emissions, air pollution, environment, urban streets

1. Introduction

Air pollution is a global problem, causing millions of premature deaths every year. This applies not only to developing countries but also to developed countries, with cities in particular struggling to meet air quality limits to adequately protect human health. Overall exposure to air pollution is often disproportionately affected by the relatively short time spent commuting to work or in close proximity to vehicles. Road transport is the largest source of nitrogen oxides (NOx) and a significant source of fine particulate matter (PM2.5) (particulate matter smaller than 2.5 microns). Emissions from traffic typically have a significant impact on air quality because they are released into the air near ground level [1].

In order to implement the tasks defined in the Development Strategy of New Uzbekistan for 2022-2026 [2], increase the effectiveness of measures taken to ensure “green” and inclusive economic growth within the framework of the Strategy for the Transition of the Republic of Uzbekistan to a “green” economy, as well as further expand the use of renewable energy sources and resource saving in all sectors of the economy, the Program for the Transition to a “green” economy and ensuring “green” growth in the Republic of Uzbekistan until 2030 was approved [3] by Resolution of the President of the Republic of Uzbekistan, dated December 2, 2022 No. PP-436 [4].

2. Methodology

Existing research shows that measuring air pollution in roadside areas requires the use of various methods and instruments, such as gas analyzers, dust meters, and mobile monitoring stations. These methods allow the concentration of harmful substances such as carbon monoxide, nitrogen oxides, sulfur dioxide, and suspended particles to be assessed. For the planned experimental studies, the traditional measurement method using a mobile gas analyzer was chosen.

The analysis used data obtained using stationary and mobile monitoring stations as well as laboratory research data from the Hydrometeorological Service Agency under the Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan (Uzhydromet) [5].

Air quality monitoring in Tashkent is carried out at 13 stationary posts of Uzhydromet for the following indicators: dust, sulfur dioxide, nitrogen dioxide, nitrogen oxide, carbon monoxide, phenol, hydrogen fluoride, ammonia, formaldehyde, and heavy metals. Observations are carried out in accordance with regulatory documents GOST 17.2.3.01-86 [6], SanPiN 0053-23 [7], daily, three times a day (7:00, 13:00, and 19:00 local time).

Figure 1 shows an interactive map of the atmospheric air quality of the city of Tashkent for 13 stationary posts of Uzhydromet [5]: PNZ No. 1 - Tashkent: Yunusabad district, st. Chingiz Aitmatova; PNZ No. 2 – Tashkent: Yashnabad district, Magtymguly Ave.; PNZ No. 4 – Tashkent: Yakkasaray district, st. Babura; PNZ No. 6 – Tashkent: Mirzo-Ulugbek district, st. Small ring village; PNZ No. 8 – Tashkent: Chilanzar district, st. Chilanzar; PNZ No. 12 – Tashkent: Almazar district, st. Ahmad Donish; PNZ No. 14 – Tashkent: Mirabad district, st. Yangizamon; PNZ No. 15 – Tashkent: Mirabad district, Amir Temur Ave.; PNZ No. 18 – Tashkent: Yashnabad district, st. Asalobod; PNZ No. 19 – Tashkent: Yunusabad district, Amir Temur Ave.; PNZ No. 23 – Tashkent: Sergeli district, st. Chartak; PNZ No. 26 – Tashkent: Chilanzar district, st. Zargarlik; PNZ No. 28 – Tashkent: Kibray, st. Koramurt.

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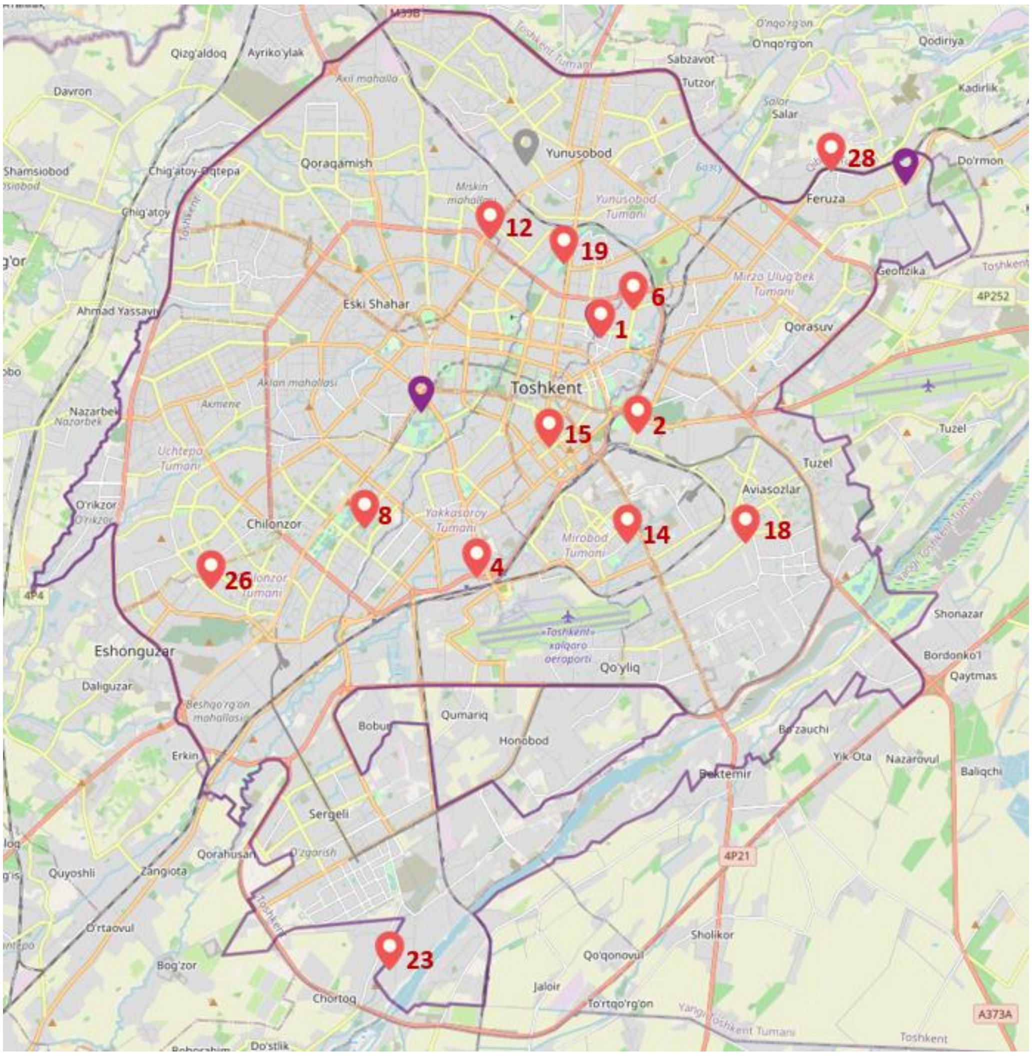

Fig. 1. Map of Uzhydromet stationary posts for monitoring air pollution in the city of Tashkent

To conduct observations and collect information on monitoring the level of dust in the atmospheric air with fine particles, as well as the content of total dust at the same time, the department for monitoring sources of emissions into the atmospheric air, at the expense of its own funds from the Center for Specialized Analytical Control in the Field of Environmental Protection (CSAC) [8], purchased the following measuring instrument: the portable dust analyzer "DustTrak DRX 8534" (Fig. 2).

Fig. 2. Gas analyzers of the Center for Specialized Analytical Control: a) "DustTrak DRX 8534"; b) "Testo 350"; c) Aspirator; d) ECOLAB

In addition, at the expense of CSAC funds, the following modern devices for monitoring sources of pollutant emissions were purchased: a portable automatic gas analyzer, "Testo 350", designed for automatic monitoring of the concentrations of harmful substances at organized sources of industrial emissions for the content of pollutants such as nitrogen dioxide, oxide nitrogen, nitrogen oxides, carbon monoxide, and sulfur dioxide. An aspirator for taking air samples through absorption devices and special filters, designed for use in sampling both sources of industrial emissions and atmospheric air (in populated areas). Has the ability to operate on battery power.

Automatic multichannel portable gas analyzer ECOLAB (with a module for storing sensors and recharging an additional kit), designed for automatic monitoring of the concentrations of harmful substances in the atmospheric air (settled areas) for the content of pollutants such as nitrogen dioxide, carbon monoxide, sulfur dioxide, formaldehyde, hydrogen sulfide, methane, phenol, ammonia, hydrogen fluoride, etc.

The presence of existing types of gas analyzers in the Republic of Uzbekistan is shown in Fig. 3.

Fig. 3. Portable gas analyzers (source: https://glotr.uz/) [9]

3. Results and Discussion

When studying the level of atmospheric pollution by exhaust gases, the dependence of the content of impurities in the atmosphere on the intensity of vehicle traffic, the width of streets and highways, time of day, and weather conditions, as well as on the type and density of buildings, the height of buildings, and the degree of landscaping, is established.

Observations are carried out on all days of the working week, hourly, from 6 a.m. to 1 p.m. or from 2 p.m. to 9 p.m., alternating days with morning and evening periods. At night, observations are carried out once or twice a week.

Observation points are selected on urban streets in areas with heavy traffic and are located on various sections of the streets in places where cars are often broken and the largest number of harmful impurities are emitted. In addition, points are organized in places where harmful impurities accumulate due to weak dispersion (under bridges, overpasses, tunnels, narrow sections of streets, and roads with multi-story buildings), as well as in areas where two or more streets intersect with heavy traffic.

Places for placing devices are selected on the sidewalk, in the middle of the dividing strip, if there is one, and outside the sidewalk, at a distance of half the width of the one-way roadway. The point furthest from the highway must be located at least 0.5 m from the wall of the building. On streets crossing a main highway, observation points are located at the edges of sidewalks and at distances exceeding the width of the highway by 0.5, 2, or 3 times [6].

The choice of pollutants, such as carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO2), sulfur dioxide (SO2), etc. (Fig. 4 and Fig. 5), to study the impact of exhaust gases from vehicles on the environment on sections of urban streets is justified by several key factors: direct origin from automobile emissions; significant health impact; widespread in urban environments; possibility of management and reduction.

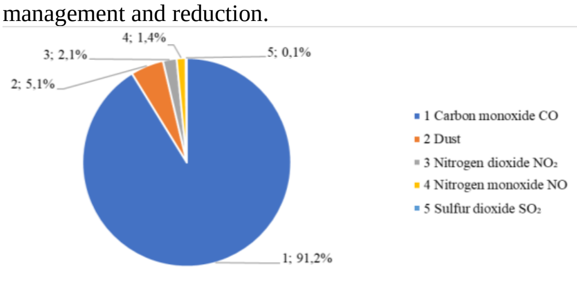

Fig. 4. Composition of atmospheric air pollutants studied for analysis from 2018 to 2023

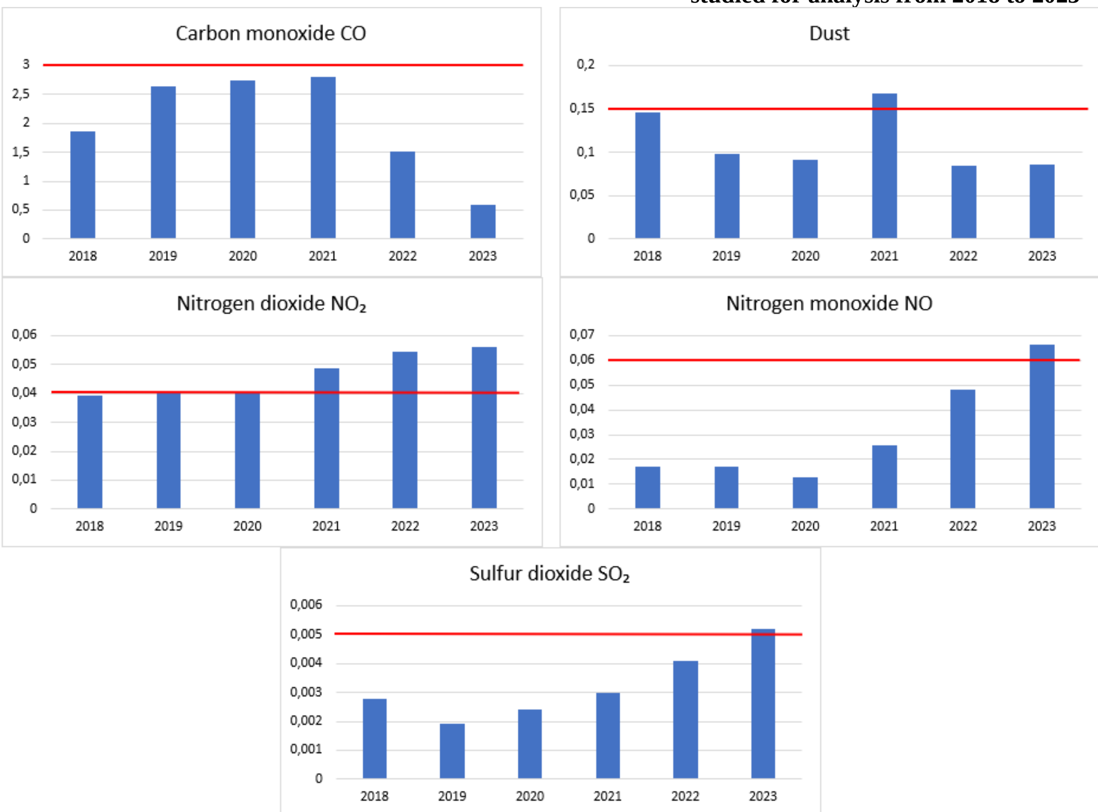

Fig. 5. Dynamics of changes in average annual concentrations (mg/m3) of pollutants by year (2018–2023)

From Fig. 4, it can be seen that the main pollutants are carbon monoxide and dust. In Fig. 5, you can see that certain substances' concentrations either increase or decrease over the years. An increase or decrease in the average annual concentration of pollutants in the atmospheric air can be caused by many factors. The reasons for the increase in concentration may be: industrial activity, increased motorization, urbanization, seasonal factors, waste combustion, natural factors, etc. The reasons for the decrease in concentration may be: environmental measures, decrease in industrial activity, increase in the number of electric vehicles and electric buses, improvement of public transport, natural conditions, etc. These factors may vary depending on the region, time of year, and current economic conditions, which makes the analysis of changes in the concentration of pollutants a complex and multifactorial process. In the future, research should include an in-depth study of these factors influencing the reasons for the increase or decrease in the average annual concentration of pollutants in the atmospheric air.

Future studies should conduct a comparative analysis of the processed data from experimental studies obtained using a gas analyzer and the data provided by Uzhydromet. This will identify differences and similarities between the two data sources and determine the accuracy and reliability of each method's measurements. The analysis will help improve air quality monitoring methods and assess the environmental situation in the study region.

4. Conclusion

Having analyzed all existing methods for determining and measuring the level of air pollution from exhaust gases on various sections of urban streets, it was concluded that the most optimal option for gas analyzer experiments was selected. The automatic multi-channel portable gas analyzer ECOLAB is effectively suitable for conducting experiments to determine the level of air pollution from exhaust gases in various sections of urban streets.

The goal and objectives of the study in the future are to study the impact of vehicle exhaust gases, depending on the intensity of traffic flow and its composition, on the environment of the Republic of Uzbekistan, especially in large cities, as well as their negative impact on drivers, passengers, pedestrians, and cyclists in various sections of city main streets.

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The practical importance of the Maple software

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Abstract: In this article, the mapple program, designed for solving mathematical problems in various ways, calculation and graphic methods, its wide application in various fields, its advantages and conveniences is explained in detail.

Keywords: I Mathematical Computation, Visualization, Graphing, Data Analysis, engineering concepts, 2D and 3D graphs

1. Introduction

The Maple software, particularly suited for mathematical computations, can play a significant role in developing and enhancing Intellectual Transport Systems (ITS). Here's how Maple's capabilities could be useful in this field [1].

2. Research methodology

1.**Route Optimization**: Maple can model complex algorithms needed for calculating optimized routes for vehicles in real-time. By using its symbolic computation and data analysis capabilities, it can solve equations and algorithms that manage dynamic traffic conditions, weather patterns, and road obstacles.

2.**Traffic Flow Analysis**: ITS often requires accurate traffic forecasting and flow analysis to manage congestion. Maple's data analysis tools can process large datasets, allowing for real-time simulations and predictive modeling of traffic patterns, which helps in proactive congestion management. [2]

3.**Vehicle and Pedestrian Safety**: Using Maple, transport system developers can simulate scenarios to improve safety. This includes computations related to vehicle braking distances, acceleration in various conditions, and pedestrian crossing behavior. Maple's ability to handle high-level mathematics makes it possible to simulate these conditions accurately, providing safety insights for ITS design.

4.**Environmental Impact Assessment**: With Maple's computational abilities, ITS can incorporate models to assess and minimize environmental impacts. It can be used to optimize routes that reduce fuel consumption or calculate emissions for various traffic scenarios, supporting eco-friendly transport solutions.

5.**Integration with Machine Learning Models**: Maple can preprocess data for machine learning models that ITS often rely on. For example, ITS might use machine learning for predictive maintenance of transport infrastructure, where Maple can handle initial data manipulation and complex mathematical modeling. [3]

6.**Dynamic Toll Pricing**: Maple's mathematical toolkit allows for the creation of models that adjust toll prices based on demand, time, and congestion levels in real-time, which can reduce traffic bottlenecks and promote efficient road use.

Maple is a powerful software tool designed for mathematical computation, analysis, and visualization, widely used in academia, engineering, finance, and other fields requiring advanced mathematical modeling. Here's an overview of Maple's main capabilities:

1. **Mathematical Computation**

• **Symbolic Computation**: Maple excels in symbolic math, which allows it to manipulate algebraic expressions, solve equations symbolically, and perform calculus operations like differentiation and integration exactly (not approximations).

• **Numerical Computation**: It also handles high-precision numerical calculations, essential for engineering and scientific applications that require exact results. [4]

2. **Visualization and Graphing**

• Maple has extensive plotting capabilities, allowing users to create 2D and 3D graphs, visualize data, and even animate mathematical concepts.

• These visual tools make it easier to understand complex mathematical relationships and to present results in an accessible format. [5,7]

3. **Data Analysis and Statistical Modeling**

• **Data Manipulation**: Maple can process and analyze large datasets, making it useful for applications involving statistical modeling, data cleaning, and transformation.

• **Statistical Functions**: It includes a suite of statistical tools for hypothesis testing, regression analysis, and probability distributions, aiding fields like finance, research, and engineering. [6]

4. **Interactive Document Environment**

• Maple has an environment where users can create interactive documents, combining live computations, plots, and formatted text. This is helpful for creating educational resources, reports, and presentations that include dynamic elements.

5. **Programming and Automation**

• Maple's programming language allows users to automate repetitive tasks, write scripts, and develop custom mathematical tools. Its language is designed specifically for mathematical applications, making it user-friendly for those with a math background.

• The software also supports integration with other programming languages like Python, MATLAB, and R, enabling users to incorporate Maple into larger workflows or software systems.

6. **Applications in Research and Industry**

• **Engineering and Physics**: Maple is used for modeling physical systems, solving differential equations, and

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performing complex computations related to mechanics, electronics, and thermodynamics.

- **Finance and Economics**: In finance, Maple helps with risk modeling, pricing of financial derivatives, and optimizing investment strategies by analyzing and solving equations related to financial markets.
- **Education**: Its interactive tools make it a popular choice for teaching mathematics and engineering concepts, as it allows students to experiment with real-time calculations and visualizations.[7]

7. Maple's Ecosystem and Resources

- **Extensive Documentation**: Maple includes comprehensive documentation, tutorials, and examples that support beginners and advanced users alike.
- **MapleCloud**: Users can share and access resources, applications, and tools created by the community, enhancing collaboration and sharing of best practices.
- **Toolboxes and Add-ons**: Maple has various add-ons for specific applications like MapleSim for physical modeling, Maple Flow for engineering calculations, and others tailored to niche industries.

Maple is known for its versatility in handling both basic and highly specialized mathematical tasks. This makes it valuable for anyone working with math-intensive problems across different industries and disciplines. [7]

We can see the working process of the mapple program with the help of the following examples

Calculation of fuel consumption of a car for 100 km

$$Q_s = \frac{K_n * K_N * g_{eN} * (N_\varphi + N_W)}{36 * \rho_e * \eta_{k.y} * V_a}, \frac{1}{100} km$$

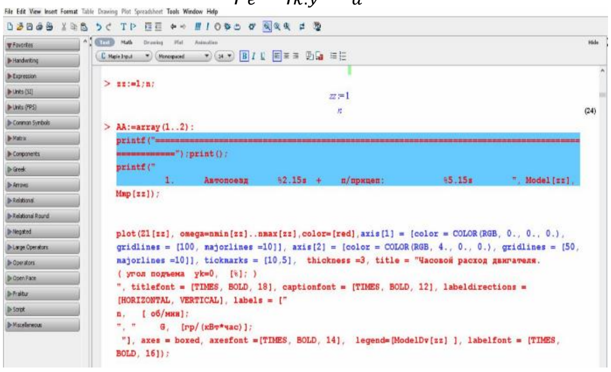

Figure 1. Calculation of the hourly consumption of the engine through the Maple program

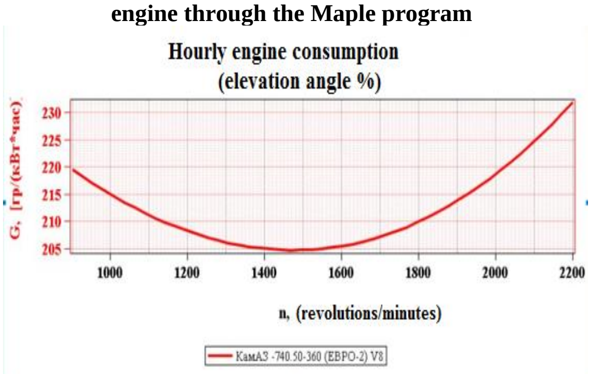

Figure 2. Graphical representation of the engine's hourly consumption at 0 percent height

Apart from these, Maple has ample opportunities to carry out analytical transformations of mathematical formulas. To them include operations such as bringing similar ones, factoring, opening parentheses, bringing a rational fraction to normal appearance and many others. [8, 9]

In addition, the maple program includes several different procedures.

The move procedure is universal and can be used to study the motion of a longing with any given equations of motion. For example, let's calculate the characteristics of the movement of a point whose laws of coordinate changes have the following form [10]

$> x := \cos(t/3)$ $\qquad x := \cos\left(\frac{1}{3}t\right)$

$> y := \frac{3}{2} * \sin(t/2)/2$ $\qquad y := \frac{3}{4}\sin\left(\frac{1}{2}t\right)$

$> move\ (x, y, t3.5, 0.2 - 0.25 - 0.5 - 0.75 - 1, 002, 0.02)$

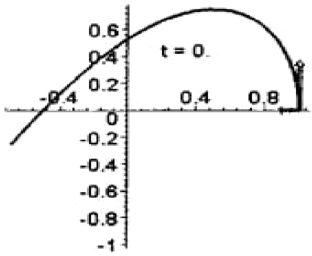

Figure 3. a) For the case where the point's movement starts at the (x,y) coordinate w<0

$v(x, y) = [0, \quad 375]$

$w(x, y) = [-1, \qquad -0]$

$w(tau, p) = [0, \qquad 1]$

$ro = 1{,}26$

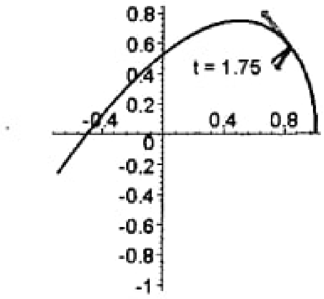

Figure 3. b) (x,y) position of point movement starting from t=1.75 second acceleration

$v(x, y) = [-1.84, \qquad 240]$

$w(x, y) = [-928e - 1, \quad -144]$

$w(tau, p) = [-583e - 1, \quad 161]$

$ro = 570$

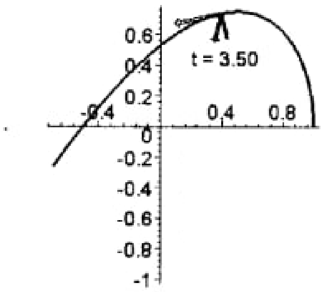

Figure 3. c) The graph of the movement of the point in the (x,y) coordinate, reaching the highest point at t=3.5 seconds and then decreasing again

$$v(x,y) = [-307, \quad 668e-1]$$
$$w(x,y) = [-433e-1, \quad -184]$$
$$w(tau,p) = [-816e-1, \quad 172]$$
$$ro = 575$$

3. Conclusion

As mentioned in this article using examples, the Mapple program is characterized by its ease of use in solving mathematical problems, mathematical modeling and many similar areas of the industry. Maple software is a convenient tool widely used for solving mathematical problems, which combines calculation and graphical methods. The program effectively helps in solving algebraic expressions, differential equations, optimization problems and many other mathematical functions. Maple's advantages include its high-precision computing power, visualization capabilities, and wide application in various fields, including physics, economics, engineering, and other scientific fields. It simplifies mathematical calculations and allows users to solve complex problems quickly and accurately.

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Program evaluation of the enterprise exploitation service process

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Abstract: In this article, the industrial infrastructure, first of all, the developed system of roads and railways, their effective functioning is an important condition and factor in reducing the total production costs. This, in turn, enhances the competitiveness of the products and the economy as a whole. In order to ensure the accelerated development of modern production and social infrastructure, and to create favorable conditions for the consistent and sustainable economic growth, a special program "On Additional Measures for Further Development of Production and Social Infrastructure in 2019" was adopted and its implementation under strict control. It is desirable to determine the annual production program for the enterprise аф using the coefficients of avtomobile,in this αт with the accounting of technical preparation coefficients. Inadequate points of equipment for the lack of conditions for the complete performance of technological processes in the regions and workshops at the enterprise. Should improve the exploitation service at the enterprise. This paper provides designing methodical recommendations and using there results to improve traffic safety in transport.

Keywords: car, traffic safety, traffic, traffic signs, dangerous site

1. Introduction

Deep transformations, gradual reform and liberalization of all aspects of political and socio-economical life, democratic renewal and modernization of our society are being rapidly developed in our country. The next priority is further development of production and social infrastructure as an important factor of modernization of the country and increasing employment.

Special attention should be given to this priority, which is of utmost importance. There are several reasons.

First, the development of infrastructure will create the necessary conditions for the establishment of new enterprises and development of the economy as a whole, as well as the opportunities for the development of the country's rich mineral resources.

Secondly, the industrial infrastructure, first of all, the developed system of roads [6] and railways, their effective functioning is an important condition and factor in reducing the total production costs. This, in turn, enhances the competitiveness of the products and the economy [3] as a whole.

Thirdly, the development of social infrastructure, provision of the population with clean drinking water, energy, the construction of social facilities and, ultimately, improvement of living standards.

Fourth, infrastructure development is a labor-intensive industry. This will create new jobs, provide employment to the population, especially young people, and increase the incomes and welfare of the people.

The rapid development of passenger cars worldwide in Uzbekistan, with the need to increase the technical rigidity and culture of driving cars, necessitates the creation of a comprehensive network of technical service [4] zones. Many organizations and enterprises in the country are involved in projects of technical service zones.

However, no technical literature has been developed to cover all aspects of TSS yet. This disadvantage, in turn, has a significant impact on the quality and performance of the work, due to the variety of equipment, despite their generalities. Many car service stations have been designed and used in the global [5] automotive industry.

This article covers the development of new projects of automotive maintenance stations, summarizing their economic and manufacturing processes, taking into account the experience gained in the field of automotive industry.

2. Research methodology

The main purpose of the article is to summarize the design process for the maintenance areas and make recommendations for their efficient use. It provides a feasibility study of the technologies and their technical performance.

In order to ensure the accelerated development of modern production and social infrastructure, and to create favorable conditions for the consistent and sustainable economic growth, a special program "On Additional Measures for Further Development of Production and Social Infrastructure in 2019" was adopted and its implementation under strict control.

Effective operation of the motor transport enterprise is a combination of the efficient operation of working posts in the production regions and workshops. To this end, technological development needs to be assessed in order to further develop the social infrastructure of motor transport enterprises.

The ATC assesses the annual production program using a variety of methods, depending on the impact level. That is, using cycles, rapid computational and computational methods.

3. Result and Discussion

At the same time, the calculator is calculated based on the aggregate data for calculating the daily production volume of the rolling stock at the enterprise (volume of transportation, total annual transportation):

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It is desirable to determine the annual production program for the enterprise α_{ϕ}using the coefficients of avtomobile,in this α_T with the accounting of technical preparation coefficients.

$$\alpha_i = \frac{D_r \cdot \alpha_T}{D_c} \quad (1)$$

In this regard, it is necessary to take into account the annual production volume of the rolling stock in ATC.

Carrying out an assessment of the composition of the vehicles involved in the transport of vehicles by the coefficient of use of cars in scientific terms is as follows;

$$Q_{year} = Q_{day} 361 \cdot \alpha_f = \frac{T_N \cdot \vartheta_T \cdot \beta \cdot q \cdot \gamma_e}{\mathcal{L}_{day} + \pounds_{ot} \cdot \vartheta_T \cdot \beta} \cdot 361 \quad (2)$$

Here is; $Q_{year} -$ *daily traffic amount*

T_N – time in work

ϑ_T – technical speed

β – using distance coefficient.

q – norminal load capacity.

γ_c – use of cargo handling capacity.

$\mathcal{L}_{day}$ – daily walking distance.

$\pounds_{ot}$ – overloading time.

According to this assessment, annual transportation$\alpha_f$is related to the use of in-house car ratios.

In order to calculate α_f the ratio of use of in-house vehicles,it is necessary to α_T- First evaluate the technical readiness ratio according to operating conditions:

$$\alpha_T = \frac{1}{1 + \mathcal{L}_d\left(\frac{d}{1000} + \frac{D_c}{\mathcal{L}_{cr}}\right)} \quad (3)$$

The evaluation process should be based on the total cost of car maintainance and the total annual maintenance;

You should first take into account the annual distance for your product.

$$\mathcal{EL} = A_i \cdot \mathcal{L}_d \cdot 365 \cdot \alpha_i \quad (4)$$

Here is:$A_i -$ *number of automobiles*

Expression studies were performed on the example of auto-assembling No. 11 at Marjanbulak gold-ore deposit in Gallaaral district.

Particularly in it: the automobiles [1, 7] in enterprises $A_i = 75$

Identified the normal amount of walking distance to full repair $\mathcal{L}_{cr} = 520000\ km$ the amount of heavyconditions $\mathcal{L}_{cr} = 385000\ km.$

1- TS *distance* $\mathcal{L}_1 = 3000\ km$

2- TS *distance* $\mathcal{L}_2 = 10000\ km$

Daily walking distance $\mathcal{L}_D = 210$км

Comparison dates of automobiles 2-TS and CR$d = 0.315\ days$ DR=24 day senterprises working day 305.

These information were taken for the exploitation condition from the experimental research center MAHSERVIS in Jizzakh city, Sharof Rashidov street. The calculation for the whole enterprise is made as follows.

$$N_{c1} = \frac{L_{cr}}{L_{c1}} = \frac{385000}{385000} = 1 \quad (5)$$

$$N_2 = \frac{L_{cr}}{L_2} - N_{cr} = \frac{386000}{10000} - 1 = 38.5 - 37 \quad (6)$$

$$N_1 = \frac{L_{c1}}{L_1} = N_{yer} - N_2 = \frac{386000}{3000} - 1 - 37 = 90 \quad (7)$$

$$N_{dc} = \frac{L_{cr}}{L_{dr}} = \frac{386000}{25000} = 1540 \quad (8)$$

$$D_{7K} = \frac{L_{cr}}{L_{dr}} = \frac{38600}{250} = 1540 \quad (9)$$

During the cycle standing days in 2-TS, CR and DR

$$D_T = \frac{\mathcal{L} \cdot l_{UKT}}{1000} D_{cr.te} \cdot N_{XE} = \frac{0.315 \cdot 38600}{1000} + 24 \cdot 1 = 145\ day \quad (10)$$

$$\alpha_T = \frac{D_E}{D_E + D_T} = \frac{1540}{1540 + 141} = 0.91$$

According to the calculation the automobiles in enterprises α_T-Technical preparation coefficient of vehicles in the company is calculated for the exploitation condition for the company as followers:

$$\alpha_T = \frac{1}{1 + \mathcal{L}_{dr}\left(\frac{d_2 \cdot K_2 + d_{dr} \cdot K_{cr}}{10000} + \frac{D_{cr}(\eta_u - 1)}{\mathcal{L}_{cr} \cdot \eta_i}\right)} \quad (11)$$

Here is: $d_{2n} d_{pr} \cdot 2 - TS$ ва CR Comparing days

$$d_2 = \frac{D_2 \cdot 1000}{\mathcal{L}_2} day/1000\ km \quad (12)$$

$$d_{cr} = d - d_2\ day\ /1000\ km \quad (13)$$

d-2-TS and in CR normative general comparing days

$$d = d^h \cdot k_y \quad (14)$$

for quarry $d^H = 0.1\ day/1000$км coefficient of correction $K_i = 1.26\ d = 0.5 \cdot 1.26 = 0.63\ k/1000\ km$

$$d_2 = \frac{1 \cdot 1000}{10000} = 0.1\ k/1000\ km$$

$$d_{cr} = 0.63 - 0.1 = 0.53\ k/1000\ km$$

K_2 The coefficient that takes into account the type of movement is equal $K_2 = 2.011$ for the Gallaaral quarry.

K_{CR} – Current repairing works volume that takes into account coefficient $K_{CR} = 0.5$

According to above mentioned information α_T-technical preparation coefficient is determined.

$$\alpha_i = \frac{1}{1 + 250\left(\frac{0.1 \cdot 2.05 + 0.53 * 0.5}{1000} + \frac{24(2-1)}{386000}\right)} = 0.88$$

As it is seen from the calculation, $\alpha_i = 0.88$, it is necessary to revise the normative parameters for the enterprise in order to improve the expropriation service at the enterprise. Depending on the ratio of α_i-technical readiness to use in cars, the ratio of coefficients is determined as follows.

$$\alpha_i = \frac{D_y}{D_{cy}} \cdot \alpha_T \cdot K_i \quad (14)$$

Here is :K_i- is the coefficient for the reduction due to technical problems with the use of vehicles under the conditions of expropriation.

1. $K_i = \frac{D_{EY}}{D_Y \cdot \alpha_T}$ (15)

Here is:D_{EY}- annual exploitation days.

ATC for specific excretion conditions is calculated as follows:

$$K_i = \frac{D_{EO}}{D_i \cdot \alpha_T} = \frac{301}{301 \cdot 0.88} = 1.13$$

$$K_i = \frac{301}{301 \cdot 0.91} = 1.10$$

For the real codition of enteprise

$$\alpha_i = \frac{301}{301} \cdot 0.88 \cdot 1.13 = 0.830$$

During cycle for the condition of enterprise

$$\alpha_i = \frac{301}{301} \cdot 0.91 \cdot 1.1 = 0.836$$

In terms of operating environment at the enterprise

$$\alpha_i = \frac{D_Y}{D_K} \cdot \alpha_T = \frac{301}{301} \cdot 0.88 = 0.73$$

4. Conclusion

In conclusion, it should be noted that for the enterprise, the same type of cars $\alpha_i = 0.73, \alpha_i = 0.830, \alpha_i = 0.836,$ can be interpreted as:

1. Due to non-conformity of operation requirements of DTC

2. $A_i = 75$ per day the technical parameters of Ai=62

correspond to technical parameters, while, $A_i = 13$, exactly 17% of the vehicle is not technically ready for work;

3. Inadequate points of equipment for the lack of conditions for the complete performance of technological processes in the regions and workshops at the enterprise.

4. Should improve the exploitation service at the enterprise.

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Increasing the role of titanium alloys in the aviation industry: problems and solutions

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Abstract: This article analyzes the importance of using titanium alloys in the aviation industry, their unique physical-mechanical properties, and the complexities of the manufacturing process. It discusses the processing technologies of titanium alloys, the issues of improving cost efficiency, and optimizing technological regimes. The relevance of this topic is based on scientific and practical approaches to the use of advanced materials in the aviation industry.

Keywords: titanium alloys, aviation industry, machining technologies, material properties, corrosion resistance, lightness and strength, technological optimization, scientific and practical research, production costs, aviation innovations

1. Introduction

Titanium alloys have become one of the most important materials in the aviation industry due to their unique properties such as high strength, lightness, and corrosion resistance. These characteristics play a significant role in ensuring the reliability, efficiency, and long service life of aircraft and other aviation equipment. Titanium alloys are especially important for ensuring the lightweight nature of aircraft structures, as well as optimizing fuel consumption by reducing their weight [1].

However, the challenging mechanical processing and high production costs of titanium alloys limit their widespread use. The processing of titanium alloys typically requires high temperatures, special tools, and technological procedures, leading to higher production costs. Additionally, due to the high density and hardness of titanium, operations such as shaping, cutting, and welding become more difficult, which reduces production efficiency. The table below compares the properties of titanium materials with those of other materials [5;10].

Material	Strength (MPa)	Corrosion Resistance	Specific Gravity (g/cm³)	Machining Complexity
Titanium Alloys	1000-1200	High	4.5	High
Aluminum	400-500	Medium	2.7	Medium
Steel	800-2000	Low	7.8	Low
Composite Materials	150-300	Very High	1.8-2.2	Low

- **Strength (MPa):** The material's resistance to tensile stress.
- **Corrosion resistance:** The material's ability to withstand oxidation or other harmful effects in environmental conditions.
- **Machining complexity:** The difficulty of working with the material during production (requires high-level cutting tools and technologies).

Therefore, optimizing the processing of titanium alloys and improving technological regimes are important scientific and practical issues. Such optimizations can be achieved by implementing new processing technologies, creating specialized equipment for more efficient material processing, or developing new alloys. These processes will enable broader use of titanium alloys in the aviation industry and help reduce production costs [8; 9].

2. Research Methods and Results

Studies on the use of titanium alloys in the aviation industry highlight their unique physical-mechanical properties. The material's high strength, corrosion resistance, and lightweight make it an ideal choice for reducing aircraft structure weight, increasing efficiency, and extending service life. Specifically, titanium alloys are widely used in **aircraft engines** (for turbine blades, compressor parts, and other engine components due to their high strength and heat resistance, **Ti-6Al-4V), braking systems (Ti-6Al-2Sn-4Zr-2Mo** (Beta Titanium)), and fuselage parts (where strength and impact resistance are required, for primary elements of the aircraft chassis with the **Ti-10V-2Fe-3Al** alloy), as they provide high performance and optimize fuel consumption by reducing weight [2].

However, the mechanical processing of titanium alloys is very complex, as the high strength and hardness of these materials make cutting and shaping challenging. Specifically, issues such as cutting speed and tool wear reduce production efficiency [3]. Therefore, it is necessary to implement innovative technologies to improve the manufacturing process. Based on research, a number of solutions have been proposed to develop optimal technological regimes for processing titanium alloys and to improve the design of cutting tools to increase their efficiency, addressing the challenges encountered during the processing of titanium alloys [4].

Several challenges arise in the processing of titanium alloys:

- Due to their low thermal conductivity, heat accumulates in the tool zone during the cutting process, causing rapid tool wear.

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- The high chemical reactivity of the material may lead to reactions with the cutting tool, negatively affecting the surface quality.
- The strength and elasticity properties cause vibrations during the processing, making it difficult to maintain accuracy.

To prevent and resolve these challenges in the processing of titanium alloys, the following methods should be applied [5].

Heat management:

- **Cooling systems:** Using high-pressure and efficient cooling systems reduces heat in the tool zone during cutting. For example, water-oil mixtures:
- Special additives in cooling fluids ensure faster heat dissipation.
- Water-oil emulsions prevent corrosion and enhance operational efficiency. These systems not only effectively dissipate heat during processing but also improve cutting precision, extend tool life, and enhance surface quality.
- **Special cutting tools:** Heat-resistant coated tools, such as tungsten carbide or ceramic-coated tools, can be used.
- Due to the low thermal conductivity of titanium alloys, high temperatures are generated in cutting zones.
- **Tungsten carbide tools:** Withstand high heat (800–1000 °C), preventing rapid tool wear.
- **Ceramic tools:** Operate at very high temperatures (above 1000 °C) and do not react with the metal, making them ideal for titanium materials [7].

Managing chemical activity:

- **Protective coatings:** Applying special chemical coatings to tool surfaces can reduce the likelihood of reactions. Examples include **TiN, TiAlN, AlCrN, DLC,** and **ZrN.**
  - Additionally, protective coatings offer the following benefits:
- Prevent wear on the tool surface.
- Enhance heat resistance.
- Prevent reactions with titanium.
- Improve smoothness, making the processing easier and enhancing precision.
- **Improving the working environment:** This involves optimizing conditions to control and enhance the interaction between tools and materials during the processing of titanium alloys. Several methods can be applied for this purpose:
- **Use of inert gases:**
  - Titanium alloys exhibit high chemical activity, reacting with oxygen, nitrogen, or hydrogen in the air.
  - This degrades surface quality and complicates the cutting process.
  - *Application:* Inert gases, such as argon or helium, are introduced into the working area to form a protective layer that prevents reactions and preserves surface quality [9].
- **Use of cooling and lubricating agents:**
  - To reduce heat generation and friction during the process, water-oil emulsions are used.
  - These help slow tool wear and improve accuracy.
- **Temperature control:**
  - Excessive heat in the cutting zone accelerates tool wear and reduces processing quality.
  - High-pressure cooling systems, cryogenic cooling (liquid nitrogen or carbon dioxide), or mist cooling methods are used to regulate temperature.
- **Dust and debris management:**
  - Dust and debris generated during processing can affect quality and damage equipment.
  - Ventilation systems or dust extraction devices are employed to maintain a clean working environment.
- **Firm tool mounting and adjustment:**
  - Stability during cutting ensures accuracy.
  - High-quality clamping devices and sturdy mounting systems are used to prevent tool movement.

3. Reducing vibrations

Stable equipment: These are modern machines and systems designed to ensure high precision, durability, and resistance to vibrations when processing titanium alloys. Examples of such equipment include the

DMU monoBLOCK series and the NHX 6300 (horizontal machining center) [6].

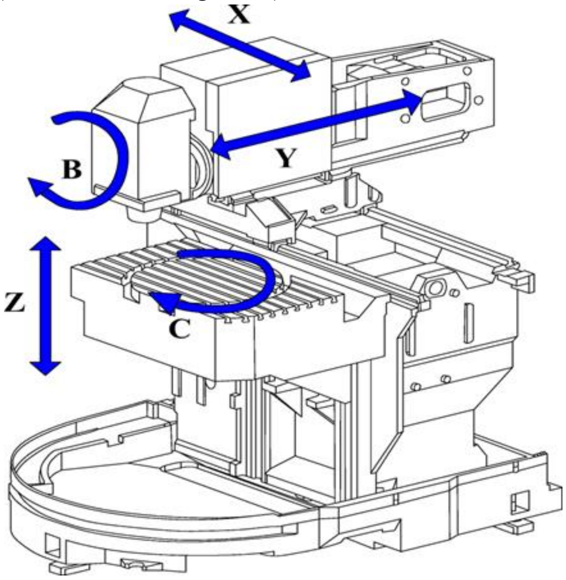

Figure 1. DMU-80

Figure 2. NHX 6300

4. Conclusion

Titanium alloys play a crucial role in the aviation industry as lightweight and durable materials. Their high corrosion resistance and mechanical properties enhance the efficiency of aircraft structures and engines. However, challenges in processing and high production costs limit their application, necessitating process optimization and the adoption of innovative technologies.

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Bibliometric analysis of improving the performance system of human robot collaborative (HRC) assemblies based on standardization

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Abstract: In recent years, the use of Human-Robot Collaboration (HRC) in manufacturing systems has grown significantly, within the framework of Industry 4.0 and emerging Industry 5.0. The purpose of this study is to review and analyze the scientific papers written on improving performance systems of HRC based on standardization. 224 documents were obtained in the general search, after eliminating duplicates and applying certain inclusion and exclusion criteria, 65 papers were used for this review.

Keywords: human robot collaboration (HRC), standardization, quality control, assembly, industry 4.0 Efficiency, Scopus

1. Introduction

Collaborative robots, also known as cobots, are emerging as a promising technology in the field of robotics. These robots are designed to work alongside humans and are capable of performing a wide range of tasks, from simple pick-and-place operations to complex assembly tasks [1]. Due to their ability to work safely and efficiently alongside human workers, cobots have become increasingly popular in the manufacturing industry. In particular, they are widely used in product assembly where their use leads to increased productivity, improved quality and reduced costs [2].

Human-robot collaboration (HRC), or the collaboration between cobots and human operators, is one of the cornerstones of both Industry 4.0 and Industry 5.0, which focus on integrating digital technologies into the manufacturing process [3]. In these new industrial paradigms, there is a rising need for flexible and agile production systems that can quickly adapt to changes in demand and product design. In fact, in today's market, there is a growing demand for short runs of a wide variety of products. This is due to increasing customer demand for customisation, which is leading to an increase in the number of variants of the same product [4, 5]. This approach, called mass customisation, involves the use of flexible manufacturing processes that can quickly and cost-effectively adapt to the specific needs, preferences and requirements of customers [6].

Collaborative robots are well suited to these needs, as they can be easily programmed and reconfigured to perform a wide range of tasks and can work alongside human workers to improve overall efficiency and productivity. In addition, cobots can provide real-time data and feedback that can be used to optimise production processes and improve product quality. The ability to collect data in real time also allows cobots to be integrated into the digital twin of the entire production system [7] that is essential for the continuous monitoring of production processes and machine diagnostics.

Another key aspect in a competitive market is product quality. To achieve business success, it is essential to implement and improve quality control procedures [8]. The need for quality control in all production systems is to prevent non-conforming products from reaching the end customer or end-user [9]. Collaborative robots are increasingly used in quality control, as their ability to accurately perform repetitive and monotonous tasks can ensure the consistent production of high-quality products.

Furthermore, the use of cobots can also reduce the risk of injury or strain to human workers, resulting in increased productivity and a safer working environment. As a result, the adoption of cobots for quality control is a promising solution for improving product quality and competitiveness.

This study provides three main conclusions:

During the period 2002-2024, academic interest in this topic has increased and the keywords are HRC, standardization, quality control, assembly, industry 4.0;

A list of authors who have conducted scientific work on the basis of HRC is compiled;

The top 12 countries that conducted scientific work based on HRC are presented based on geographical analysis.

VOS viewer software was used to investigate the bibliometric research method and bibliographic display maps. There are three phases to the bibliometric research process, they are search criteria and source identification, software and data extraction, and then data analysis and interpretation. To our knowledge, several bibliometric comparative reviews on HRC have been published. This study serves as a continuation of the above related studies.

2. Research methodology

The Scopus search engine was used to find a comprehensive literature on the HRC of the theory. Scopus is one of the most comprehensive databases of citations and abstracts for peer-reviewed literature. Based on Figure 1, there are three steps in the bibliometric research process, which are search criteria and source identification, software and data acquisition, and then data analysis and interpretation.

Step 1, source identification with search criteria and bibliometric analysis, consists of scientific database retrieval and publication information collection from the Scopus database. In the search process, we initially identified documents with the terms "HRC". As a result of the bibliometric search, 224 documents were found, and when we synthesized them for the years 2002-2024, 194

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documents were identified. Bibliometric analysis was performed on the basis of 65 documents.

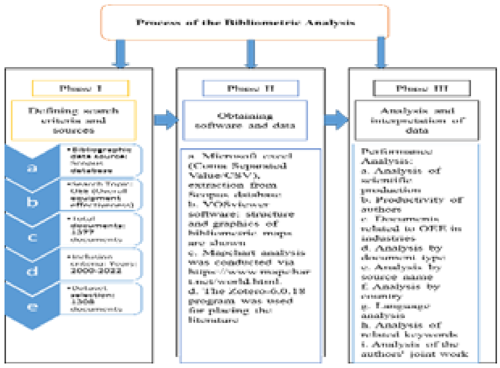

Figure 1. Process of the Bibliometric Analysis

In Phase 2, the results were downloaded from the Scopus database in three different formats. The following data was received in CSV format for data viewing through Microsoft Excel: Authors, affiliations, titles, publication years, cited publications, abstracts, author keywords and other important bibliographic information are included in the downloaded metadata, which must be examined and improved. The use of bibliometric approaches to describe the knowledge structure of HRC project is illustrated. The outcome of VOS viewer software analysis, such as Bibliometric coupling; includes co-citation analysis and keyword co-occurrence.

The site www.mapchart.net was effectively used in the formation of analyzes by countries. Zotero software was used to compile the list of references. The results obtained in the Phase 3rd stage were analyzed.

3. Results and Discussion

We can see the development dynamics of scientific research on determining Human Robot Collaboration (HRC) between 2002 and 2024 through Fig.2. Between these years, 65 scientific researches were conducted, and these indicators are fluctuated during the given years. In particular, the maximum increase points of the indicators are more than 10 in 2021 and 2023.

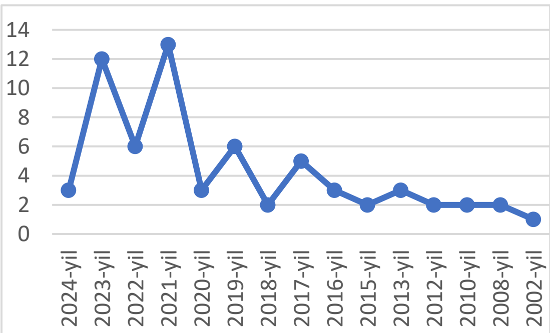

Figure 2. Growth of scientific production relating to HRC (www.scopus.com)

In the Scopus database, 159 authors conducted scientific research on the Human Robot Collaboration (HRC), and the top 24 authors who has done at least two scientific research were determined by Figure 3.

Fig. 3 is built on the basis of the Poretto diagram, and we can see the obtained results.

Fig.3 shows us that "Saenz, J." is considered the most effective among the authors who conducted research on HRC, and he is on the first place with 5 indicators. In addition, 8 of them has 3 and 15 of them has 2 indicators respectively.

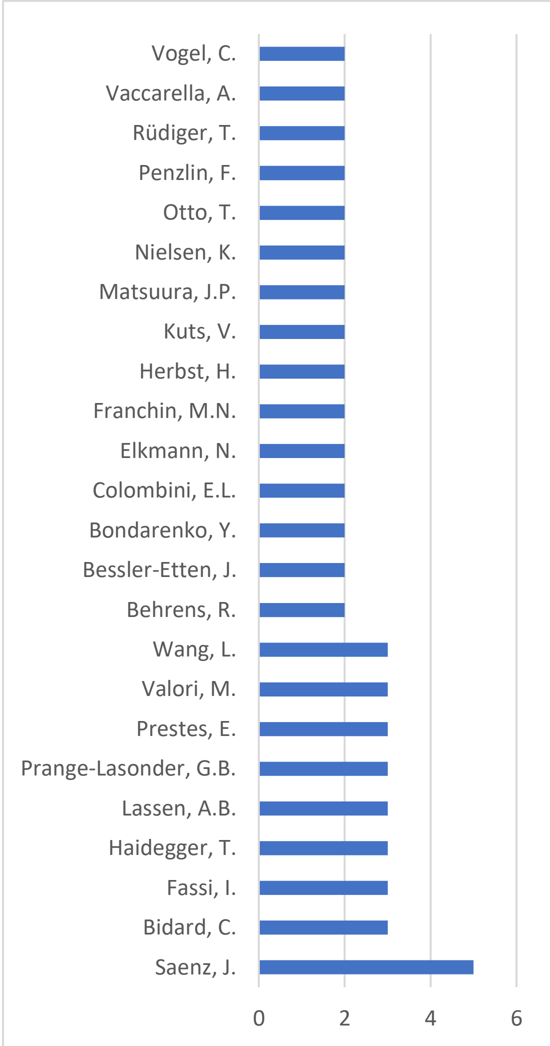

Figure 3. Top-24 authors who has done at least two scientific research

In the Scopus database, scientific works were carried out in 18 directions on the Human Robot Collaboration (HRC).

Almost 30% of the total scientific research was carried out in the direction of Computer Science and Engineering, 6% in the direction of Medicine.

Through Fig.4, we can see how the work done on HRC in the Scopus database is distributed by source. The main place in this is occupied by articles (43%), conference papers (36%), reviews (11%), book chapters and conference review (5% each) respectively.

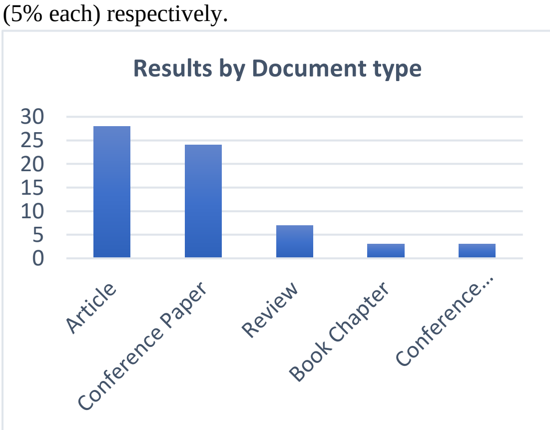

Figure 4. Results by document type

Fig. 5 shows which country is active in HRC research. Roughly 113 countries have conducted research on HCR. When we determined the top 12 in this regard, it is clear that most of the research was done by European countries almost 70%. If we go in detail Germany took first place with 17%, Italy with 13%, Brazil and the United States with 10% each respectively.

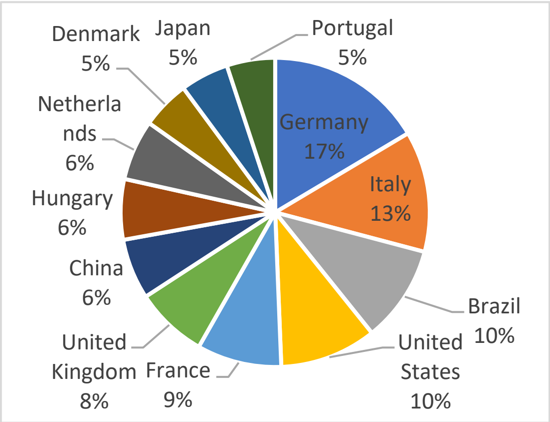

Figure 5. Results of Geographical analysis of research on HRC in 2002-2024

Fig. 6 was formed based on the information obtained from the Scopus database. The site www.mapchart.net was used to create a world map and place data.

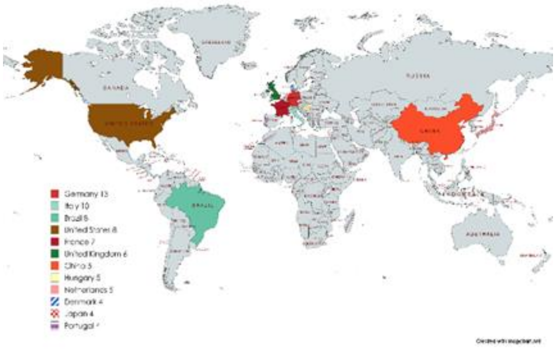

Figure 6. Geographical analysis of research on HRC in 2002-2024

4. Conclusion

Using bibliometric and network analysis, this paper provided an overview of the distribution of publications on Human Robot Collaboration (HRC). By querying the Scopus database with predefined keywords, a collection of 65 published papers was retrieved. There are three phases, first search criteria and source identification, second software and data acquisition, and third data analysis and interpretation. In summary, research findings on HRC using VOS Viewer have been identified. Collaborative robots have become popular in assembly processes because they can work alongside human workers to perform repetitive tasks without interruption or fatigue, increasing the efficiency of the production process. They also create a safer working environment by performing hazardous tasks that could put human workers at risk.

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Modeling the processes of conversion of asymmetrical three-phase currents into output voltage

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Abstract: In the monitoring and management of electric power supply systems around the world, great attention is paid to determining and standardizing the values of measured and controlled quantities and parameters based on signal transformation processes, to the accuracy and reliability of measurement indicators, and to the algorithms and practical software products that provide them. In this direction, in countries with advanced technology and technics, including the USA, Germany, France, Sweden, Italy, Japan, China, Korea, and Russia, measuring and control devices, tools, and measuring and control signals that determine the multi-parameter, functionality, and speed of reactive power indicators, the development of new structures, work algorithms and software of transducers and sensors supplying primary signals is considered urgent, and the application of research results to practice is of great importance.

Modern calculations and design require the use of complexes in the study of electromagnetic converters of primary current into secondary voltage of complex and variable quantities. This articale presents mathematical expressions for determining the values and parameters used in electrical and magnetic transformer parts and sensor designs of assymmetrical three-phase current converter sensors (ATPCCS) used in control and reactive power control systems of power plants. supply systems are presented.

Keywords: assymmetrical three-phase current, sensors, primary currents, secondary voltage, graph model

1. Introduction

In modern power supply systems (PSS), the accurate measurement and control of reactive power are critical for ensuring energy efficiency, maintaining power quality, and optimizing system reliability. These tasks are particularly challenging in environments where asymmetrical and non-sinusoidal currents occur due to unbalanced loads, harmonic distortions, or the integration of distributed energy resources. Addressing these challenges requires advanced measurement and sensing technologies capable of reliably converting complex electrical quantities into manageable signals for analysis and control.

Assymmetrical three-phase current converter sensors (ATPCCS) require the use of modern calculation and design complexes in research issues involving three-phase primary current to secondary voltage electromagnetic converters. This article presents research models and mathematical expressions of the processes, quantities, and parameters of the three-phase electromagnetic current transformers used in the measurement and control systems of the reactive power of the power supply systems (PSS), as well as the elements and structures of the three-phase electromagnetic current transformers [1,2].

Asymmetrical Three-Phase Current Converter Sensors (ATPCCS) represent an innovative solution to these challenges. These sensors are specialized electromagnetic devices designed to transform three-phase primary currents into secondary output voltages. ATPCCS play a crucial role in modern PSS by enabling the monitoring and management of reactive power under both ideal and non-ideal operating conditions. Their applications extend to industrial automation, renewable energy systems, and smart grid technologies, where precise and efficient reactive power control is essential.

This article presents a comprehensive study of the operational principles, mathematical models, and design elements of ATPCCS. It focuses on the conversion processes of three-phase primary currents into secondary voltages and investigates the parameters and structures that influence their functionality [3,4].

2. Research Methodology

The process of changing the reactive power of power supply systems from symmetric three-phase primary currents to the output signal in the form of secondary rated voltage and the modeling and research of the devices and sensors involved in this process are carried out on the basis of the following algorithms:

ATPCCS devices with different physical and technical characteristics that provide the conversion of electrical energy into a secondary signal, the process of energy and signal conversion in energy sources, and the process of monitoring and modeling the structure of the control sensor:

1. A model of the process of converting the primary electric current I_{in} into the magnetic driving force F_{μ} is created (Fig. 1):

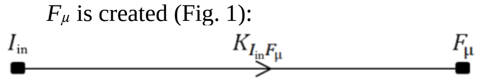

Fig. 1. Model of the process of transformation of the primary electric current I_k into the magnetic driving force F_{μ}

where - $K_{I_{in}F_{\mu}}$ is the interchain coupling coefficient of the conversion of electric quantity to magnetic quantity.

- an analytical view (1) of the relationship between the magnetic driving force F_{μ} of the magnetic switching part and the primary electric circuit current I_k is created:

$$F_{\mu} = K_{I_{in}F_{\mu}} I_{in}, \quad (1)$$

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where $K_{I_{in}F_\mu}$ is the inter-chain coupling coefficient of the process of transformation of the magnetic driving force F_μ into the primary current of the electric circuit I_k.

2. A model of the process of changing the magnetic driving force F_μ and the magnetic flux Φ_μ is created (Fig. 2):

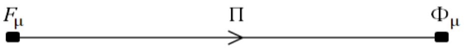


Fig. 2. Model of the process of transformation of F_μ - magnetic driving force into Φ_μ - magnetic flux

where П is the coupling coefficient of the conversion of the magnetic driving force to the magnetic flux.

- an analytical view (2) of the relationship between the magnetic flux Φ_μ magnetic driving force F_μ and the primary electric circuit current is created:

$$\Phi_\mu = ПF_\mu, \quad (2)$$

where П is the coupling coefficient of the magnetic driving force F_μ and the process of changing to electromagnetic current Φ_μ.

3. A model of the interconnection between the magnetic flux Φ_μ and the secondary output voltage U_{out} - the secondary signal is created (Fig. 3):

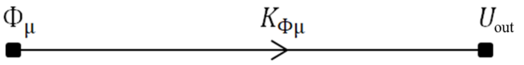


Fig. 3. Model of the process of converting the magnetic flux Φ_μ into the secondary output voltage U_{out} - the secondary signal.

The analytical expression (3) of the process of converting the magnetic flux Φ_μ into the three secondary output voltages U_{out} of the magnetic transformer part is made:

$$U_{out} = K_{\Phi\mu Uout}\,\Phi_\mu\,, \quad (3)$$

where $K_{\Phi\mu Uout}$ is the inter-chain coupling coefficient of the transformation of the magnetic flux Φ_μ into the secondary output voltage U_{out}.

a) A graph model for generating the output voltage of a single-phase single-sensing element ATPCCS with aggregate parameters of the power supply system (PSS) connected to the reactive power source is formed (Fig. 4).

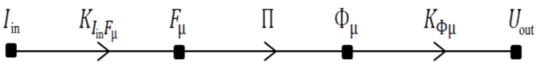


Fig. 4. A graph model for generating the output voltage of single-phase single-sensing element electromagnetic current-to-voltage converters with increased functionality

An analytical expression (4) formed on the basis of the graph model of generating the output voltage of a single-phase single-sensing element ATPCCS with aggregated parameters of the PSS reactive power source of the power network is in the form of an analytical expression (4) [9]:

$$U_{out} = K_{IinF\mu} П_\mu\, K_{\Phi\mu}\, I_{in} \quad (4)$$

where: $K_{IinF\mu}$ is the inter-circuit coupling coefficient of the process of transformation of the magnetic driving force into the primary current of the electric circuit.

$П_\mu$ - the inter-chain coupling coefficient of the conversion of the magnetic flux to the magnetic current.

$K_{\Phi\mu}$ - the inter-circuit coupling coefficient of the conversion of the magnetic current to the secondary output voltage.

I_{in} - electric circuit primary current.

A graph model of the output voltage of the two-phase single-sensing element ATPCCS with distributed parameters of the power network connected to the PSS reactive power source is formed (Fig. 4).

b) The graph model of generating the output voltage of three-phase three-sensing element ATPCCS with distributed parameters of the power network connected to the PSS reactive power source is presented in Figure 5:

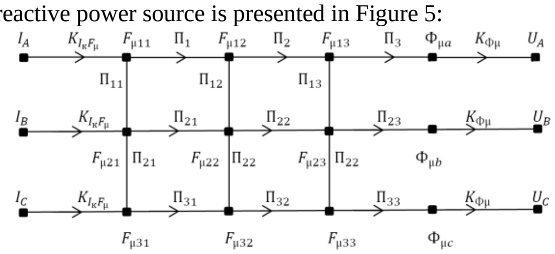


Fig. 5. Graph model of output voltage generation of electromagnetic current-to-voltage converters with extended functionality with distributed parameter three-phase three sensitive elements

The analytical expression formed on the basis of the graph model for the formation of the output voltage of the three-phase ATPCCS with three sensitive elements with distributed parameters is in the form of (5), (6) and (7):

$$U_A = W_{IU}(I_A, U_A)I_A + W_{IU}(I_B, U_A)I_B + W_{IU}(I_C, U_A)I_C\,, \quad (5)$$

$$U_B = W_{IU}(I_A, U_B)I_A + W_{IU}(I_B, U_B)I_B + W_{IU}(I_C, U_B)I_C \;, (6)$$

$$U_C = W_{IU}(I_A, U_C)I_A + W_{IU}(I_B, U_C)I_B + W_{IU}(I_C, U_C)I_C \;, (7)$$

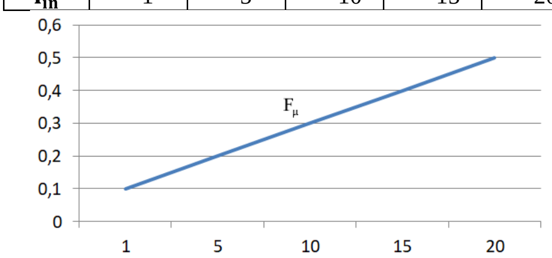
where: $W_{IU}(I_A,U_A)$, $W_{IU}(I_B,U_A)$, $W_{IU}(I_C,U_A)$, $W_{IU}(I_A,U_B)$, $W_{IU}(I_B,U_B)$, $W_{IU}(I_C,U_B)$, $W_{IU}(I_A,U_c)$, $W_{IU}(I_B,U_c)$, $W_{IU}(I_C,U_c)$ - primary currents I_A, I_B, I_C transfer functions secondary to U_A, U_B, U_C through the switching band. Analysis of analytical expressions generated based on graph models and algorithms presented in Figures 4 and 5. [5,6,7,8].

Three-phase electromagnetic current-to-voltage converters are reliable devices for determining reactive power asymmetry in the power supply system, allowing to ensure the control of the power source with the specified accuracy and speed based on the reception of normative signals for information measuring devices [10,11].

High accuracy, speed, extended functionality of the ATPCCS information-measurement system used in the control and management of reactive power of power supply systems, i.e. changing one, two, three and more values and parameters at the same time and ensuring the fulfillment of the requirements for sensitivity are the main indicators of signal converters.

Table-1

$K_{I_{in}F_\mu}$	0.1	0.2	0.3	0.4	0.5
I_{in}	1	5	10	15	20

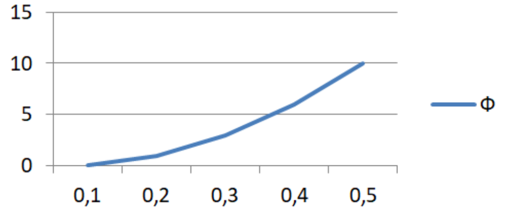


Graph-1. This graph given by (1)

Graphic representation of the relationship between the magnetic driving force F_μ of the magnetic switching part and the primary electric circuit current I_k.

Table-2

П	0,1	0,2	0,3	0,4	0,5
F_μ	0,1	1	3	6	10

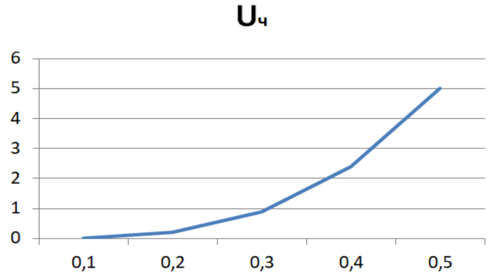


Graph-2. This graph given by (2)

Graphical representation of the relationship between the magnetic flux Φ_μ magnetic driving force F_μ and the primary circuit current.

Table-3

Φ_μ	0,01	0,2	0,9	2,4	5
$K_{\Phi_\mu U_ч}$	0,1	0,2	0,3	0,4	0,5



A graphical representation of the process by which the magnetic transformer converts the magnetic flux Φ_μ into a three-secondary output voltage U_{out}.

3. Conclusion

To sum up, the need to take into account the interaction of three-phase currents flowing from the primary phases of electric networks with the help of electromagnetic converters, to analyze the magnitudes and changes of magnetic currents and to generate signals in the form of voltage in the secondary circuit made it possible to create a new category of three-phase current-to-voltage converters. Therefore, the research algorithm and models of the process and parts of the transformation of the multiphase primary currents of the reactive power sources into the secondary signal $U_ч$ - the output voltage were created. The created graph models provided an opportunity to study the signal transformation process and structure of three-phase current sensors based on clarity and high formalization.

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Traffic flow characteristics and their impact on air pollution in urban streets: a case study of Tashkent

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Abstract: This study investigates traffic flow characteristics on major streets in Tashkent, focusing on Amir Temur and Fargona Yuli streets, to evaluate their impact on vehicular emissions and air pollution. The analysis examines temporal variations, vehicle composition, and traffic dynamics based on observational data from 2023 to 2024. Key findings highlight peak congestion periods, the dominance of passenger cars in traffic composition, and the significant contribution of heavy vehicles to emissions. The results provide insights into how traffic characteristics influence urban air quality, laying the groundwork for sustainable transportation and environmental policies.

Keywords: traffic flow, vehicular emissions, urban air pollution, environmental impact, urban streets

1. Introduction

Urbanization and economic growth in Tashkent have significantly increased vehicular traffic, leading to challenges for air quality and public health. The city's rapid expansion, combined with a rising number of vehicles, has resulted in a noticeable decline in air quality, directly affecting residents' well-being. Vehicular emissions from passenger cars, trucks, and buses are a major source of urban air pollution, contributing to respiratory diseases and environmental degradation. Traffic congestion exacerbates these emissions, as vehicles spend more time idling or moving slowly, increasing emissions per unit of travel. Studies by Barth & Boriboonsomsin [1], Jandacka et al. [2], and the IEA [3] highlight the detrimental health and environmental impacts of congestion.

This research focuses on analyzing traffic flow along Amir Temur and Fargona Yuli streets, two of Tashkent's busiest roads, to explore their relationship with vehicular emissions and their contribution to urban air pollution. By studying these key transport corridors, the research aims to provide insights into how traffic dynamics can be managed to mitigate environmental impacts.

2. Research Methodology

Research on traffic-induced air pollution highlights the need for sustainable urban mobility solutions to mitigate congestion's environmental effects. Barth & Boriboonsomsin [1] showed that heavy congestion is linked to increased CO_2 emissions, as vehicles consume more fuel when idling or moving slowly. Similarly, Ravish & Swamy [4] suggest that intelligent traffic systems, such as real-time monitoring and signal optimization, can reduce emissions by improving vehicle flow. Researchers like Litman [5], Santos [6], and Azizov & Beketov [7] stress the importance of integrating emission-reduction strategies into transport planning, advocating for public transport, cycling, and electric vehicles. Jandacka et al. [2] highlight regional differences in traffic emission impacts, noting that cities like Tashkent require context-specific solutions due to unique traffic dynamics.

Traffic flow data was collected from Amir Temur and Fargona Yuli streets over a year, spanning various days and time slots (8:00–20:00). The data included vehicle types—cars, trucks, buses, and others—along with vehicle counts per hour. This data was analyzed to identify peak congestion times and assess the impact of congestion on emissions. By observing traffic flow, this study aims to understand how congestion contributes to air pollution and explore potential solutions.

3. Results and Discussion

Traffic Volume Analysis

Table 1

Traffic Volume on Amir Temur Street (vehicles/hour)

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
8:00-9:00	6,338	6,210	6,194	6,221	6,089	5,286	3,216
9:00-10:00	6,122	5,975	5,897	6,086	6,347	5,647	3,342
10:00-11:00	5,796	5,545	5,436	5,657	5,968	4,976	3,230
11:00-12:00	6,089	5,869	5,655	5,716	5,450	4,567	3,125
12:00-13:00	5,832	5,746	5,634	5,845	5,348	5,016	3,263
13:00-14:00	5,625	5,312	5,162	5,428	5,348	4,810	3,190
14:00-15:00	5,187	5,230	5,322	4,968	5,078	4,397	2,902
15:00-16:00	4,986	4,864	4,378	4,710	4,656	4,056	2,741

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16:00-17:00	5,241	5,475	5,512	5,189	5,324	4,568	3,450
17:00-18:00	5,786	6,210	5,730	5,746	6,134	5,475	2,985
18:00-19:00	6,347	6,256	6,310	6,187	6,436	5,582	4,330
19:00-20:00	6,185	6,233	6,160	6,350	6,124	5,446	3,946
Total	69,534	68,925	67,390	68,103	68,302	59,826	39,720

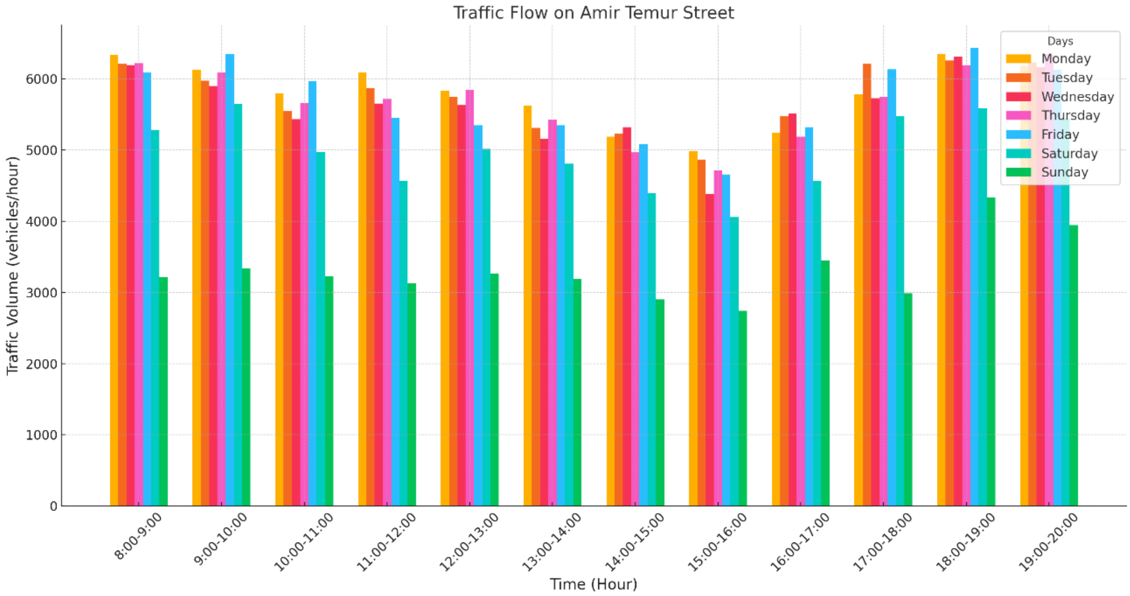

Figure 1. Traffic Flow on Amir Temur Street. ***Represents hourly traffic volume per day***

Table 2

Traffic Volume on Fargona Yuli Street (vehicles/hour)

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
8:00-9:00	4,866	5,151	5,054	5,189	5,020	4,142	2,935
9:00-10:00	5,186	5,094	5,148	5,294	5,164	4,267	3,086
10:00-11:00	5,247	4,902	5,076	5,348	4,983	4,186	2,706
11:00-12:00	4,986	4,853	4,973	5,139	5,019	4,286	3,125
12:00-13:00	4,752	4,628	4,628	4,829	4,698	4,075	3,189
13:00-14:00	4,532	4,459	4,752	4,511	4,572	3,875	3,096
14:00-15:00	4,729	4,825	4,619	4,352	4,765	3,942	2,946
15:00-16:00	5,049	5,209	4,752	4,698	4,993	3,712	2,843
16:00-17:00	5,124	5,216	5,037	4,817	5,065	3,956	2,975
17:00-18:00	5,275	5,148	5,162	5,193	5,269	4,218	3,048
18:00-19:00	5,346	5,038	5,087	5,007	5,137	4,307	3,142
19:00-20:00	5,075	5,547	5,113	5,127	4,801	4,297	3,276
Total	60,167	60,070	59,401	59,504	59,486	49,263	36,367

The data reveal that peak traffic volumes on Amir Temur and Fargona Yuli streets coincide with increased vehicular emissions during morning (8:00–10:00) and evening (17:00–19:00) hours. Passenger cars dominate, accounting for over 90% of traffic, with trucks and buses contributing significantly to emissions. These results are critical for assessing the environmental impact of urban traffic, as highlighted in [1, 2, 7].

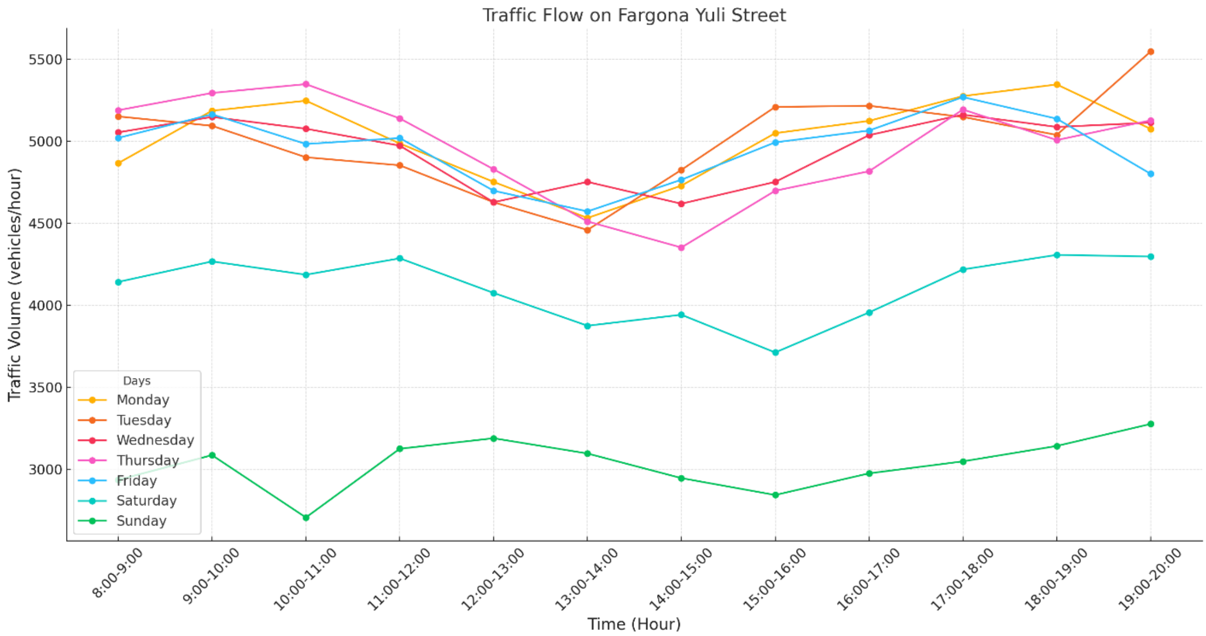

Figure 2. Traffic Flow on Fargona Yuli Street. ***Depicts hourly variation in traffic volume***

4. Conclusion

This study highlights the intersection between traffic characteristics and environmental concerns in Tashkent. Amir Temur and Fargona Yuli streets exemplify how urban traffic dynamics influence air pollution. Addressing these issues requires a multi-faceted approach, integrating sustainable transportation policies and emission reduction strategies to improve urban air quality.

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State control in monitoring the greening of city roads and streets

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Abstract: As cities continue to expand, green spaces are vital for maintaining environmental balance and improving the quality of life for residents. However, urbanization, combined with climate change, poses significant challenges to the preservation of these spaces. Local government bodies play a crucial role in ensuring the sustainability of urban green areas. Their responsibilities include planning and allocating land for parks, gardens, and green corridors, which help to mitigate the urban heat island effect, enhance air quality, and provide recreational areas. Local authorities also need to implement policies that protect existing green spaces from overdevelopment and maintain biodiversity. Moreover, local governments must foster community engagement, encouraging citizens to participate in the creation and maintenance of green areas. Public-private partnerships can further support the development of urban parks, with businesses contributing to the creation of green spaces while benefiting from improved aesthetics and environmental quality. In the face of climate change, urban green spaces offer essential ecological services. By addressing the challenges of urbanization and climate change, local governments can ensure that cities remain livable, resilient, and sustainable for future generations.

Keywords: road transport infrastructure, natural soil-climate conditions, trees, bushes, effective monitoring, monitoring of greening of avenues, parks, central streets, city roads, and streets

1. Introduction

The processes of modernization of the country are visible at every step and are bearing results. The appearance of cities and villages is changing; new settlements and smooth, modern roads are being built. Large-scale socio-economic reforms implemented in the republic in recent years and aimed at increasing the economic potential of the regions and fundamentally changing the appearance of cities and villages, in turn, require more rapid development of the road transport infrastructure.

While the greened area participates in the formation of the environment, it is primarily subject to natural soil-climate conditions and human activity [1].

State control over the greening of city roads and streets is very important to achieve sustainable urban development and create a healthier and more livable environment for residents [2]. The greening of urban areas, including urban roads and streets, is the strategic planting of trees, shrubs, and other plants to improve urban air quality, reduce heat island effects, mitigate the effects of climate change, and improve overall aesthetics. includes planting in a way. However, without effective monitoring and enforcement mechanisms, these activities cannot be implemented or maintained properly [2].

2. Research Methodology

The problems and shortcomings of landscaping and beautification in Uzbekistan were divided into several types:

First: "limited sources of financing." Improvement works are carried out at the expense of funds allocated from the local budget, or, in other words, at the expense of taxpayers' funds. In this case, land owners and land users do not have any obligation to beautify adjacent areas.

Second, "the exact area of the areas to be improved has not been determined." The condition of the passports in the areas to be improved is unsatisfactory. As a result of the analysis, it was shown that the size of the real areas to be improved is several times larger than the areas recorded in the passport.

Certain types of areas, in particular the centers of settlements (alleys, parks, and central streets), are partially beautified by improvement departments, state bodies, residents, and business entities, while the rest of the areas are neglected.

Third: "The workload is too much" The volume of work of improvement departments is 3–4 times higher than their existing capabilities, which has a negative impact on the quality of their work. According to the norm, the cleaning area of one employee in one day should be 3,500 m2, but in practice, the average load is 9,997 m2, which is almost three times higher than the established norm [3].

Fourthly, "lack of monitoring and outdated technology". There are a total of 4,522 machines on the balance sheet of the improvement departments in the republic, of which 888, or 20%, are in defective condition.

There is no mechanism for monitoring areas, which would significantly save time, material, and labor resources, as well as increase the quality of improvement work.

Fifthly, "the elements of public-private partnership, outsourcing, and public control do not exist." The lack of elements of a public-private partnership limits the possibility of attracting additional effective resources. The introduction of this partnership on the basis of specific requirements makes it possible to attract the material, technical, and labor resources of the private sector.

Not only the relevant organizations, but also the participation of the population in the greening of city roads and streets is important in the organization of landscaping works.

State control refers to the authority and responsibility of the government to control and regulate various aspects of urban planning and development, including the greening of

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city roads and streets. This is to set policies, guidelines, rules, and standards for the implementation of green infrastructure, to monitor compliance with these rules, to provide financial incentives or penalties for compliance or non-compliance, and to ensure that green initiatives are implemented as intended. may include inspections [4].

3. Result and Discussion

Monitoring the greening of urban roads and streets is a process of monitoring the condition and development of green spaces in the urban environment. This is an important task for improving the ecological situation, creating a comfortable urban environment, and preserving biodiversity. As part of the monitoring of the greening of the city streets, the study of green areas, analysis of their condition, identification of problems and improvement of plant care, and development of measures for the expansion of green areas are carried out. Another important aspect of monitoring is monitoring compliance with the rules for planting trees and shrubs in the city in order to preserve the health of plants and maintain the aesthetic appearance of the city [5].

Urban street greening monitoring involves tracking the progress and effectiveness of urban revegetation efforts by planting tree seedlings, installing green infrastructure, and implementing other sustainable practices. Methods of monitoring the greening of city streets have been developed [6].

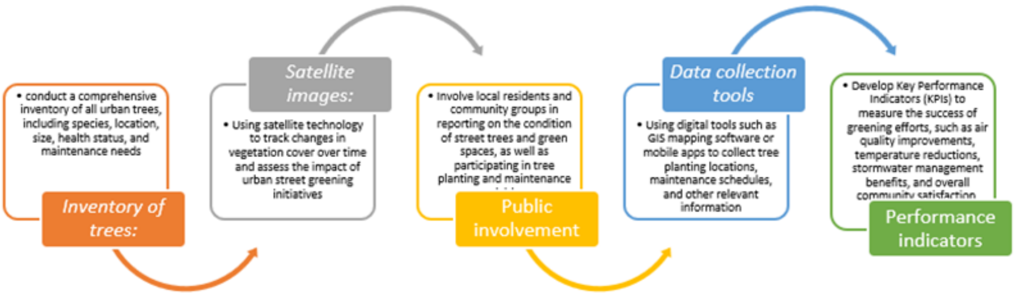

Figure 1. Monitoring scheme for greening city roads and streets

By regularly monitoring urban street greening through these and other methods, local governments can ensure that their sustainability goals are met and that cities become healthier and more vibrant places to live.

One of the main directions of state control in monitoring the greening of city roads and streets is to set specific goals and tasks for the implementation of green infrastructure. This could include setting targets for the percentage of tree shade cover, ensuring that a certain number of trees are planted each year, or providing guidelines for including green space in new developments.

Another important aspect of government control is the allocation of resources for green infrastructure projects. Public authorities can provide funding through grants or subsidies to support tree planting initiatives, green space development, or maintenance activities.

In addition to providing financial support, public authorities can also play a role in coordinating efforts among various stakeholders involved in greening city streets. This can involve working with local authorities, community groups, non-profits, private businesses, and residents to develop comprehensive greening plans and ensure everyone is working towards common goals. Public oversight can help facilitate communication between stakeholders and foster collaboration to maximize the impact of green infrastructure projects [7].

Another important task of state control is to control compliance with regulations related to the greening of city roads and streets. This may include regular inspections to ensure that trees are planted according to specifications [8], maintaining proper tree maintenance practices such as regular watering and pruning, removing invasive species, or implementing regulations related to the protection of trees during construction activities.

4. Conclusion

In short, state control should play a decisive role in controlling the greening of city streets by setting specific goals and objectives, providing financial support, coordinating efforts among stakeholders, controlling compliance with regulatory documents, applying sanctions for non-compliance, conducting inspections, collecting data on green infrastructure indicators, and assessing the effectiveness of the measures taken to achieve the goals of sustainable urban development. Overall, government oversight is critical to ensuring that cities effectively implement green infrastructure initiatives on their roads and streets. By setting mandates, supporting funding, maintaining compliance, and coordinating stakeholder engagement, state governments play a critical role in creating healthier, more sustainable, and more livable urban environments through strategic greening efforts.

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Traffic flow velocity analysis on urban roads: a study of Uzbekistan's key transportation route

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Abstract: The velocity of traffic flow is the primary indicator of road traffic performance and reflects the main goal of movement on the road. This study investigates the velocity characteristics of traffic flow on selected urban road segments in Uzbekistan, including sections of 4R21 (17–18 km), A373a (23–24 km), and 4R2 (20–21 km). By analysing modal speeds, velocity distribution curves, and cumulative density, the research highlights the impact of road conditions and traffic density on overall traffic dynamics. The findings aim to provide actionable insights for improving urban transportation systems.
Keywords: traffic flow velocity, modal speed, urban road conditions, traffic density, traffic analysis

1. Introduction

The speed of traffic flow is an essential parameter for assessing the efficiency and safety of road networks. In Uzbekistan, understanding the dynamics of traffic flow has become increasingly important due to urban expansion and the growing number of vehicles. Traffic speed is influenced by factors such as road conditions, vehicle characteristics, and driver behaviour, making it a critical focus area for transportation studies.

As emphasized by [1], "The development of road infrastructure is a crucial element in fostering economic growth and ensuring regional connectivity, requiring substantial investments and innovative approaches to modernize and maintain the transportation network."

The most objective indicator on the road is a graph showing the variation in speed along the entire route. However, plotting such a speed variation curve requires the use of a laboratory vehicle along the route. This presents certain practical challenges and, in most cases, is not feasible. Therefore, in practice, conclusions are drawn by measuring the instantaneous speed of vehicles at characteristic sections of the road when organizing traffic.

The speed of vehicles and traffic flow is largely dependent on the "Vehicle – Driver – Road – Pedestrian – Environment" (V-D-R-P-E) system. Speed selection is determined by two main criteria: minimizing travel time; ensuring traffic safety [2].

Moreover, the driver's skill, experience, psychophysical state, and purpose of travel significantly influence speed selection. Additionally, factors such as the technical condition of the vehicle, road conditions, environmental factors, and pedestrian activity play a major role in speed variability.

Traffic flow velocity serves as a critical parameter for assessing road network performance, influencing both safety and efficiency. According to Zhu et al. [3], analysing traffic velocity patterns helps identify congestion hotspots and optimize road usage. Similarly, Wang et al. [4] highlight the role of traffic flow analysis in reducing urban transport emissions. Li and Song [5] emphasize that integrating speed distributions into urban planning can improve traffic safety and efficiency. Furthermore, studies by Kim et al. [6] demonstrate the effectiveness of real-time monitoring systems in managing traffic flow and mitigating congestion.

This study examines traffic flow velocity on specific road sections in Uzbekistan. It aims to analyse modal speeds and evaluate the effects of road conditions and traffic density on the velocity of individual vehicles and overall flow.

2. Research Methodology

The process of changing the reactive power of power supply systems from symmetric three-phase primary currents to the output signal in the form of secondary rated voltage and the modeling and research of the devices and sensors involved in this process are carried out on the basis of the following algorithms:

ATPCCS devices with different physical and technical characteristics that provide the conversion of electrical energy into a secondary signal, the process of energy and signal conversion in energy sources, and the process of monitoring and modeling the structure of the control sensor:

A graphical representation of the process by which the magnetic transformer converts the magnetic flux Φ_{μ} into a three-secondary output voltage U_{out}.

This study utilized empirical formulas and observational techniques to analyse traffic flow velocity. Data were collected on three road segments using a combination of manual and automated methods. Zhu et al. [3] advocate for the use of GPS and sensor-based tools for precise traffic measurements. Wang et al. [4] emphasize the importance of employing dynamic data collection methods to capture temporal variations in traffic flow. Li and Song [5] suggest that incorporating automated video analysis enhances the accuracy of traffic studies. The research also drew from methodologies outlined by Kim et al. [6], focusing on adaptive techniques to analyse speed distributions under varying road conditions.

The maximum constructive speed of a vehicle ($Vmax$) depends on the power of its engine. Observations indicate that drivers only occasionally operate at $Vmax$ for short durations. Under good road conditions, vehicle speeds typically range between 0.7–0.85 $Vmax$, which is primarily observed on straight, level road segments.

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In practice, road conditions often include inclines, declines, minor curves in the plan, reduced visibility distances, and vertical curvature. Additionally, variations in traffic volume and composition significantly affect instantaneous speed values. Under real-world road conditions, the speed of individually moving vehicles can range from 150–120 km/h to as low as 40–30 km/h [7].

We will examine the variation in traffic flow velocity in relation to road conditions and traffic volume using examples from urban roads in Uzbekistan.

The average traffic flow velocity under different road conditions can be determined using the following empirical formula:

$$Vavg = Va \times Kd \qquad (1)$$

Where:

Va: instantaneous speed of free-flowing vehicles (km/h),

Kd: coefficient accounting for speed variations based on road conditions.

To determine the effect of traffic volume on traffic flow velocity, the following formula is used:

$$Vavg = Va \times (1 - R \times N) \qquad (2)$$

Where:

R: coefficient accounting for speed reduction due to traffic volume,

N: traffic volume (vehicles/hour).

Measuring Traffic Speed. The simplest and most convenient method for measuring traffic speed involves using a stopwatch. For this, a 50–100 m section of the road is marked. To precisely record the time of entry and exit, markers or transverse lines are placed on the road. Observers are positioned 10–15 m from the road to start and stop the stopwatch as vehicles enter and exit the marked section. The results are recorded in a prepared table [8].

Automatic Measurement Methods. The following automatic measurement methods and detectors are used to study traffic speed:

Table 1

Measurement Methods and Detectors

Measurement Method	Detector Types
Mechanical-Contact	Pneumatic, electronic contact, magnetic, vibrational, roller
Inductive-Magnetic	Electromagnetic, magnetic
Pulsed Sensing	Infrared, ultrasonic, radiolocation
Vehicle Radiation	Infrared radiation of engines, vehicle noise measurement
Photoelectric	Photography, stereography, cinematography
Television	Video recording, pulse-transmitting devices
Mobile Laboratory Vehicles	Speed measurement using various onboard apparatus

For urban roads in Uzbekistan, variations in Kd values based on surface roughness are provided in the following table:

Table 2

Surface Roughness and Kd Values [9]

Surface Roughness (km/cm)	≤80	80–120	120–170	170–220	220–300	>300
Kd Value	0.96	0.92	0.88	0.85	0.80	0.68

To measure and analyse traffic flow velocity, observations were conducted on selected road sections:

— 4R21 (17–18 km);
— A373a (23–24 km);
— 4R2 (20–21 km).

Data were collected using mechanical, optical, and automated measurement tools, including contact sensors, inductive-magnetic devices, and video-based systems (Figure 1).

Figure 1. Determining Traffic Flow Velocity

3. Results and Discussion

Speed distribution for each section was analysed. Graphs (Figure 2 and Figure 3) were created to represent density and cumulative density.

Modal Speeds:

— 4R21: 53 km/h;
— A373a: 52.5 km/h;
— 4R2: 54 km/h.

Key factors affecting velocity include:

Road Conditions: Surface quality, visibility radius, and gradients.

Traffic Composition: Variations in vehicle types and driver behaviour.

Environmental Conditions: External factors such as weather and pedestrian activity.

Velocity distribution and cumulative density curves were plotted for all sections. These curves help identify critical speed thresholds (e.g., 15%, 50%, 85%).

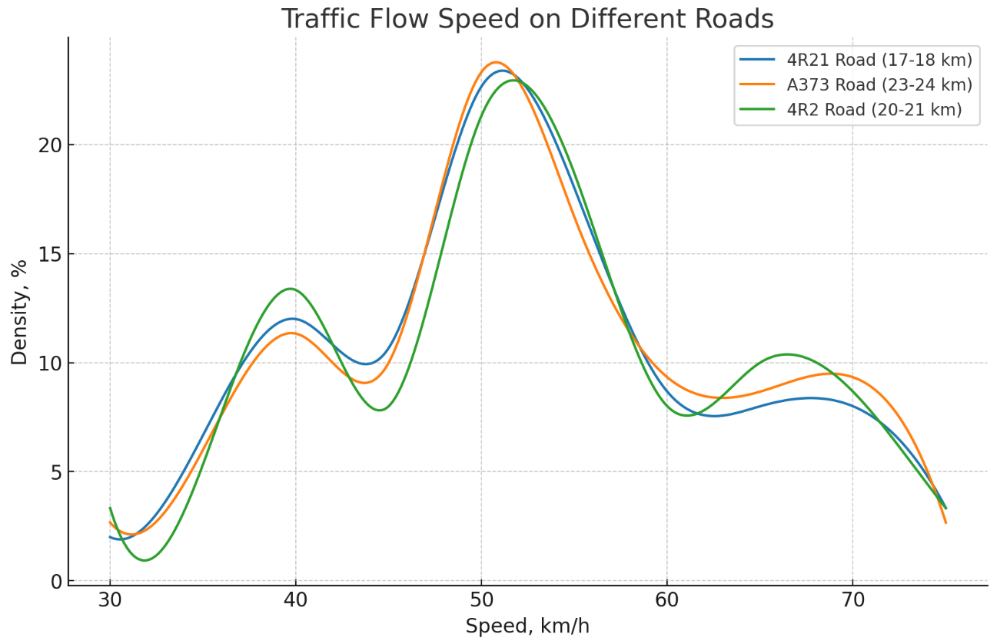

Figure 2. Speed Distribution Curve

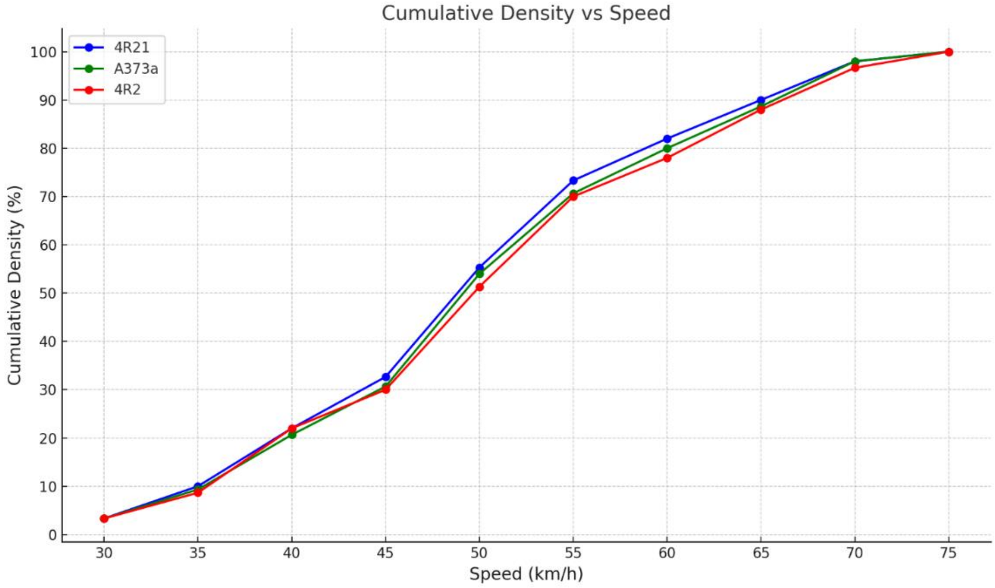

Figure 3. Cumulative Distribution Curve

Traffic flow velocity measurements on three road sections in Uzbekistan—4R21 (17–18 km), A373a (23–24 km), and 4R2 (20–21 km)—revealed variations in modal and percentile speeds.

For section 4R21, the modal speed ($Vmod$) was 53 km/h, with 15th, 50th, and 85th percentile speeds of 40 km/h, 52.5 km/h, and 63.5 km/h, respectively. Section A373a had a modal speed of 52.5 km/h, with percentile speeds of 41 km/h, 53 km/h, and 65 km/h. Section 4R2 recorded a modal speed of 54 km/h and percentile speeds of 41.5 km/h, 51 km/h, and 66 km/h.

These findings highlight the variability in traffic flow dynamics and underscore the importance of modal and percentile speeds in traffic management and road safety optimization.

4. Conclusion

This study on traffic flow speed in Uzbekistan highlights the impact of road conditions, vehicle status, driver skills, and environmental factors on movement. The derived empirical formulas offer a way to predict speed based on factors like sight distance, road smoothness, and curvature.

Experiments on sections of roads such as 4R21, A373a, and 4R2 revealed key speed values, showing how traffic density and road conditions affect vehicle speeds. The findings provide valuable insights for improving traffic management, road design, and safety in Uzbekistan.

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