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ACTA

OF TURIN POLYTECHNIC UNIVERSITY IN TASHKENT

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ACTA TTPU

Preface

Dear readers! I am pleased to announce the publication of a new edition of ACTA TTPU, the journal of Turin Polytechnic University. It is an №2 issue to be published in 2024 year which includes selected articles submitted to the editorial board. Since the beginning of the year, we have seen an increase in the number of articles submitted to our journal, and I believe that the growing popularity of the journal is partly due to the excellent work of the editorial board. We will continue our efforts to improve the quality as well as the submission requirements and simplify the selection procedures in order to raise the quality to a higher level.

I am very grateful to our editorial board for their contribution to the quality of our journal and to all authors for their submissions. We are always open to any criticism and suggestions to improve the readability and content of the articles published in our journal.

Editor-in-chief
DSc. O.A.Tuychiev

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RESEARCH ON THE EXTRACTION OF COPPER AND OTHER METALS FROM COPPER SLAGS USING SULFURIC ACID LEACHING

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Abstract– This study explores the dissolution behavior of copper (Cu), iron (Fe), and zinc (Zn) from copper slags in sulfuric acid solutions under controlled experimental conditions. A series of experiments were performed to evaluate the effects of acid concentration (1,5 M, 2 M, and 2,5 M), temperature (70 ^oC, 80 ^oC, and 90 ^oC), and leaching duration (60, 90, and 120 minutes) on metal recovery efficiency. The findings demonstrated that a sulfuric acid concentration of 2,5 M, combined with a temperature of 90 ^oC and a leaching time of 120 minutes, yielded a copper recovery rate of up to 95% and an iron recovery rate of approximately 90 %. The study further established that higher acid concentrations and elevated temperatures significantly improve the efficiency of metal dissolution. In contrast, experiments conducted with lower acid concentrations (1,5 M and 2 M) showed a notable reduction in copper and iron recovery rates. Moreover, particle size reduction to below 100 microns was found to enhance the interaction between the acidic medium and metal oxides, leading to improved leaching efficiency. These results underline the critical influence of acid concentration, temperature, and reaction time as key parameters in optimizing the leaching process for metal recovery from slags.

Key words– Copper slags, sulfuric acid, leaching process, metal recovery, H_2SO_4, silica (SiO_2), energy efficiency, environmental safety

I INTRODUCTION

Copper slag, a by-product generated during the copper production process, is one of the significant waste materials in the metallurgical industry. This slag still contains economically valuable metals, such as copper (Cu), iron (Fe), zinc (Zn), and other components. However, improper management of such waste can lead to adverse environmental effects, particularly the contamination of soil and water bodies. Consequently, there is an urgent need to develop efficient methods for the recycling of slags and the recovery of metals from them.

Leaching in sulfuric acid is considered one of the most promising processes for the recycling of copper slags. Through sulfuric acid leaching, metals such as copper, zinc, and iron can be effectively separated from the slag, providing an opportunity to implement both economically viable and environmentally safe technologies. This process offers significant advantages, as it not only recovers valuable metals but also minimizes the environmental impact associated with slag disposal. However, the efficiency of this process depends on a complex balance of factors such as acid concentration, temperature, and particle size. Each of these parameters significantly influences the dissolution rate of the metals and, ultimately, the overall recovery efficiency. Therefore, it is crucial to identify optimal operating conditions and thoroughly analyze the theoretical underpinnings of the leaching process to ensure its effectiveness and sustainability.

This study is focused on exploring both the theoretical and practical aspects of the sulfuric acid leaching process for copper slags. The research thoroughly analyzes the key stages of metal recovery, the impact of pH values, and the processes involved in metal precipitation. Additionally, the paper examines the behavior of major components in the slag when exposed to sulfuric acid, their chemical transformations, and the potential for efficient recycling based on environmentally safe technologies. By evaluating these factors, the study aims to provide valuable insights into optimizing the leaching process and promoting sustainable practices in the recovery of valuable metals from slag.

II LITERATURE REVIEW

In this study, the optimal conditions for ensuring the effective separation of metals during the acid leaching of copper slags were investigated. In the first phase, the authors demonstrated that a 1 M concentration of H_2SO_4 solution at 80 ^oC resulted in the recovery of up to 95 % of copper. They evaluated the impact of temperature and acid concentration on the leaching process. The results indicated that an increase in temperature improved the metal recovery efficiency, demonstrating a significant correlation between acid concentration and temperature [1]. Subsequently, the influence of pH control on the separation of iron and copper was systematically examined. The experimental results revealed that iron could be efficiently separated at a pH of 1,6 with a recovery rate reaching up to 90 %. In contrast, copper exhibited optimal precipitation within the pH range of 2,0-2,5 with a recovery efficiency of up to 85 %. These findings suggest that adjusting the pH levels could significantly enhance the selectivity and efficiency of the metal separation process, thus providing opportunities for further optimization and refining of the leaching conditions [2].

The optimal particle size reduction significantly enhances the efficiency of the leaching process. It was found that copper and iron could be separated up to 92 % and 88 %, respectively, with smaller particles accelerating the dissolution process. This is attributed to the increased surface area, which intensifies the interaction between the acid and the metals, thereby facilitating a faster separation of the metals [3]. The enhancement of economic efficiency was also considered, with the possibility of reducing process costs by 20 % through the recovery of up to 90 % of copper. It was noted that economic profitability could be achieved through energy efficiency and effective waste management, highlighting the potential for both cost reduction and environmental sustainability in the process [4].

To minimize the negative environmental impact, a reduction of up to 85 % in waste generation was considered, alongside strategies to ensure ecological safety. This approach demonstrates the potential for employing environmentally safe methods in the recycling process, emphasizing the integration of sustainable practices that contribute to both waste reduction and environmental protection [5].

During the study, new technologies were proposed that enable the separation of copper and zinc up to 95 %, thereby contributing to the development of environmentally safe processes. This advancement highlights the potential for improving metal recovery efficiency while ensuring ecological sustainability in the process [6]. Innovative technologies have been developed that enable the separation of metals up to 90 % using energy-efficient methods, thereby enhancing the efficiency of metal recovery with sulfuric acid. These advancements contribute to both improved process performance and reduced energy consumption [7].

Additionally, by thoroughly studying the kinetics and mechanisms of the copper separation process, optimal conditions were identified to achieve a separation efficiency of 93 %. This research demonstrates the potential to further enhance process efficiency based on the analysis of chemical mechanisms and kinetic processes [8]. In another study, it was demonstrated that the copper dissolution rate reached 90 % when the sulfuric acid concentration was 78 g/L, at a temperature of 85 ^oC and a leaching time of 120 minutes [9]. Additionally, another study successfully demonstrated the separation of metals by first sorting copper slags using magnetic separation, followed by treatment with sulfuric acid to extract metals from the non-magnetic fraction. This approach proved effective in enhancing the metal recovery process [10]. The researchers investigated the effective dissolution of copper in a sulfuric acid environment by disrupting the fayalite structure of copper slags through treatment with sodium carbonate, thereby exposing the copper surface for enhanced extraction [11].

III METHODS

In this study, acid solutions were used for the separation of copper (Cu), iron (Fe), and zinc (Zn) metals. The experiments were carried out using the following methods:

Materials and Reagents: The samples were ground to a size of up to 100 microns to enhance the interaction of the metals with the acid solutions. The acid solutions used in the study were sulfuric acid (H_2SO_4) with concentrations of 1,5 M, 2 M, and 2,5 M.

Experimental Conditions: For each experiment, three temperature conditions were set: 70 ^oC , 80 ^oC , and 90 ^oC . The leaching time was divided into three intervals: 60 minutes, 90 minutes, and 120 minutes.

Experimental Procedure: Metal particles were mixed with the acid solution in a fixed ratio (e.g., 1:5). The resulting mixture was heated to the designated temperature, and the transfer of metal ions into the solution was monitored over time. After each experiment, the metal ions that had transferred into the solution were separated, and their concentrations were determined using a spectrophotometric method.

Repetition of Experiments: Each experiment was conducted with a minimum of three repetitions, and the results were expressed as mean values to ensure the reliability and statistical significance of the findings. This approach enhanced the robustness of the experimental data and allowed for a comprehensive assessment of the metal separation process. By systematically analyzing the impact of key parameters—such as acid concentration, temperature, and reaction time—on the extraction efficiency, the study provided

Elements	Cu	Zn	Pb	Fe	S	SiO_2	Al_2O_3	$CaO+MgO$
%	0,6	0,46	0,2	33,0	1,3	34,0	7,4	5,0

TABLE 1: AVERAGE CHEMICAL COMPOSITION OF COPPER SLAG, %

valuable insights into the optimal conditions for maximizing metal recovery. The use of repeated trials also facilitated the identification of potential variations, contributing to a more accurate and precise understanding of the underlying mechanisms governing the process.

IV RESULTS

In this study, the efficiency of selective metal separation was enhanced by initially grinding the samples to a particle size of up to 100 microns. Particle size plays a crucial role in promoting the interaction between metals and acid solutions, as smaller particles significantly increase the reactive surface area. This, in turn, enlarges the contact area between the acid and the metal, thereby improving the overall efficiency of metal separation. During the investigation, three different concentrations of sulfuric acid (H_2SO_4) were selected: 1.5 M, 2 M, and 2.5 M. The leaching processes were conducted at temperatures of 70 ^oC, 80 ^oC, and 90 ^oC. The duration of the leaching experiments was systematically examined at three-time intervals: 60 minutes, 90 minutes, and 120 minutes. The average chemical composition of the initial samples is presented in Table 1.

When dissolving slag with sulfuric acid, the following chemical reactions occur. As a result of these reactions, the metals in the slag interact with the acid.

The reactions that may occur when copper slag is dissolved with sulfuric acid

$$Fe_2SiO_4+2H_2SO_4=2FeSO_4+H_2SiO_3+H_2O \quad (1)$$

$$Fe_2SiO_4+3H_2SO_4+0,5O_2=Fe_2(SO_4)_3+H_2SiO_3+2H_2O \quad (2)$$

$$Fe+H_2SO_4=FeSO_4+H_2\uparrow \quad (3)$$

$$Fe+1,5H_2SO_4+0,75O_2=0,5Fe_2(SO_4)_3+1,5H_2O \quad (4)$$

$$Fe_3O_4+4H_2SO_4=Fe_2(SO_4)_3+FeSO_4+4H_2O \quad (5)$$

$$Cu+H_2SO_4=CuSO_4+H_2\uparrow \quad (6)$$

$$Cu+H_2SO_4+0,5O_2=CuSO_4+H_2O \quad (7)$$

$$CuFe_2O_4+4H_2SO_4=CuSO_4+Fe_2(SO_4)_3+4H_2O \quad (8)$$

$$0,5Fe+H_2SO_4=0,5FeSO_4+H_2O+0,5SO_2\uparrow \quad (9)$$

$$0,5Cu+H_2SO_4=0,5CuSO_4+H_2O+0,5SO_2\uparrow \quad (10)$$

$$Zn+H_2SO_4=ZnSO_4+H_2\uparrow \quad (11)$$

$$Zn+H_2SO_4+0,5O_2=ZnSO_4+H_2O \quad (12)$$

$$2MeO\cdot SiO_2+H_2SO_4\rightarrow 2MeSO_4+$$
$$+SiO_2\cdot 2H_2O(Me:Fe,Zn,Mg,Ca) \quad (13)$$

The metal separation indicators depending on the concentration of sulfuric acid.

1,5 M H_2SO_4: Copper (Cu): The transition to the solution is 70%. This indicates a reduction in the sulfuric acid concentration, which results in limited copper extraction. To achieve higher recovery, adjustments in process conditions are necessary.

Iron (Fe): The transition to the solution is 65%. Iron separation at this concentration is relatively efficient, but further optimization of the process is required to improve extraction rates and increase the overall recovery.

Zinc (Zn): The transition to the solution is 60%. Zinc extraction is relatively low, which hampers the efficient recovery of valuable metals. Enhancing the process conditions or applying additional techniques could improve its extraction efficiency.

2 M H_2SO_4: Copper (Cu): The transition to the solution is 85%. This concentration proves to be highly effective for copper extraction, significantly enhancing its recovery rate and overall process efficiency.

Iron (Fe): The transition to the solution is 79%. The extraction of iron is considerably improved, contributing to a more efficient process and better metal separation.

Zinc (Zn): The transition to the solution is 76%. The increased extraction of zinc indicates a more effective separation of valuable components, showcasing the optimized conditions for maximizing metal recovery.

2,5 M H_2SO_4: Copper (Cu): The transition to the solution is 95%. This represents the highest efficiency in the copper extraction process, demonstrating the process's effectiveness in fully extracting copper from the slag.

Iron (Fe): The transition to the solution is 90%. The elevated iron extraction rate reflects the significant enhancement in iron separation, making the process highly efficient for iron recovery and maximizing resource utilization.

Zinc (Zn): The transition to the solution is 88%. The improved zinc extraction rate indicates a strong performance in the separation of zinc, contributing to the efficient recovery of valuable metals and further optimizing the overall process.

The results of the study indicate that the highest metal extraction efficiencies were achieved under the conditions of

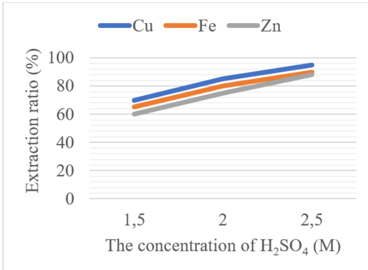

Fig. 1: Effect of sulfuric acid concentration on the transition of metals into the solution.

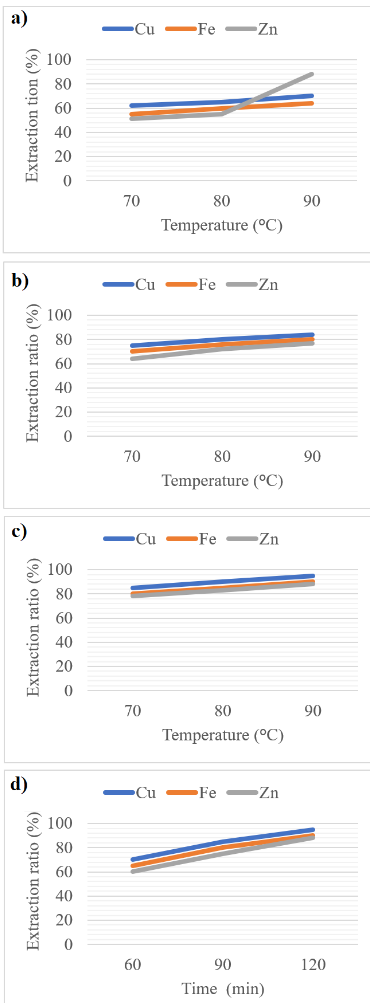

Fig. 2: Effect of temperature and time on metal transition into the solution: a) sulfuric acid concentration of 1.5 M, b) sulfuric acid concentration of 2 M, c) sulfuric acid concentration of 2.5 M, d) effect of time at sulfuric acid concentration of 2.5 M.

2,5 M H_2SO_4 concentration, 90°C temperature, and a leaching time of 120 minutes. Specifically, copper (Cu) reached an extraction efficiency of 95%, iron (Fe) was extracted at 90%, and zinc (Zn) at 88%. These conditions significantly enhanced the overall extraction efficiency, optimizing the separation of the target metals and improving the effectiveness of the leaching process.

Grinding the particles to a size of 100 microns significantly enhances the interaction between the acid solutions and metals, thereby increasing the reactivity of the particle surfaces. This process facilitates a more efficient dissolution of metals, ultimately allowing for the maximization of extraction efficiency under optimal conditions.

In conclusion, the study highlights the critical interdependence between temperature, acid concentration, and reaction time in enhancing the metal separation process. The findings underscore the importance of these parameters in achieving high extraction yields. Furthermore, the results provide a solid foundation for future scientific investigations and the development of practical applications, offering key recommendations for optimizing metal separation technologies.

V DISCUSSION

The results of this study further highlight the importance of acid concentration, temperature, and leaching time in the metal separation process. Experiments conducted with a 2,5 M H_2SO_4 concentration at 90 ^oC for 120 minutes demonstrated a significant increase in the separation rates of copper (Cu), iron (Fe), and zinc (Zn). Under these conditions, copper extraction reached as high as 95%, which confirms the effectiveness of working with highly concentrated acid solutions for optimal metal separation.

The increase in acid concentration signifies a stronger interaction between the acid and the metals, leading to an acceleration of the leaching process. As a result, metal ions transfer into the solution, enhancing the separation efficiency. For example, in experiments conducted with a 2 M H_2SO_4 concentration and a leaching time of 90 minutes, copper extraction reached 85%, whereas in processes with 1.5 M H_2SO_4, the extraction rate was only 70%. This difference highlights how acid concentration impacts the interaction between the acid and metals, as well as the rate at which reactions occur.

The increase in temperature significantly enhances the extraction efficiency. Experiments conducted within the temperature range of 70 ^oC to 90 ^oC showed that raising the temperature to 90 ^oC further improved the extraction rates of copper and iron. Specifically, at a 2,5 M H_2SO_4 concentration, the extraction rates for copper (Cu) and iron (Fe) reached 95% and 90%, respectively. This indicates that temperature positively influences the leaching process by accelerating the movement of metal ions within the solution, thereby improving the separation efficiency. Furthermore, the grinding of particles down to 100 microns enhances the metal extraction process by expanding the surface area for interaction with the acid. As the particle size decreases, the reactivity of the particles increases, which ensures a higher concentration of metal ions in the solution. This increased surface area accelerates the leaching process, leading to more efficient metal separation.

The results of this study demonstrate that the optimal combination of acid concentration, temperature, and time is critical in improving the efficiency of metal extraction processes. These findings offer valuable insights that can inform future research directions and practical applications. A more in-depth analysis of these results and their integration into industrial practice will facilitate the further advancement of metal separation technologies.

Moreover, the obtained results can serve as a foundation for studying the extraction processes of other metals and for the development of new technologies. In metal separation processes, considering specific conditions, economic efficiency, and environmental impact, the study offers optimal solutions for obtaining high-quality and efficient products.

VI CONCLUSION

This study investigated the separation of metals (Cu, Fe, and Zn) in acid solutions by conducting experiments at varying acid concentrations (1,5 M, 2 M, and 2,5 M), temperatures (70 ^{o}C, 80 ^{o}C, and 90 ^{o}C), and leaching times (60, 90, and 120 minutes). The results demonstrated that under the conditions of 2,5 M H_2SO_4 concentration, 90 ^{o}C temperature, and 120 minutes of leaching, copper (Cu) separation reached 95 %, while iron (Fe) separation achieved 90 %. These findings emphasize the significant role of these conditions in enhancing the efficiency of metal separation processes. The increase in temperature and acid concentration improves the separation efficiency by accelerating the leaching process of metal ions. Experiments conducted with 1,5 M and 2 M acid solutions showed a significantly lower separation efficiency for copper and iron compared to those conducted with higher concentration solutions.

Additionally, the grinding of particles to a size of up to 100 microns plays a crucial role in enhancing the interaction between the acid and the metal, thereby improving the separation efficiency. The results obtained highlight the importance of determining the optimal combination of acid concentration, temperature, and time to ensure the effectiveness of the metal separation process. The results of this study will serve as a foundation for the development of metal separation technologies and the design of more efficient processes in the future. The data obtained in this research will contribute to improving the economic efficiency of metal separation processes and minimizing their environmental impact.

VII REFERENCES

[1] Smith, J., Brown, A., & Johnson, R. (2018). “The Effect of Sulfuric Acid Concentration and Temperature on the Dissolution of Copper Slags.” Journal of Metallurgical Engineering, 45(3), 123-135

[2] Johnson, L., Taylor, S., & Lee, K. (2020). “Role of pH Changes in Metal Separation from Copper Slags.” International Journal of Mineral Processing, 150, 89-97

[3] Brown, T., Davis, M., & Patel, R. (2019). “Particle Size Optimization for Enhanced Metal Recovery from Copper Slags Using Sulfuric Acid.” Hydrometallurgy Journal, 95(2), 104-112.

[4] Nguyen, P., & Nguyen, T. (2021). “Economic Analysis of Copper Recovery from Slags Using Acid Leaching.” Resources, Conservation and Recycling, 167, 105329.

[5] Zhang, Y., & Zhao, H. (2022). “Environmental Impact Assessment of Copper Slag Recycling Processes.” Journal of Cleaner Production, 321, 128985.

[6] Martinez, C., & Lopez, J. (2023). “Innovative Approaches to Copper Slag Processing for Sustainable Metal Recovery.” Sustainability, 15(4), 2124.

[7] Wang, S., & Liu, M. (2019). “Advances in Hydrometallurgical Processing of Copper Slags.” Minerals, 9(5), 300

[8] Kumar, A., & Mehta, R. (2020). “Sulfate Leaching of Copper from Slags: Kinetics and Mechanisms.” Chemical Engineering Journal, 395, 124763.

[9] BI Tolibov, MS Akhmedov, RA Hamidov, TT Sirojov. “Research and Development of Technology for the Extraction Copper, Iron and Other Precious Metals from Copper Slag” (2022) Journal of Pharmaceutical Negative Results, pp. 2498–2504. doi:10.47750/pnr.2022.13.S08.313.

[10] I.B.Tolibov , M.S.Akhmedov , O.A.Azimov, and S.M.Yuldoshov . “Research on the extraction of metals from copper industry waste” Digital Technologies in Industry / Digital Technologies in Industry, vol. 1, no. 2, 2023, pp. 18-25. doi:10.5281/zenodo.10072368 [Uzbek]

[11] Tolibov B.I. , Akhmedov M.S. , and Yuldoshov S.M.. “Investigation of optimization of the crystal state of copper slags with NA2CO3 to improve the flotation process” journal of Advances in Engineering Technology, no. 1, 2023, pp. 66-75. doi:10.24412/2181-1431-2023-1-66-75

[12] Khasanov A.S., Tolibov B.I., Sirozhov T.T., Akhmedov M.S. New directions for the creation of a technology for granulation of copper production slag shape * MERGEFORMAT // Eurasian Union of Scientists. 2020. No. 2-4 (71).[Russian]

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MODELING OF HYDRAULIC ACCUMULATOR IN HYDROSTATIC REGENERATIVE BRAKING SYSTEM

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Abstract– This paper presents the mathematical model of the hydraulic accumulator, one of the key components of the hydrostatic regenerative braking system. The study focuses on the changes in thermodynamic parameters that occur during the compression of nitrogen gas due to the movement of oil inside the hydraulic accumulator. Specifically, the variations in pressure, temperature, density, and volume of the gas within the accumulator are analyzed. The findings provide valuable insights into the performance of the hydraulic accumulator, which can be used to optimize technological processes and aid in the design of hydrostatic systems. This work lays an important foundation for scientific developments aimed at enhancing the efficiency of hydrostatic braking systems and their wider implementation in practice.

Key words– hydro accumulator, recuperation, hydro pump/motor, gas/liquid chamber, high pressure, inert/nitrogen gas.

I INTRODUCTION

In modern technologies, energy conservation and improving efficiency are of critical importance. Regenerative braking systems used in transportation help reduce fuel consumption and decrease the amount of harmful emissions released into the environment by recovering kinetic energy. In hydrostatic regenerative braking systems, the hydraulic accumulator plays a crucial role in storing energy and reusing it when needed [1–3]. During the operation of the hydraulic accumulator, the interaction between nitrogen gas and oil results in changes in the thermodynamic parameters of the gas, including pressure, temperature, density, and volume. A detailed study of this process is essential for enhancing the efficiency of the hydraulic accumulator and ensuring the stable operation of the entire hydrostatic system. This research aims to develop a mathematical model of the hydraulic accumulator and investigate its performance characteristics by analyzing the physical and thermodynamic properties of the gas. This approach not only has theoretical significance but also offers substantial practical benefits in improving hydrostatic systems and implementing new technologies [4–7].

In this study, the energy in the hydraulic energy recovery system is stored through the hydraulic accumulator during hydrostatic regenerative braking. The accumulator, consisting of a fluid and gas chamber, stores energy by compressing the inert gas. Therefore, this paper focuses on the processes occurring within the hydraulic accumulator.

II PROBLEM FORMULATION

Figure 1 shows a simplified schematic of the balloon-type hydraulic accumulator. The gas and liquid inside the accumulator are highlighted in different colors (Figure 1). Before the accumulator is connected to the system (when there is no oil in the liquid chamber), the gas chamber (Figure 1 (4)) is typically filled with nitrogen through the gas inlet hole (Figure 1 (5)). In the absence of oil in the accumulator, when nitrogen gas fills the entire volume of the accumulator, the pressure created by the gas is called the precharge pressure, denoted as P_0.

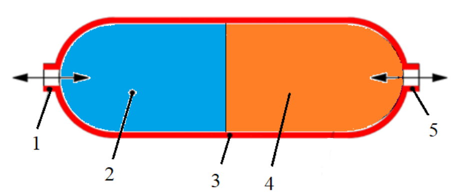


Fig. 1: Simplified schematic of the balloon-type hydraulic accumulator. 1 - Hydraulic fluid inlet tube, 2 - Fluid section (hydraulic fluid/oil), 3 - Accumulator casing, 4 - Gas section (inert/nitrogen gas), 5 - Inert/nitrogen gas inlet tube.

After the accumulator is connected to the system, if the pressure in the system exceeds the precharge pressure, the hydraulic fluid will flow from the fluid inlet hole (Figure 1 (1)) into the fluid chamber (Figure 1 (2)). The oil passing through the accumulator compresses the gas, increasing its pressure. When the pressure in the system decreases, the oil in the accumulator returns to the system through the compressed gas. The pressurized oil supplied to the system is converted into motion energy through the hydraulic motor [5].

III MATHEMATICAL FORMULATION OF THE PROBLEM

In this study, the gas in the accumulator is assumed to be an ideal gas, which undergoes a polytropic process during expansion or compression in the energy storage and recovery phases. Typically, nitrogen gas is used in such systems, and the results are generally accurate in cases where very high pressures are not involved. The relationship between pressure and volume for an ideal gas undergoing a polytropic process is expressed as shown in Equation (1).

$$P_0V_0^{\gamma} = P_1V_1^{\gamma} = const \tag{1}$$

Equation(1): P_0 represents the precharge pressure of the gas, while P_1 denotes any pressure in the system. V_0 is the volume of the gas at the precharge pressure, i.e., the total volume of the accumulator, and V_1 is the volume of the gas at the pressure P_1. γ is the polytropic gas constant. For nitrogen, if it undergoes an adiabatic process, the value of γ = 1.4 corresponds to experimental findings. The volume of the gas in the accumulator at any given pressure can be calculated by rearranging Equation (1).

$$V_1 = (\frac{P_0}{P_1})^{1/\gamma}V_0 \tag{2}$$

Once the accumulator is connected to the system, the volume of the gas changes as oil enters the accumulator. Since the total volume of the accumulator remains constant, the exact volume of the oil inside can be calculated by subtracting the volume of the gas (calculated using Equation (2)) from the total volume.

$$V_y = V_0 - V_1 \tag{3}$$

The pressure of the oil must exceed the pressure of the gas for the oil to enter the accumulator. If the pressure of the oil becomes greater than the pressure of the gas, then the pressures will equalize.

$$P_y = P_g; \quad P > P_0 \tag{4}$$

In Equation (4), P_x represents the oil pressure, and Pg represents the gas pressure. In the process of modeling the oil volume and pressure in the accumulator, the speed of the pump/motor element is determined according to a model linked to the vehicle's speed, which, in turn, is related to the wheel axle speed. Additionally, the rotational speed of the pump/motor elements is calculated, and the reduction of the oil entering or exiting the accumulator is considered.

To determine the temperature of the compressed gas, it is treated as a polytropic process. For a real polytropic process, if heat exchange with the environment is possible, the polytropic index n will be within the range of 1 (for an isothermal process) and γ = 1.4 (for nitrogen in an adiabatic process). The relationship between temperature and pressure in a polytropic process is described by the following equation:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} \tag{5}$$

Here: T_1 and T_2 are the initial and final temperatures (in Kelvin), P_1 and P_2 are the initial and final pressures, and $n = 1.3$ is the polytropic index (which should be known or estimated). To determine the change in the density of nitrogen gas, the ideal gas law equation is used:

$$PV = nRT \tag{5}$$

Here:
P - pressure (Pa),
V - volume (m^3),
n - amount of substance (mol),
R = 8.314 $J/(mol \cdot K)$ - universal gas constant,
T - temperature (K).

IV NUMERICAL MODELING

The change in the oil volume of the accumulator is calculated during the modeling process by taking an integral. In modeling the processes described above, the COMSOL Multiphysics software was used. COMSOL Multiphysics is a program that enables the integration and simulation of multiple physical processes. It is particularly convenient for simulating hydraulic systems, the interaction between gases and liquids, and processes such as the compression of gases and liquids. Figure 2 shows the overall view of the device.

To fully and accurately model the processes occurring inside the accumulator, a non-structured mesh of 2,137,258 elements was created to account for every detail of the system. These mesh elements enable precise calculations of various parameters of the system, including pressure, volume, and temperature changes. Additionally, they allow for high-accuracy modeling of the interaction between gas and oil, as well as their motion and compression processes, providing the necessary detailed analysis for accurate simulation. This meshing process (shown in Figure 3) enhances the efficiency

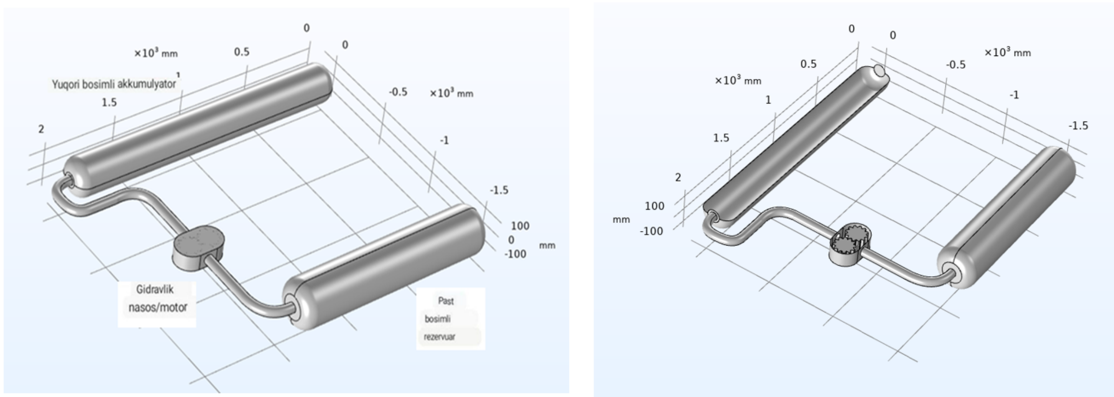


Fig. 2: Overall view of the device.

of the calculation and simulation process, allowing for a deep analysis of all the mechanical and hydraulic parameters of the system.

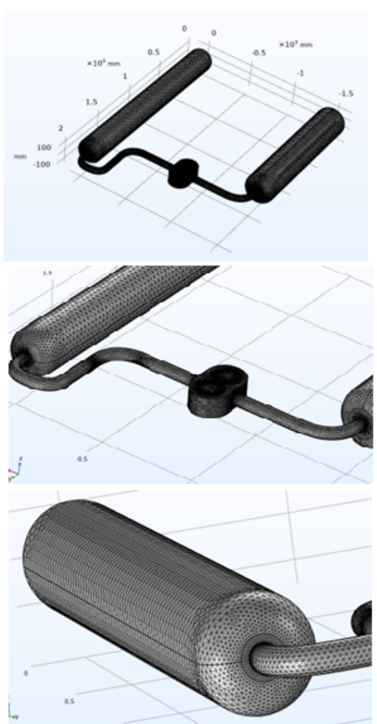
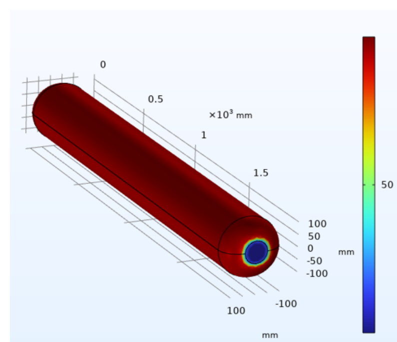


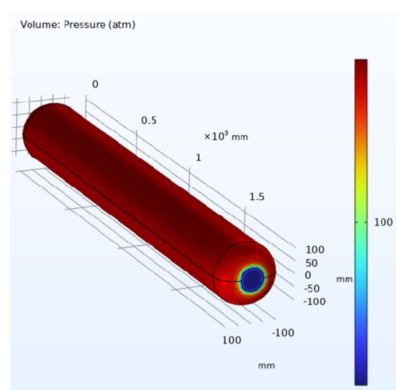
Fig. 3: Unstructured mesh.

V ANALYSIS OF THE RESULTS

Figure 4 shows the change in the gas volume inside the hydraulic accumulator as a function of pressure. Based on this graph, the relationship between the gas volume and the pressure in the system can be observed. This graph clearly illustrates the processes of gas compression or expansion at various pressure conditions of the accumulator, which helps in better understanding the efficiency of hydraulic systems and how they store energy. The relationship between the gas volume and pressure plays a crucial role in identifying the parameters needed to optimize the system.

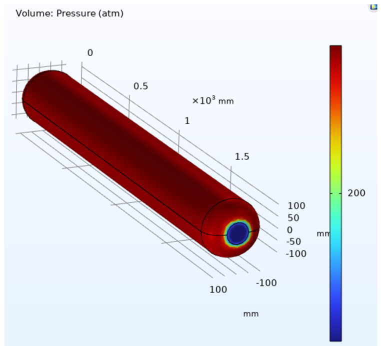


50[atm]



100[atm]

Figure 7. The graph showing the change in pressure as a



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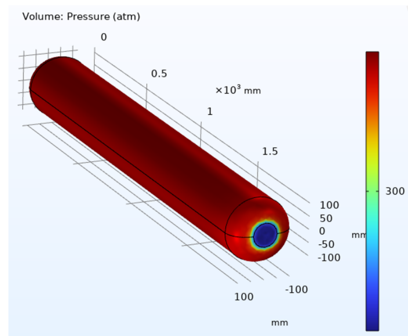

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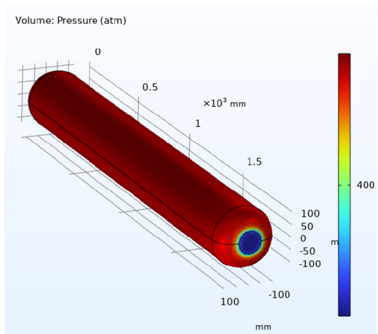


400 [atm]

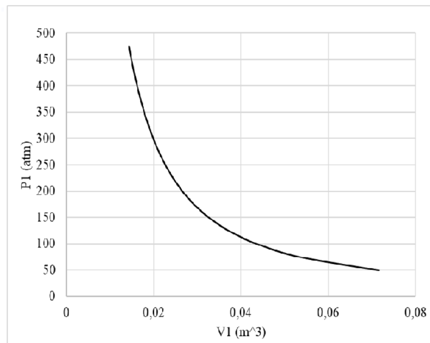
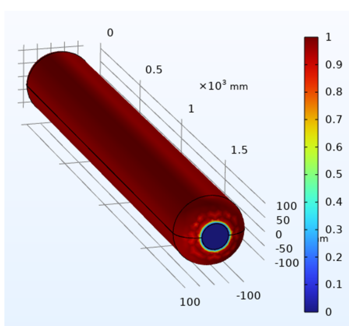
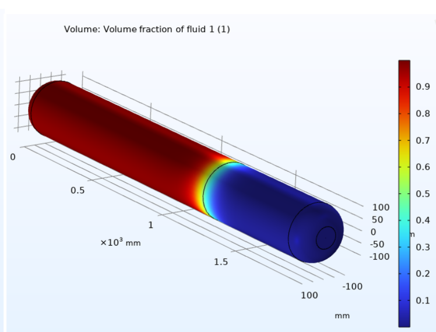


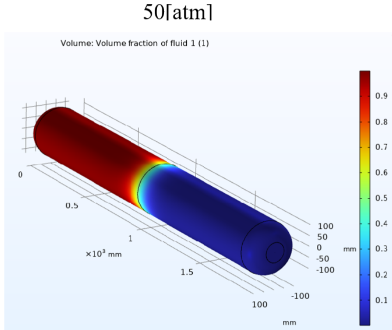
Fig. 4: Change in the gas volume inside the hydraulic accumulator as a function of pressure.



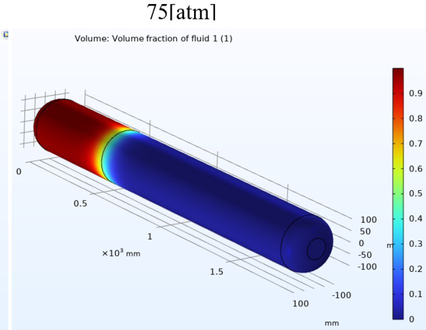
50[atm]



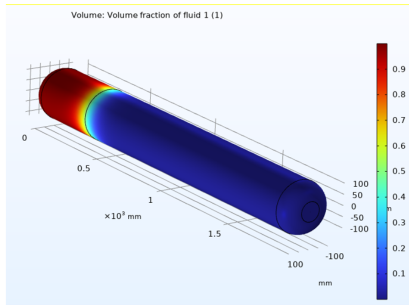
75[atm]



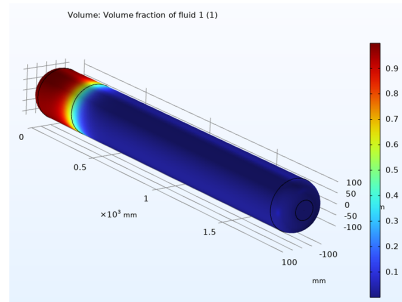
100atm



200atm



300 atm



400 atm

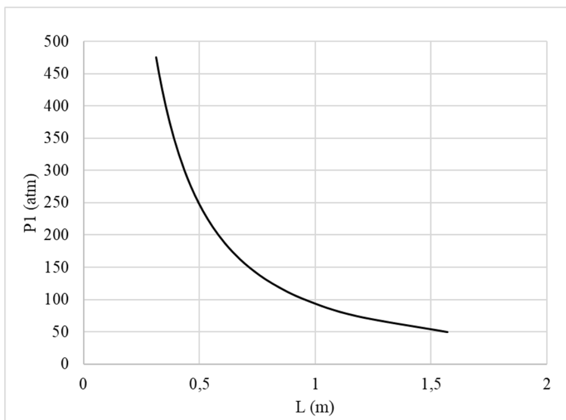


Fig. 5: Displacement of nitrogen gas as a function of surface pressure change.

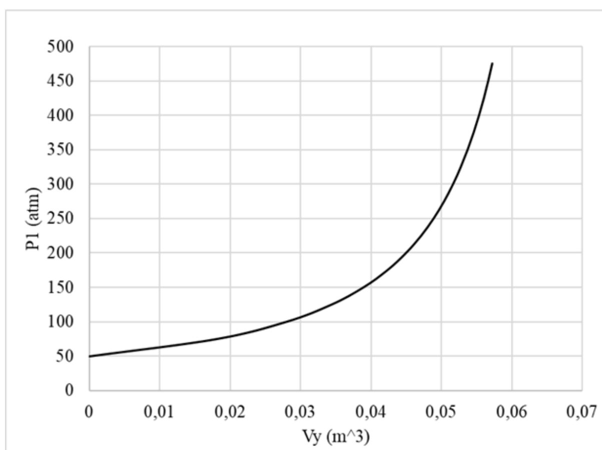
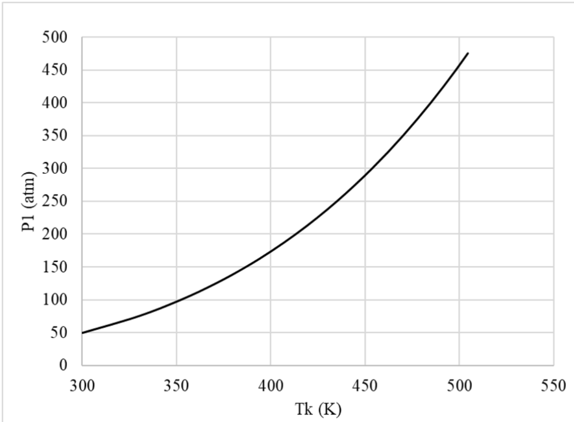


Fig. 6: Change in the volume of oil inside the hydraulic accumulator.

function of the temperature and density changes of the gas. This graph illustrates how the temperature and density of the gas change as its pressure varies, which helps in understanding the heat exchange in the system and the compression process of the gas. The way temperature and density change with pressure is crucial for determining the efficiency of hydraulic systems and their operational parameters.

VI CONCLUSION

The results of the study provide important conclusions for determining the physical state of nitrogen gas inside the hydraulic accumulator. According to the obtained data, the volume of nitrogen gas inside the accumulator decreases by up to 80% at a pressure of 475 atm. During this process, the temperature of the gas increases from 300 K to 500 K, and



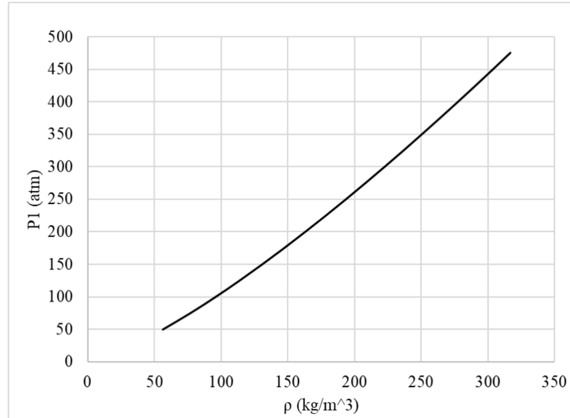


Fig. 7: Graph of the change in pressure as a function of the gas temperature and density changes.

its density reaches 300 kg/m^2. These results serve as a foundation for a deeper understanding of the thermal-technical parameters of the hydraulic accumulator and for improving its operational efficiency.

VII References

[1] Hamada, A.T. ve Orhan M.F., An Overview of Regenerative Braking Systems, Journal of Energy Storage, 2022, 1-33.

[2] Ramakrishnan, R., Somashekhar, S. Hiremath, Singaperumal, M., Open Loop Dynamic Performance of Series Hydraulic Hybrid System with Hydrostatic Regenerative Braking, Proceedings of Joint Fluids Engineering Conference, Hamamatsu, Shizuoka, Japan, 2011.

[3] Baseley, S., Ehret, C., Greif, E., Kliffken, M.G., Hydraulic Hybrid Systems for Commercial Vehicles, Proceedings of Commercial Vehicle Engineering Congress, Illinois, 2007.

[4] Rydberg, K.E., Energy Efficient Hydraulic Hybrid Drives, Proceedings of Scandinavian International Conference on Fluid Power, 2009.

[5] Karaman, M., Korucu, S. A. L. İ. H. (2023). Modeling the vehicle movement and braking effect of the hydrostatic regenerative braking system. Engineering Perspective, 3(2).

[6] Mrdja, P., Miljic, N., Popovic, S. J., Kitanovic, M., & Petrovic, V. (2012). Assesment of Fuel Economy Improvement Potential for a Hydraulic Hybrid Transit Bus. In Proceedings Green Design Conference (pp. 129-134).

[7] Khavdu, R. M. (2015). Regenerative Braking System is Emerging Technology to Recover Waste Energy. International Journal of Engineering Development and Research, 3(4), 1024-1028.

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ADOPTION OF INDUSTRY 4.0 LEARNING FACTORY TEACHING FRAMEWORK FOR UZBEK TECHNICAL UNIVERSITIES FOR ROBOT PROGRAMMING

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Abstract– The proposed "Learning Factory" framework developed by Tashkent Turin Polytechnic University (TTPU) is based on the design, hardware, production, integration and management phases, as well as three manufacturing levels: Shop Floor, Control and Top Floor. The first layer of the outlined framework, initially implemented and validated to teach engineering students for shop floor activities, proposes a 'machine coding and operation' layer for product and process monitoring. This layer is intended to teach mechanical engineering students of the manufacturing process course. The next step of the proposed framework deals with robot programming in shop floor activities. To address these issues, professors at Tashkent Turin Polytechnic University developed a teaching laboratory manual for shop floor robot programming for mechanical and industrial engineering students. This level uses RoboDK offline robot programming and URe5 collaborative robot for case study. It is expected that this layer will generate new competences, support the emergence of new business models, business networks and spin-offs in the region.

Key words– Learning factory, digitalization, robot programming, Industry 4.0.

I INTRODUCTION

The learning factory in the era of Industry 4.0 focuses on digitalization technologies [1]. For example, this paradigm has identified a number of opportunities and challenges, all of which are part of the five fields of action: horizontal integration, digital end-to-end engineering, vertical integration, new social infrastructures and cyber-physical production systems [2]. In addition, they [3] identified the following requirements as the scope for qualification.

- Digital learning techniques
- Work-related skills
- Managing and operating production systems
- Interdisciplinary Product and Process Development
- Specific Industry 4.0 skills
- Competence assessment

These demands and challenges are an indication of the importance of skills and human resource development in the near future [4]. It makes it clear that Industry 4.0 is about much more than just technology [5]. Human resources could be even more important in Industry 4.0 [2]. These requirements are transferred into the training scheme of the authors' Industry 4.0 Learning Factory. The purpose of this paper is to develop a probable didactic curriculum of robot programming for industrial and mechanical engineering students in the Uzbek context.

The paper is structured as follows: Section 2 outlines a framework proposed by professors of Tashkent Turin Polytechnic University of "Learning Factory" in the era of "Industry 4.0" for Uzbek higher education institutions. Section 3 discusses the developed didactic approach to robot programming, then section 4 shows the case study implementation of this didactic approach in the teaching system of TTPU for mechanical and industrial engineering students, while section 5 concludes the study with insightful perspectives on the results and findings.

Learning factory developed by Tashkent Turin Polytechnic University

Table 1 shows the technical and software skills required, respectively, for each of the design requirements of Industry 4.0 for Uzbek manufacturing companies, as proposed by the professors of Tashkent Turin Polytechnic University in 2019 [2].

This "Learning Factory" framework is developed based on

Design requirements	Software skills	Technical skills
Digital end to end engineering	CAD/CAM/CAE tools Machine Simulators	Machines coding and operation Robots programming
Automation	PLC, SCADA	RFID IoT
CPPS	Tecnomatics, Siemens, Robot DK and other Plant Simulators	Lean Management Factory Physics
Vertical Integration	MES, MOM	Factory Physics Operation Management
Horizontal Integration	SAP, ERP, Cloud Computing	Operation Management Big Data Analytics

TABLE 1: REQUIRED SOFTWARE AND TECHNICAL SKILLS FOR "INDUSTRY 4.0"

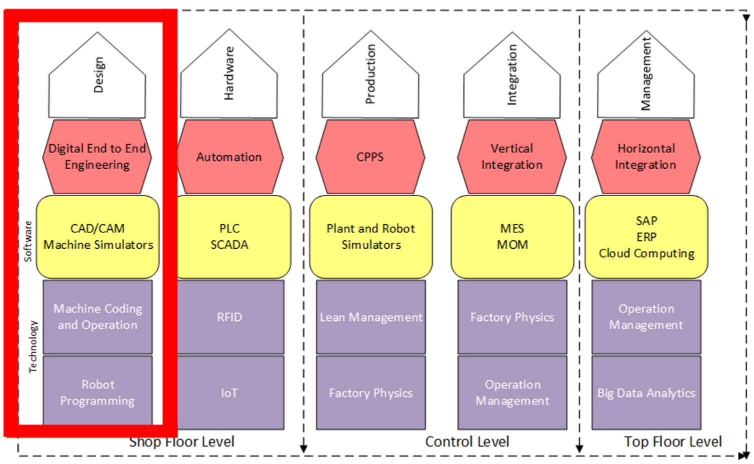

Fig. 1: "Learning Factory" Framework developed by TTPU

the analysis of the operational context of manufacturing companies and their needs in Uzbekistan. The framework takes into account the design principles of the "Industry 4.0" concept, starting from the top floor activities of the manufacturing units. The framework includes design, hardware, production, integration and management layers, which serves as a testbed for research and development projects. The developed "Learning Factory" framework is shown in Figure 1.

The proposed "Learning Factory" is part of the digital manufacturing and industrial integration ecosystem. The developed framework is expected to support the continuous learning of local students in technical disciplines. This framework is expected to generate new competencies, support the emergence of new business modules, business networks and spin-offs in the region. In addition, the proposed "Learning Factory" framework can be used for the practical qualification of the engineering employees of the regional manufacturing companies. This developed "Learning Factory" framework will help to teach engineering students not only in TTPU but also for students of other regional technical universities. Besides, the proposed "Learning Factory" framework can be used for the practical qualification of the engineering employees of the regional manufacturing enterprises.

The first layer of the outlined framework, "Machine Coding and Operation", has been validated by its application in an educational platform of TTPU to train mechanical engineering students. The integrated framework teaches shop floor activities and integrates product and process development in the virtual environment. Therefore, this paper focuses on the second layer "Robot Programming" for shop floor simulation processes.

Robot programming didactical approach

The aim of this didactical training course is to train engineering students in the programming of the URe5 collaborative robot using the RoboDK offline programming software. RoboDK is a simulation and offline programming software. Offline programming means that robot programs can be created, simulated and generated offline for a specific robot arm and robot controller. RoboDK can help you with manufacturing operations using industrial robots. In this tutorial guide, the following collaborative URe5 robot is used, as shown in Figure 2.

Fig. 2: URe5 collaborative robot workstation and corresponding CAD model

This programming didactic training is project based. The following tutorials will be followed in order to program the URe5 robot using RoboDK as shown in Table 2.

Topic:
Create UR5e robot station and single-point follow programming
Pick and place programming of the UR5e robot
Follow path for gluing engine block using SolidWorks
Follow path and point programming with URe5
Simulation of a 2D camera in an automated line with a URe5 robot
Spot welding programming with URe5 robot

II CASE STUDY

In this study, using the RoboDK simulator, the idea of programming the URe5 robot manipulator online, i.e. from any point on the ground, was proposed to the bachelor and master students of the Technical University. The general idea of this simulator is shown in Figure 3 below.

Fig. 3: URe5 robot manipulator online control simulator

This study will establish a secure connection between a PC and the UR5e robot using OpenVPN. The aim of the project is to create a remote connection that allows users to control the UR5e robot from anywhere using a secure Virtual Private Network (VPN) connection. The implementation of this simulator has involved the following main tasks, the general view of which is presented in the following 4 images.

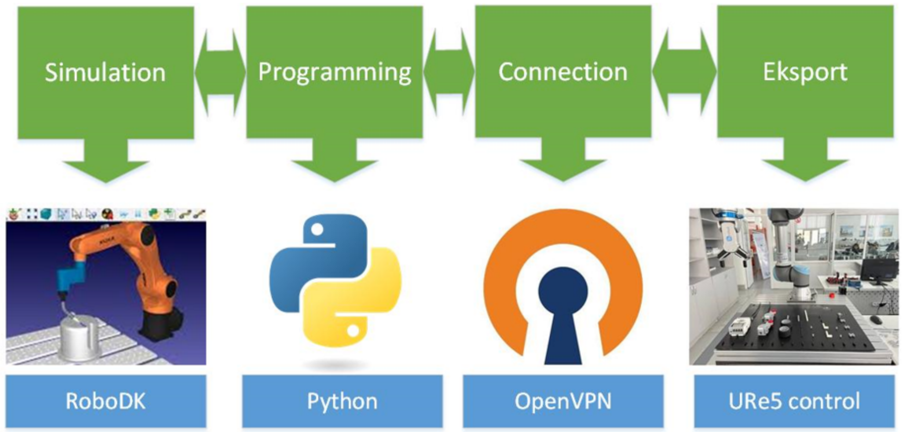

Fig. 4: Robot remote control simulator

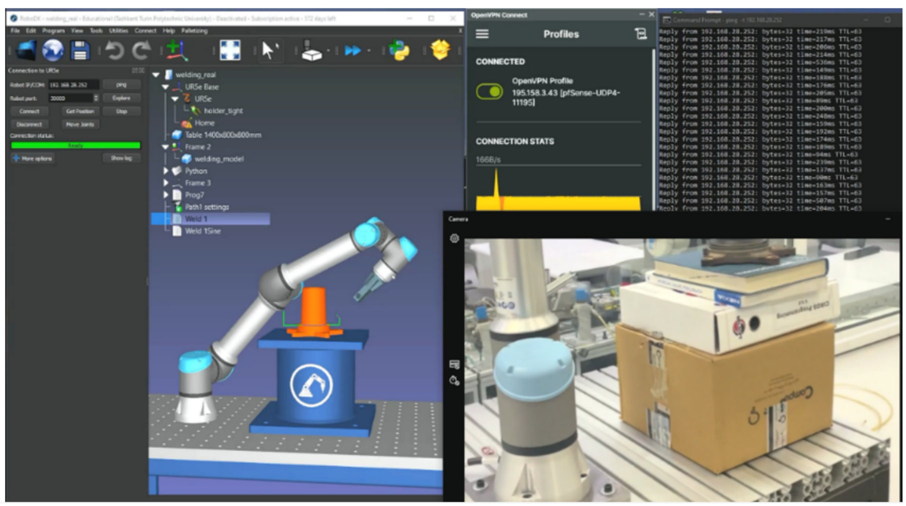

Fig. 5: Remote connection to a real robot

Simulation and Programming: Using RoboDK's intuitive GUI, robot programs are created by defining waypoints, trajectories and desired motions for the UR5e robot. The created programs are simulated in RoboDK to confirm their correctness and to optimize the robot's movements. This step helped to identify and correct problems before deploying the programs to the actual robot. Connect and export the programs. Once the programs had been tested and refined in RoboDK, they were exported in the appropriate format compatible with the UR5e robot as shown in Fugure 5. The exported robot programs were placed on the UR5e robot, allowing the necessary tasks to be performed remotely and automatically via an OpenVPN connection. When installing and using OpenVPN, remember to follow good security practices such as using strong passwords, keeping your software up to date and configuring appropriate firewall rules to protect your network. Note that specific steps and configuration details may vary depending on your network settings, OpenVPN version and operating system. It is always recommended that you consult your OpenVPN documentation and refer to the UR5e robot user manual for detailed instructions. The addition of RoboDK programming has significantly increased the capabilities and functionality of the project. By integrating RoboDK with an OpenVPN connection, we were able to perform complex tasks remotely with the UR5e robot, ensuring accurate and efficient operations. The combination of offline programming, simulation and deployment enabled seamless management and automation, helping to increase efficiency and reduce risk.

III SUMMARY AND OUTLOOK

The paper summarizes the experience of teaching educational robotics with a focus on the methodological system. Thus, we considered quantitative estimates of the use of robots as tools in higher education institutions.

IV REFERENCES

[1] E. Mo, C. Dan, S. Ishwar and W. Tom , "SEPT Learning Factory for Industry 4.0," Education and Applied Research, vol. 23, pp. 249-254, 2018.

[2] I. Kambarov, A. Hoshimov, A. Rustamov and J. Inoyatkhotjaev, "The Path to Industry 4.0. Creation of Learning Factory for education students of technical universities in Uzbekistan," in International Seminar of "NIT, Gifu College" and Partner Universities Environmental Sustainability, Disaster Prevention and Reduction and Engineering Education, Gifu, Japan, 2019.

[3] R. Pittschellis, "Multimedia Support for Learning Factories," in Procedia CIRP, 2015.

[4] I. Kambarov, G. D'Antonio, K. Aliev, P. Chiabert and J. Inoyatkhodjaev, "Uzbekistan towards Industry 4.0. Defining the gaps between current manufacturing systems and Industry 4.0," in PLM18 Conference, Turin, Italy, 2018.

[5] M. Hermann, T. Pentek and B. Otto, "Design Principles for Industrie 4.0 Scenarios: A Literature Review," in Hawaii International Conference on System Sciences (HICSS), 2016.

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EXTENDING THE SERVICE LIFE OF DIESEL LOCOMOTIVE DIESEL ENGINES THROUGH THE USE OF MODERN DIAGNOSTIC METHODS

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Abstract– Efficient use of diesel locomotives imply, in particular, high reliability in operation, minimum maintenance and repair costs, and maximum utilization of resource and energy potential. In this regard, a special role is assigned to technical diagnostics. The current reliability of a diesel locomotive at each given moment of its use depends on a number of factors acting in the period of time preceding this moment. For example, the reliability of a newly built locomotive depends on the level of research and development, the quality of manufacturing of assemblies and parts, as well as their assembly and adjustment. The reliability of a locomotive in operation is determined not only by the above factors, but also by the conditions in which it operates (climate, air dustiness, track layout and profile, weight of trains, etc.), as well as by the organization of its maintenance and repair (method of locomotive maintenance by crews, qualification of locomotive crews, frequency of inspections and repairs and volumes of repair work performed during these inspections and repairs, quality of repair work, etc.).

Key words– JSC “O‘zbekiston temir yo‘llari”, diesel locomotive, diesel crankshafts, service life of diesel locomotive, mobile diagnostic device

I Introduction

Globally, special attention is paid to the use of modern technologies and methods to improve energy efficiency in railway transport in an increasingly competitive transport market. Globally, energy-related transport costs as a percentage of total railway operating costs are approximately 2.6%. At the same time, “...the main share of financial expenditures on fuel and energy resources is the expenditures on traction of trains - 72.2%”, then there is a need to develop comprehensive measures for energy saving in the operation of locomotives, taking into account the application of energy-optimal modes of traction of trains [1]. In this regard, special attention is paid to the use of energy-resource-saving technologies and algorithms for calculating the optimal train running schedule in terms of energy consumption, based on minimization of the target function [2].

The republic is implementing large-scale measures to introduce energy-efficient and resource-saving technologies in various spheres of the economy, including technological modernization of railway transport, increasing the speed of delivery, digitalization of systems for organizing and controlling train traffic, and achieving certain results. In order to increase the level of reliability of technical means, it is necessary both to improve designs and to improve the system of their maintenance and repair. The number of locomotives in JSC “Uzbekistan Temir Yo‘llari” is more than 500 units, of which about 50 are used for passenger traffic, and the rest are intended for cargo transportation and shunting operations. Almost 70% of these locomotives are diesel locomotives.

The level of reliability of diesel locomotives in operation most directly affects the performance of locomotive facilities. To ensure train operation in freight and passenger traffic in areas served by diesel locomotive traction, the locomotive industry has the right to a certain optimal inventory of diesel locomotives, which is determined by their turnover, calculated for the maximum number of days in the month of maximum transportation.

Thus, the reliability of locomotives, their assembly units and parts depend on a large number of different factors, which can be divided into three main groups:

- design and engineering;

- production and technological;

- maintenance and repair.

II THE METHODOLOGY

The problem of ensuring reliable operation of diesel locomotives has always been considered as one of the priority directions for railway transport. When solving this problem, improvement of thermal method of diagnostics of diesel locomotive diesel crankshafts operated in conditions of JSC "Uzbekistan Temir Yo'llari" is of great importance. Improvement of efficiency and reliability of locomotives requires regular control of their equipment during operation. Modern diagnostic tools prevent malfunctions in locomotive devices, provide reliable forecasting of changes in the technical condition of the main units of equipment, determine their residual life, develop and improve effective methods of data processing from the locomotive. Taking into account its real technical condition when planning the scope of locomotive equipment repair is one of the most important grounds for reducing railway operation costs and cheapening transportations. The use of diagnostic methods in this process makes it possible to determine changes in the technical condition of thermal power units and record them when planning repair volumes. In order to increase the level of reliability of technical facilities, it is necessary to improve both the designs and the system of their maintenance and repair [3].

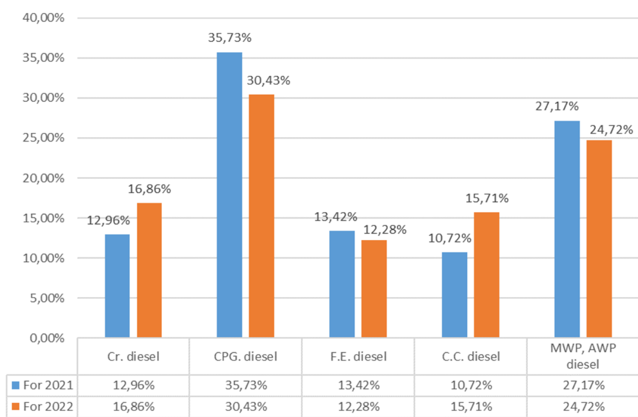


Fig. 1: Distribution of faults of diesel engine parts by components and systems (Cr – crankshaft, CPG – cylinder piston group, F.E. – fuel equipment, C.C. – cylinder cover, MWP – main water pump, AWP – auxiliary water pump).

In 2009, the diesel locomotive diesel engines were modernized on the basis of the 2TE10M diesel locomotive. As a result, a D49 diesel engine was installed instead of the 10D100 diesel, and the locomotive was named UzTE16M. As a result, more than 100 diesel engines of UzTE16M diesel locomotives were modernized. In recent years, during the operation of UzTE16M diesel locomotives, a number of crankshaft failures were detected. The crankshaft failures are micro-cracks, cracks, nitride layer scoring and crank mechanism failure. During the study, a number of crankshaft condition problems were investigated and finally a new method for assessing the technical condition of diesel locomotives was introduced. After that, it was possible to analyses the condition of the locomotive. The operational efficiency of diesel locomotives is in no small measure determined by their reliability. It is necessary to keep an eye on the units of diesel-generator unit. It is necessary to prevent failures in the diesel locomotive diesel engine system. During operation there were several cases of crankshaft breakage. According to the technological processes, surfacing and welding of the crankshaft is prohibited. As a result, the crankshaft is rejected. Preserving the reliability of diesel locomotives is the most important task of locomotive engineering. The study relates to the reliability of diesel locomotives, and it can be used in testing and diagnostics of the crankshaft of diesel locomotives. After that, it is possible to give a prediction on the units of a given locomotive.

The operational efficiency of diesel locomotives is largely determined by their reliability. The problem of increasing the level of reliability of traction rolling stock, including diagnosing diesel locomotive diesel engines, has always been considered as one of the priority problems for railway transport [4].

One of the main single indicators of reliability is the failure flow parameter - ω, which is the average number of failures of a repaired product per unit of time and characterizes the reliability of a diesel locomotive. Complex indicators quantitatively characterize at least two properties that make up reliability.

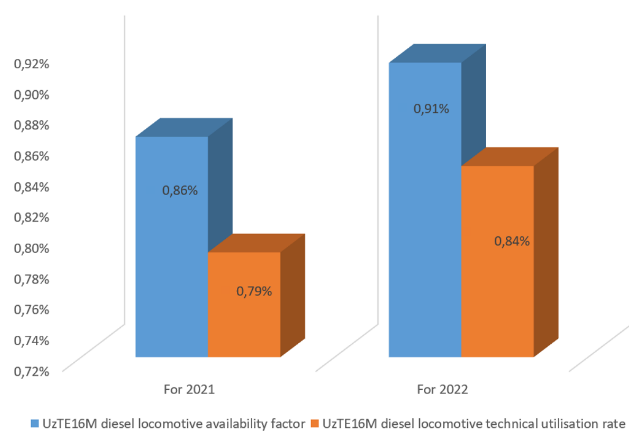


Fig. 2: Utilization indicators of UzTE16M diesel locomotives

An example (Figure 1) of a complex indicator is the availability coefficient, which simultaneously characterizes two different properties of the reliability of diesel locomotives - reliability and maintainability. Standardization and reliable assessment of the reliability level must be carried out using complex indicators (Figure 2). The use of single indicators (Figure 3) for these purposes (the failure flow parameter is the most popular among specialists) can distort the true picture of the reliability state of diesel locomotives.

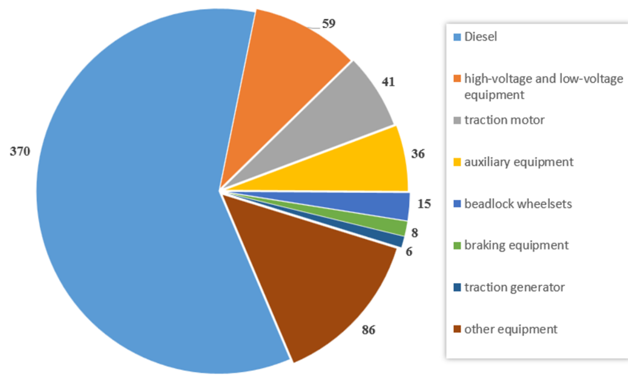


Fig. 3: Main reasons for unscheduled repairs of diesel locomotives (by type of equipment)

III RESULTS AND DISCUSSION

To determine the law of conservation of energy:

$$c\rho\frac{\partial T}{\partial \tau}+div\vec{q}=Q_V$$

where c - heat capacity of the material, $J/(kg\cdot K)$; ρ - density of the material, kg/m^3; T - temperature, K; τ - time, s; $div\vec{q}=\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}$-divergence of the heat flux vector $\vec{q}$; Q_V - volume density of internal heat sources, Wt/m^3.

Do not overheat and load during operation of diesel locomotive diesel engines. The range of oil temperature during operation 40-45^oC at a revolution of 5.83 s^{-1} (350 rpm), 60-65^oC at a revolution of 14.17 s^{-1} (850 rpm) crankshaft. Evaluation of the technical condition of the determination of heat dissipation of the crankshaft of diesel locomotives works as follows. When the crankshaft of diesel locomotive diesel engines rotates, the temperature rises and the condition of the locomotive can be predicted. The main purpose is to timely determine the beginning of overheating from friction sliding surface to prevent failure and breakage of expensive part of the diesel engine (crankshaft) by this device to measure the thermal state of the crankshaft. Currently there are no analogues of the new diagnostic system [5].

By performing this diagnosis, crankshaft journals can be prevented from breaking. The technical condition assessment of crankshaft heat dissipation determination of diesel locomotive diesel engines is carried out as follows: 2 units are installed, crankshaft temperature indication unit and display. Temperature sensor is installed as close as possible with minimum clearances of the measured part of the crankshaft for timely determination of the difference in temperature of the sliding part relative to other crankshaft necks of this link. The main purpose is to detect in time the beginning of overheating from friction of the sliding surface in order to prevent failure and breakage of an expensive part of the diesel engine (crankshaft) with the help of this crankshaft thermal condition measuring device [6].

a)

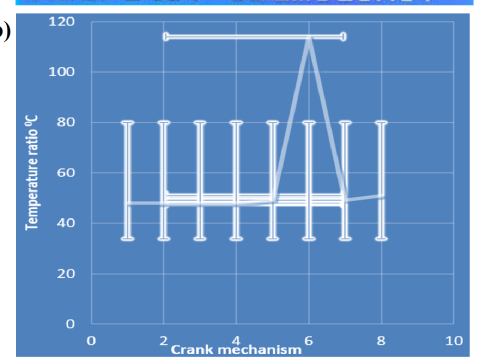

b)


Fig. 4: Diagnostics of technical condition of diesel locomotive diesel engines crankshaft by journals. a - temperature reading of the display of the diagnostic complex; b - graph of diesel engine technical condition by crankshaft journals.

IV CONCLUSION

Thus, to extend the service life of diesel locomotive diesel engines we have developed a diagnostic system to determine the heat dissipation of the crankshaft. From the graph we can predict that there is a fault on the 6th crankshaft journal. During operation, we discovered this fault and prevented the crankshaft from breaking. Introduction of modern methods of diagnostics serve for operable condition of the locomotive.

The "Improved technique of estimation of technical condition of diesel locomotive diesel crankshaft by determination of temperature indicators" is developed, which allows to establish the main criteria of estimation of technical condition of diesel locomotive diesel crankshaft by determination of temperature indicators, which are necessary for carrying out planned types of repairs (TR, CR). The mobile diagnostic device for thermal method of diagnostics on the basis of Arduino circuit for diesel locomotive diesel engines is developed, which allows to use the proposed method of mobile control.

As a result of scientific researches, a new thermal method of diagnostics and a new technical device allowing to estimate the technical condition of crankshafts of diesel locomotive diesel engines with the help of mobile diagnostics means by means of temperature indicators determination have been developed. At the same time as a result of implementation of the proposed thermal method of diagnostics the economic effect is obtained.

V References

[1] Yusufov, A. (2023). Analysis of the state and prospects for the development of the locomotive fleet JSC “o‘zbekiston temir yo‘llari” . Acta of Turin Polytechnic University in Tashkent, 13(1), 16–21. Retrieved from https://acta.polito.uz/index.php/journal/article/view/181.

[2] Valiev, M., & Kosimov, K. (2021). Diagnosing the technical condition of the diesel cylinder-piston group. In E3S Web of Conferences (Vol. 264, p. 04061). EDP Sciences.

[3] Khamidov, O., Yusufov, A., Kudratov, S., & Yusupov, A. (2023). Evaluation of the technical condition of locomotives using modern methods and tools. In E3S Web of Conferences (Vol. 365, p. 05004). EDP Sciences.

[4] Xamidov, O. R., Yusufov, A. M. U., Kodirov, N. S., Jamilov, Sh. F. U., Abdurasulov, Sh. X., Abdulatipov, U. I. U., & Seydametov, S. R. (2022). Forecasting the remaining life of the main frame and extending the service life of shunting locomotives at JSC “UTY”. Universum: technical sciences, (4-5 (97)), 47-54.

[5] Jamilov, S. (2023). TSTU modern temperature sensors for the assessment of the permissible thermal state of electric traction machines of a locomotive tractor: Shukhrat Jamilov Tashkent State Transport University, Tashkent Uzbekistan. Email: shuhratjamilov@mail.ru https://orcid.org/0000-0001-8521-0370. Acta of Turin Polytechnic University in Tashkent, 13(1), 41–44. Retrieved from https://acta.polito.uz/index.php/journal/article/view/184.

[6] Fedorov M.M Dynamic thermal models of electric machines units // Elektromashinobuduvannia ta elektroobladnannia. – 1999. –53. – pp. 70–73. (Rus)

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VIBRATION-DAMPING, ANTI-CORROSION COMPOSITE COATING FOR COMPONENTS OF TRANSPORT AND TECHNOLOGICAL MACHINERY

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Abstract– The article points to the modification and inclusion of organomineral fillers in the composition of coatings, which improve the properties of vibration reduction, as well as significantly increase the physical and mechanical properties of coatings. In order to address the problems of both mechanical wear and environmental deterioration, this study presents a composite material that has better corrosion resistance together with vibration damping capabilities. The study demonstrates the improved resistance of this coating to chemical corrosives and physical vibrations using a rigorous formulation process that incorporates sophisticated polymers and nano-materials. Significant gains in component longevity and performance are revealed by extensive testing conducted under simulated operating settings, underscoring the coating's potential to completely transform maintenance procedures in the transportation and technology industries.

Key words– Vibration-absorbing composition, fillers, coatings, composite materials, corrosion, mechanical engineering, wear.

I INTRODUCTION

The use of multifunctional composite polymer coatings to lower vibration and noise levels is currently receiving a lot of interest. This makes it possible for the performance of transportation and technological machinery to be improved, as well as for body components and assemblies to last longer. Vibration-absorbing coatings are a useful way of mitigating vibrations in metal constructions with thin walls. Materials with the ability to absorb and dissipate different kinds of noise and vibrations are known as vibration-insulating vibration-damping materials [1].

A class of materials used for vibration damping is called vibration insulation (also known as vibration damper, vibration absorber, or "vibra"). The primary goal is to lessen the metal (or plastic or other) panels' vibrational amplitude.

Car bodywork can experience both chemical and electrochemical corrosion, with electrochemical corrosion being the most common [2].

There are phases to metal corrosion. There are five known phases of corrosion. Rust patches and tiny bubbles emerge in the first step. Iron oxides (Fe_2O_3) develop and widespread rusting takes place in the second stage. When corrosion reaches its third stage, the substrate totally delaminates. The occurrence happens quickly. As a result, coatings don't stop corrosion on metal. Pitting corrosion and the formation of deep pits happen in the fourth stage. Large gapping holes start to appear in the fifth stage, and corrosion is heavily present on both sides of the substrate. Paint coatings are among the most often used techniques for protecting metal [3].

A continuous film forms on the surface of the metal with paint coatings. This prevents the aggressive impact of the environment and protects the metal from destruction. Composite polymer coatings have higher protective properties than paint coatings. The unique properties of composite polymer materials have allowed their use in various industries.

Therefore, the goal of this work is to develop a vibration-absorbing, anti-corrosion composite material and coatings based on it for the parts of transport and technological machines.

II THE METHODOLOGY

Thermosetting polymers, such as epoxy, phenol-formaldehyde, polyester, furan, and other oligomers [4], are widely used to protect metals and alloys from corrosion. Coatings based on epoxy polymer resins are resistant to alcohols, hydrocarbons, alkalis, salt solutions, and mineral acids, lubricating oils. One of the disadvantages of cured epoxy compositions based on dian resins is their low thermal resistance, brittleness, leading to compound cracking, especially when casting constructions with a large number of metal parts and during heating-cooling cycles. To improve these operational characteristics, modifying additives are usually introduced into the compound composition. Film-forming coatings from unmodified epoxy resin are characterized by low physical-mechanical and thermal indicators. Low thermal resistance and impact strength, as well as lack of elasticity, limit the use of epoxy resins as anticorrosive and electrical insulating coatings. To eliminate these deficiencies, modifiers containing various reactive functional groups are introduced into the epoxy composition, which contribute to the improvement of the operational indicators of epoxy coatings.

Therefore, ED-20 brand epoxy resin was used as the film-forming agent. As a modifier, cottonseed resin - a byproduct of the oil and fat processing plant [5,6]. Dibutyl phthalate (DBP) was used as a plasticizer, polyethylene polyamine (PEPA) as a hardener, and kaolin, talc, and graphite as fillers.

The hardener PEPA is a liquid ranging from light yellow to dark brown in color without mechanical inclusions. PEPA is often used for mixing with epoxy resin, resulting in a ready-to-use epoxy resin that, after curing, acquires new physicochemical properties. It is also used for curing paint and varnish products, adhesives, and other materials based on epoxy resins.

By adding plasticizers to the polymer mixture, composites' rheological properties can be changed, their service life extended, the technological process accelerated, production energy consumption decreased, material costs decreased, and limited raw materials conserved. This is achieved through the utilization of large-scale industrial waste in the manufacturing process.

In cured composites, plasticizers lessen brittleness and improve resilience to frost and abrupt temperature fluctuations. Nevertheless, they deteriorate the dielectric properties of epoxies, diminish thermal resistance, and weaken the material's ability to withstand bending, stretching, and compression. It takes many hours to fully prepare the resin with DBP plasticizer, thus the epoxy resin hardener should only be added to the mixture after plasticization is finished.

The main drawback of this plasticizer is how difficult it is to prepare the mix because DBP does not mix well with epoxy resin. The mixture is agitated for two hours at 50–60^{o}C to guarantee that the two components are well mixed. It is advised to carry out this task in a water bath. The mixture may boil if the composition is heated to temperatures higher than 60^{o}C, so the process needs to be closely watched. Resin that has been boiled is unfit for use and cannot be retrieved. Boiling is indicated by the appearance of foaming and the transparent resin turning matte white in color. Due to the complexity of the mixing process, DBP with resin is typically used in industrial conditions and is only applied in household settings when there are specific requirements for the color of the casting or coating. In household settings, sometimes the mixing technology is ignored, and mixing is done without heating, but the plasticizing effect achieved this way is minimal.

III RESULTS AND DISCUSSION

Theoretical investigations have demonstrated that the vibration-absorbing characteristics of the viscoelastic layer influence the damping characteristics of the vibration-absorbing coating, which are then influenced by the characteristics of the polymer matrix. The viscoelastic layer's polymer binders need to have a number of qualities, including strong adhesion, ensuring the formation of a consistently viscous mastic, having a glass transition temperature that falls within the material's specified temperature range of operation, having high resistance to a variety of harsh environments, and, in the case of mastic-cured materials, having the strength of the formed coating.

Following curing, epoxy polymers organize into a spatial network that limits the mobility of macromolecules inside them. This prevents epoxy polymers from softening that is, from changing from a solid to a plastic state when heated.

Curable polymers exhibit vibration-absorbing qualities in response to variations in interatomic distances and internal rotation, which are mainly caused by the flexibility of the inter-node fragment and segmental mobility. The potential for the latter is dependent on how atomic groups rotate along different axes within molecules. The methyl group CH_3 is one of the rotational movements (degrees of freedom) of atomic groups around the polymer chain axis that are classified as processes in the current taxonomy [7].

To impart necessary vibration-absorbing properties to polymer composite materials, solid inorganic fillers [8] are often used.

In the work [9], the most in-demand classification of fillers for polymer materials by the shape of the dispersed particles is presented:

– spherical (aerosil, glass spheres, metal oxides, chalk);
– cubic (feldspar);
– prismatic (calcite, quartz, barium oxide);
– plate-like or flaky (micas, graphite, talc);
– fibrous or needle-like (glass fiber, basalt, asbestos).

It was established that materials with flaky and fibrous fillers possess the greatest vibration-absorbing properties. Flaky fillers include mica, kaolin, graphite, glass flakes, aluminum powder, and others. The table presents the results of research on the physical-mechanical and vibration-damping properties, obtained based on epoxy resin and modified gossypol resin (GR), plasticizer, and hardener. As known, the efficiency of damping, i.e., the vibration-damping material, is assessed by the product of the logarithmic decrement of oscillations by the dynamic modulus of elasticity - δE.

IV CONCLUSION

It has been determined that grade ED-20 modified epoxy resin works well as a binder for coatings that absorb vibrations.

The physical-mechanical properties of the modified coating based on ED-20 with gossypol resin with organo-mineral fillers used in obtaining composite vibration-absorbing materials have been studied in order to create vibration-damping mechanical engineering composite polymeric materials and coatings based on them.

It has been demonstrated that adding organo-mineral fillers to the composition improves the viscoelastic properties of the vibration-damping composite polymeric materials and coatings that are developed, as well as their physical-mechanical qualities.

Properties	**Composites**	
	ED-20	**ED-20+GR**
Logarithmic decrement, δ	0,085	0,100
Loss modulus $"E", MPa$	350	378
Glass transition temperature Tg, K	390	400
Dynamic modulus of elasticity E', MPa	4045	4050
Density $\rho, g/sm^3$	1,26	1,28
Impact strength $\sigma_{ud}, N.m$	1.25	1,20
Adhesion strength σ_a, MPa	40,0	43,0
Characteristics of vibration-damping polymeric materials, $\delta\cdot$ "E", MPa	350	370,2

TABLE 1: PHYSICAL-MECHANICAL AND VIBRATION-DAMPING CHARACTERISTICS OF COATINGS MADE OF MODIFIED GOSSYPOL RESIN (GR) AND EPOXY RESIN

V REFERENCES

[1] Zhavliev S.S., Negmatov S.S., Abed N.S., Ulmasov T.U., Sattorov A.R., Study and development of vibration-damping composite polymeric materials and coatings based on them // Composite Materials- Vol. 2018, No.1, - P.42.

[2] https://abs-magazine.ru/article/pochemu-rzhavejut-avtomobilnye-kuzova-nemnogo-teorii-i-strashnaja-skazka-na-noch. Why car bodies rust // "ABS Auto" December 2015, - P.12-27.

[3] Yakovlev A.D., Chemistry and technology of paint and varnish coatings. – L.: Chemistry, 1981. – 320p.

[4] Chernin I.Z., Smekhov F.M., Zherdev Y.V., Epoxy polymers and compositions. – M.: Chemistry, 1982. – 232 p.

[5] Skadyn A.I., Technology of anti-corrosion protection of cars with Krown (crown) T40 anti-corrosion coating, International Scientific and Technical Conference "Current Problems of Shipping and Transport Development in the Asia-Pacific Region" (2019), -P.187-192.

[6] Allaerov E.Sh., Study and application of gossypol resin and its derivatives in elastomeric compositions: Thesis Cand. of Tech. Sciences. – Tashkent: , 1989. -165 p.

[7] Bartenyev G.M., Physics and Mechanics of Polymers: a textbook for technical universities / G.M. Bartenyev, Y.V. Zelenev. – M.: Higher Education, 1983. – 391 p.

[8] Donskoy A.A. Fillers for sealants of reduced density / A.A. Donskoy, N.V. Baritko // Adhesives. Sealants. Technologies. – 2006., – No.5., – P. 12–18.

[9] Fillers for polymeric composite materials: Reference book / ed. by G.S. Katz, D.V. Milevsky. – M.: Chemistry, 1981. – 736 p.

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DESIGNING A DIGITAL PROTOTYPE OF TRACTOR IN THE SOLIDWORKS ENVIRONMENT TO CREATE A VIRTUAL SIMULATION OF MOVEMENT ON VARIOUS SLOPES

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Abstract– This work shows the process of creating a digital prototype of a tractor using the SolidWorks simulation program. Also the movement of a four-wheeled tractor on different slopes is shown. Taking into account the masses of the front and rear wheels of the tractor, loads, moment of resistance, force resistance were calculated, as well as the deflection of the wheel tire when the unstable elastic wheel was turned on a slope under the influence of the side component of the load was analyzed.

Key words– 3D modeling, digital prototype, four-wheel tractor, slope, deformation, wheel movement, elastic wheel, reactive moment, wheel deflection, wheel rolling on a slope.

I Introduction

In the modern world, it is difficult to imagine any sphere of services and human activity without digital technologies. Especially in the production of such capacious and expensive products as cars, agricultural equipment, diagnostic devices and the like. In this connection, the development and modeling of digital prototypes at the early stages of design greatly facilitates subsequent calculations, the selection of necessary indicators, and also reduces production time and errors that may occur during assembly.

II THE METHODOLOGY

SolidWorks 2021 SP01 3D modeling software was used to create a digital prototype, which will be used later for virtual simulation. In particular, the required number of parts were modeled, which were included in the final assembly of the tractor prototype (Fig. 1).

Determination of operational qualities of tractors is divided into three main groups [1]:

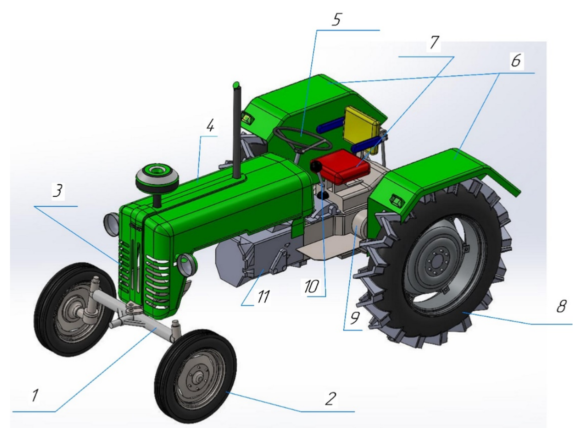

Fig. 1: Digital prototype of a tractor, which was modeled on SolidWorks 2021 SP01 1-front axle; 2-front wheel; 3-front grill; 4-bonnet; 5-steering wheel; 6- back wheels cover; 7-seat; 8-back wheel; 9-back axle; 10-transmission; 11-cluch box.

1) describing the technological (agrotechnical) adaptation of the tractor to the technological requirements arising from the working conditions;

2) to determine the operation and efficiency or technical and economic indicators of the equipment;

3) ensuring driver comfort and safety or general technical regulations. When a wheel (rigid or elastic) is rolled on an incline (deformable or non-deformable surface), unstable and stabilized wheel roll occurs. As an example of unstable wheel rotation, when the longitudinal plane of the wheel is usually located at an angle (90^o - a) to the horizontal plane (Fig. 2, a) it moves.

Wheel stabilization on a slope means its movement in the

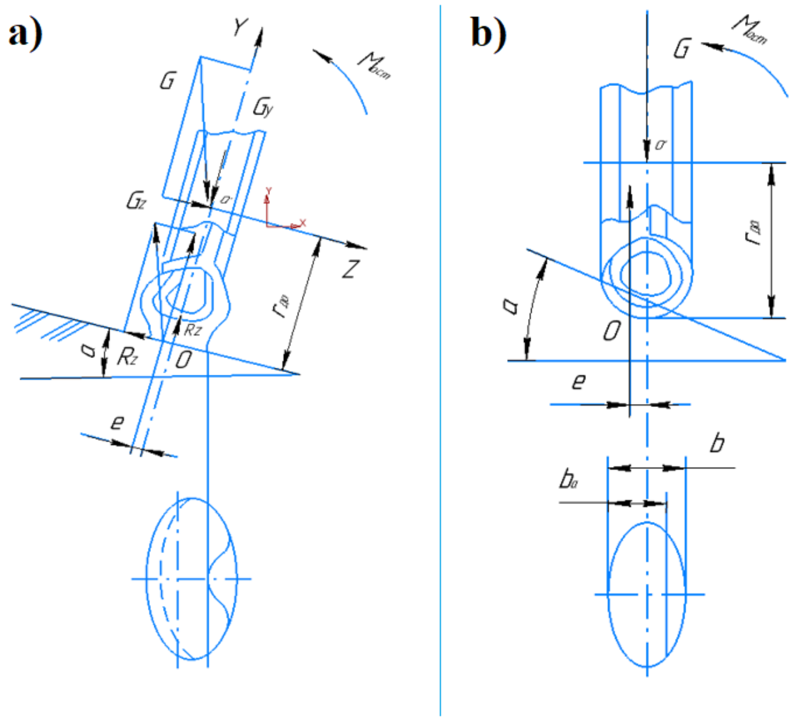

Fig. 2: Wheel movement on a slope
a) tire profile change at an angle (90^o - a)
b) changing the profile of the tire depending on the angle of the slope

transverse plane until the tractor frame is installed in a vertical position relative to the horizontal plane (Fig. 2, b). This includes the rolling of the wheels of a special steep tractor. In this case, the longitudinal plane of the wheel, within certain limits of the slope angle, is always perpendicular to the horizontal and forms an angle (90^o - a) with the surface. Wheel rolling in a stabilized mode is achieved with the help of special stabilizing devices installed on a steeply sloping tractor.

When rolling an unstabilized elastic wheel on a slope under the action of a lateral component of the load G_z the contact patch of the tire with the slope surface is distorted and takes the form of a curved ellipse. The point of application of the resultant reactions of the soil is shifted by the value l from the longitudinal plane of symmetry of the wheel.

In this case, tire side slip occurs, estimated by the coefficient k. It can be assumed with a reasonable degree of accuracy that the displacement l directly proportional to tire side slip k [2].

III RESULTS AND DISCUSSION

Based on the provided data, it was calculated in Python software [5,6].

$$g = 9.807 m/s^2; \quad \alpha = 20^\circ; \quad b = 0.255 m; \quad r_{frontleft} = 0,43 m; \quad r_{backleft} = 0,785 m; \quad m_{backleft} = 1525 kg; \quad m_{backright} = 1475 kg;$$

$$m_{frontleft} = 895 kg; \quad m_{frontright} = 855 kg:$$

$$e = \frac{b}{6} = \frac{9}{6} = 0.0425;$$

```
============= RESTART: C:\Users\jakho\OneDrive\Рабочий стол\1.py =============
b=0.255
0.0425
>>> |
```

$$G_{backleft} = m_{backleft} \cdot g = 14955.6750 \quad kg \cdot \frac{m}{s^2};$$

```
моркачап=1525
g=9.807
14955.675000000001
```

$$G_{backright} = 14465.325 \quad kg \cdot \frac{m}{s^2};$$

Where $r_{d\alpha}$ the dynamic radius of an unstabilized wheel as it rolls down a slope.

Here the weight of the tractors on each wheel is calculated.

Component soil reaction R_z prevents the wheel from slipping under the action of the load component G_z. Normal to

```
моркаунг=1475
g=9.807
14465.325
```

$$G_{front\ left} = 8777.2650\ kg \cdot \frac{m}{s^2};$$

```
молдчап=895
g=9.807
8777.265000000001
```

$$G_{front\ right} = 8384.985\ kg \cdot \frac{m}{s^2};$$

```
молдунг=855
g=9.807
8384.985
```

$$M_{axle} = M_{tilting} = G \cdot (e \cdot \cos\alpha + r_{d\alpha} \cdot \sin\alpha) = R \cdot (e \cdot \cos\alpha + r_{d\alpha} \cdot \sin\alpha) = R_z \cdot r_{d\alpha} + R_y \cdot e \quad (1)$$

$$M_{axle\ back\ left} = G_{back\ left} \cdot (e \cdot \cos\alpha + r_{d\alpha\ back\ left} \cdot \sin\alpha) = 4611.9936\ kg \cdot \frac{m^2}{s^2};$$

```
Горкачап=14955.675000000001
e=0.0425
cosa=0.939
rдоркачап=0.785
sina=0.342
4611.9936673125
```

$$M_{axle\ back\ right} = 4460.7807\ kg \cdot \frac{m^2}{s^2};$$

```
Горкаунг=14465.325
e=0.0425
cosa=0.939
rдоркаунг=0.785
sina=0.342
4460.780760187501
```

$$M_{axle\ front\ left} = 1641.0632\ kg \cdot \frac{m^2}{s^2};$$

```
Голдчап=8777.265000000001
e=0.0425
cosa=0.939
rдолдчап=0.43
sina=0.342
1641.0632938875003
```

$$M_{axle\ front\ right} = 1567.7196\ kg \cdot \frac{m^2}{s^2};$$

```
Голдунг=8384.985
e=0.0425
cosa=0.939
rдолдунг=0.43
sina=0.342
1567.7196829875002
```

the surface component of the soil reaction R_y perceives the load G_y, i.e. $R_z = G_z$ and $R_y = G_y$.

In the longitudinal plane, when a wheel rolls on a slope in an unsteady regime, forces and moments act on the wheels, similar to the case of wheels moving on a plain.

Since we can assume that the contact area of an unstabilized wheel on a slope, other things being equal, remains approximately the same as when the wheel is rolling on a horizontal surface, and only its shape is distorted (Fig. 2, a), in the first approximation for calculating forces and moments acting on the wheels in the longitudinal plane when working on a slope, you can use the formulas given in [1] for the driven and driving wheels.

It should be borne in mind that if normal loads are approximately equal for the right and left wheels of a tractor operating on a plain, then when working on a slope, these loads are redistributed: a greater load acts on the wheel located lower along the slope than on the upper one. The redistribution of loads is directly proportional to the angle of the slope.

In addition, it is necessary to take into account the fact that when an unstabilized elastic wheel rolls on a slope, significant radial and tangential deformations occur, which consumes much more energy than when the same wheel rolls on a horizontal surface. To take into account the resistance of an unstabilized elastic wheel on a slope, resulting from tire deformation, you can use the formula proposed by E.A.

Omelyanov: when rolling the driven elastic stabilized wheel on the deformable surface of the slope, other than the rolling resistance forces due to the formation of a track, it is necessary to take into account the loss of energy for normal and tangential deformation of the tire. Therefore, the formulas for determining the rolling resistance of an elastic wheel on a slope in the driven mode have the form [3, 4]: by $b\alpha = b$, $B = 7$:

$$F_{resistence2} = B \cdot G_y \cdot \sqrt{\frac{G_y}{\rho_{tyre} \cdot D^2_{given}}},$$

$$B = 7; \quad \rho_{tyre} = 80Pa; \quad D_{given} = 1.8m$$

Where B-coefficient depending on the tire design.

$$G_{y\ back\ left} = m_{back\ left} \cdot g \cdot cos\alpha = 14043.3788 \quad kg \cdot \frac{m}{s^2};$$

```
моркачап=1525
g=9.807
cosa=0.939
14043.378825
```

$$G_{y\ back\ right} = 13582.9401\ kg \cdot \frac{m}{s^2};$$

```
моркаунг=1475
g=9.807
cosa=0.939
13582.940175
```

$$G_{y\ front\ left} = 8241.8518\ kg \cdot \frac{m}{s^2};$$

```
молдчап=895
g=9.807
cosa=0.939
8241.851835000001
```

$$G_{y\ front\ right} = 7873.5009\ kg \cdot \frac{m}{s^2};$$

```
молдунг=855
g=9.807
cosa=0.939
7873.5009150000005
```

$$F_{resistance2\,back\,left} = B \cdot G_{y\,back\,left} \cdot \sqrt[3]{\frac{G_{y\,back\,left}}{\rho_{tyre} \cdot D^2_{given}}} = 371976.2306 kg \cdot \frac{m}{s^2}$$

```
B=7
Gуоркачап=14043.378825
p=80
D=1.8
371976.2306579397
```

$$F_{resistance2\ back\ right} = 355804.4904\ kg \cdot \frac{m}{s^2};$$

```
B=7
Gуоркаунг=13582.940175
p=80
D=1.8
355804.49042442837
```

$$F_{resistance2\ front\ left} = 182776.1162\ kg \cdot \frac{m}{s^2};$$

```
B=7
Gуолдчап=8241.851835000001
p=80
D=1.8
182776.11620106833
```

$$F_{resistance2\ front\ right} = 171966.3805\ kg \cdot \frac{m}{s^2};$$

```
B=7
Gуолдунг=7873.5009150000005
p=80
D=1.8
171966.3805880993
```

Considering that the rolling resistance force of the wheel due to the deformation of the soil on the plain is determined by the formula $F_{resistance} = 0.5 \cdot G \cdot \sqrt{\frac{G}{k \cdot b \cdot D^2}}$, we obtain a formula for determining the rolling resistance of an elastic unstabilized wheel in the driven mode:

$$F_{resistance\ back\ left} = 0.5 \cdot G_{y\ back\ left} \cdot \sqrt[3]{\frac{G_{y\ back\ left}}{k \cdot b \cdot D^2_{given}}} =$$

$$= 81178220.5829\ kg \cdot \frac{m}{s^2};$$

```
Gуоркачап=14043.378825
k=0.000000011
b=0.255
D=1.8
81178220.58296144
```

$$F_{resistance1\ back\ right} = 77648981.3797\ kg \cdot \frac{m}{s^2};$$

```
Gуоркаунг=13582.940175
k=0.000000011
b=0.255
D=1.8
77648981.37978896
```

$$F_{resistance1\ front\ left} = 39888139.7664\ kg \cdot \frac{m}{s^2};$$

```
Gуолдчап=8241.851835000001
k=0.000000011
b=0.255
D=1.8
39888139.76641283
```

$$F_{resistance1\ front\ right} = 37529077.4669\ kg \cdot \frac{m}{s^2};$$

```
Gуолдунг=7873.5009150000005
k=0.000000011
b=0.255
D=1.8
37529077.46697243
```

$$k = 1.1 \cdot 10^{-8};$$

$$F_{resistance\ back\ left} = F_{resistance1} + F_{resistance2} =$$

$$0.5 \cdot G_{y\ back\ left} \cdot \sqrt[3]{\frac{G_{y\ back\ left}}{k \cdot b \cdot D^2_{given}}} +$$

$$+ B \cdot G_{y\ back\ left} \cdot \sqrt[3]{\frac{G_{y\ back\ left}}{\rho_{tyre} \cdot D^2_{given}}} =$$

$$= 81550196.8136 kg \cdot \frac{m}{s^2};$$

Where D_{given}- reduced diameter of elastic wheel; ρ_{tyre}- tire air pressure; b- wheel width; G_y normal load; k coefficient of volumetric collapse of the soil.

In this, the tractor's ground contact force, resistance forces, and weight of each wheel were calculated.

When a stabilized wheel rolls on a slope, the surface of the contact patch is not only distorted in shape, but also decreases in width by $(b - b_\alpha)$ Suffice it to say, according to experimental data, when the slope is steeper than 20°,

```
B=7
Gуоркачап=14043.378825
p=80
Dпр=1.8
k=0.000000011
b=0.255
81550196.81361938
```

$$F_{resistance\ back\ right} = 78004785.8702\ kg \cdot \frac{m}{s^2};$$

```
B=7
Gуоркаунг=13582.940175
p=80
Dпр=1.8
k=0.000000011
b=0.255
78004785.87021339
```

$$F_{resistance\ front\ left} = 40070915.8826\ kg \cdot \frac{m}{s^2};$$

```
B=7
Gуолдчап=8241.851835000001
p=80
Dпр=1.8
k=0.000000011
b=0.255
40070915.8826139
```

$$F_{resistance\ back\ right} = 37701043.8475\ kg \cdot \frac{m}{s^2};$$

```
B=7
Gуолдунг=7873.500915000005
p=80
Dпр=1.8
k=0.000000011
b=0.255
37701043.84756053
```

less than half of the wheel width remains in contact with the ground. As a result, the contact pressure diagram, traction properties of the wheel, as well as the tire profile change, but to a lesser extent than the tire profile of an unstabilized wheel. On fig. 2, b) shows the change in the tire profile depending on the angle of the slope.

Therefore, the formulas for determining the rolling resistance and tangential force of an elastic wheel when working on a slope require clarification.

It should be noted that the distortion of the shape and dimensions of the contact leads to a shift in the resultant reactions of the soil R in the transverse plane by the value e up the slope. As a result, a tilting moment arises in the transverse plane

$$M_{tilting} = G_e = R_e.$$

However, this moment will be significantly less than the moment of an unstabilized wheel when working on a slope.

For a tractor with wheels stabilized in the transverse plane, it can be assumed that the load on the right and left wheels is distributed approximately evenly (if the overturning moment is not taken into account). Consider the rolling of a driven rigid stabilized wheel on a deformable slope surface. Assume that the wheels are moving under the action of a pushing force $F_{pushing}$ in steady state, i.e. $\upsilon = const$. Friction in the wheel bearings is neglected due to its smallness. A vertical load normal to the horizon acts on the wheel G (Fig.

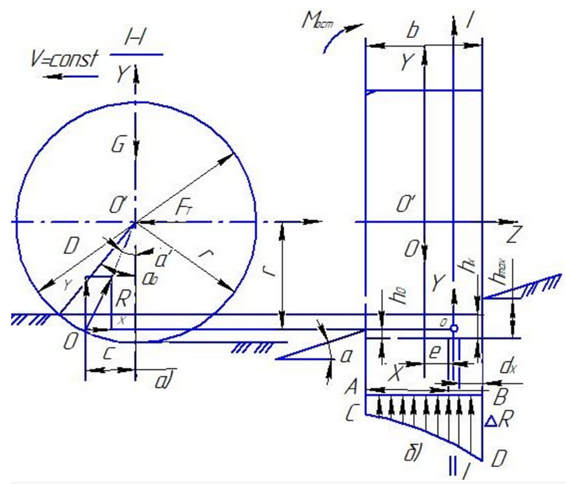

Fig. 3: Scheme of forces and moments acting on a stabilized wheel

3). From the side of the soil, reactions act on it, the resultant R which is attached at point O.

Let us decompose the resultant of soil reactions into components along the axes X and Y (Fig. 3, a). The product Y_c represents the rolling resistance moment of the wheel $X = 16170H$; $M_{resistance}$, i.e. $M_{resistance} = Y_c = X \cdot r_{d\alpha}$. Component of the resultant soil reactions X represents the rolling resistance force due to rutting. In addition, a reactive moment acts on the wheel in the transverse plane M_{axle} from the weight of the tractor frame, which keeps the wheel from tipping over under the action of a pair of force X and Y, i.e. $M_{axle} = M_{tilting} = Y_e = G_e$.

$$M_{resistance\ front\ left} = Y_C = X \cdot r_{d\alpha front\ left} = 6953.0999\ \ kg \cdot \frac{m^2}{s^2};$$

```
X=16170
rдаолдчап=0.43
6953.099999999999
```

$$M_{resistance\ front\ right} = 6953.0999\ \ kg \cdot \frac{m^2}{s^2};$$

```
X=16170
rдаолдунг=0.43
6953.099999999999
```

$$M_{resistance\ back\ left} = 12693.45\ \ kg \cdot \frac{m^2}{s^2};$$

```
X=16170
rдаоркачап=0.785
12693.45
```

$$M_{resistance\ back\ left} = 12693.45\ \ kg \cdot \frac{m^2}{s^2};$$

```
X=16170
rдаоркаунг=0.785
12693.45
```

The moments of resistance of each wheel of the tractor were calculated.

From fig. 3b it can be seen that the rut depth along the width of the wheel b after its passage does not remain constant compared to the rut depth when the wheel is rolling on a horizontal surface or the unstabilized wheel is rolling on a slope. The displacement e of the reaction Y in the transverse plane depends on many factors, and primarily on the vertical load, wheel parameters and the physical and mechanical properties of the soil.

It can be assumed that the point O of application of the resultant soil reactions R (as well as its vertical component Y and horizontal component X) will be located in the center of gravity of the plot $ABCD$ of soil reactions ΔR acting in the plane $I-I$ (see Fig. 3, b) [2].

With some approximation, the plot of soil reactions $ABCD$ can be replaced by a trapezoid. Then

$$e = \frac{b}{6}e = \frac{b}{6 \cdot h_{max}} \cdot (h_{max-h_0});$$

When $h_0 = 0$ plot of soil reactions ΔR takes the form of a triangle and $e = \frac{b}{6}$.

```
...
============= RESTART: C:\Users\jakho\OneDrive\Рабочий стол\1.py =============
b=0.255
hmax=1
h0=0
0.0425
>>> |
```

It depicts the movement of tractors on different slopes. There we can see the twists and turns of different roads.

IV CONCLUSION

The development, creation and design of a digital prototype is a very time-consuming process that takes a lot of time. But the further use of such a prototype greatly facilitates subsequent processes. In particular, the calculations performed show how the wheels are deformed when driving on various slopes and curvature of such a heavy structure as a tractor.

V REFERENCES

[1] J.Sh.Norkulov, Sh.Z.Ihsanova and A.K. Karimov , The Study of the slope movement of a Four-Wheeled Tractor, Acta of Turin Polytechnic University in Tashkent, 2020, 10, 31-35.

[2] Guskov V.V. Tractors. Theory. 1977.

[3] Kutkov G.M. Tractors and Cars. Theory and Technological Properties. 2004.

[4] G.I. Gladov Tractors: Device and Maintenance, 1999.

[5] Vasiliev A.N. Python on examples. practical course in programming/ Science and Technology. Saint Petersburg. 2016.

[6] Mark L., We study Python. The fourth edition., St. Petersburg-Moscow., 2011.

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GEOMETRIC MODELING OF CURVED SHAPES AND CUBIC SPLINE APPROXIMATION IN ENGINEERING GRAPHICS

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Abstract– This paper presents a study on cubic spline interpolation, focusing on its application in modeling smooth and continuous curves for engineering graphics. Cubic splines are a series of third-degree polynomial functions connected at control points, ensuring smooth transitions that are critical in fields such as CAD, computer graphics, and animation. This research addresses the challenges encountered when modeling with irregular control points and non-uniform intervals, which can cause traditional cubic spline interpolation methods to generate oscillations or lose continuity. By investigating the mathematical framework of cubic splines, including boundary and continuity conditions, we propose an adaptive approach that improves interpolation performance in these challenging configurations. Computational experiments validate the effectiveness of the method, demonstrating smoother and more accurate curve representations in edge cases. This adaptive cubic spline interpolation approach provides an enhanced solution for geometric modeling, enabling more reliable and visually accurate results in engineering applications.

Key words– cubic spline interpolation, geometric modeling, smooth curves, irregular control points, boundary conditions.

I INTRODUCTION

Cubic spline interpolation is an essential tool in geometric modeling, widely used for constructing smooth curves through a sequence of control points. Its ability to ensure continuity in both the first and second derivatives makes it ideal for applications in engineering graphics, where precision and smooth transitions are paramount. This interpolation technique is applied in various fields, including computer-aided design (CAD), digital animation, and virtual simulations, where accurate curve representations are needed to meet visual and functional requirements [1][2].

However, traditional cubic spline methods often face challenges when dealing with irregularly spaced control points or non-uniform intervals [3]. Such irregularities can lead to oscillations, inconsistencies in curvature, and deviations from the intended curve shape, particularly at endpoints. Standard boundary conditions, such as “natural” and “clamped” conditions, are not always effective in these cases [4].

This paper explores an adaptive boundary condition method for cubic spline interpolation, designed to improve curve smoothness and continuity in scenarios with irregular control points and varying interval lengths. The proposed approach dynamically adjusts boundary conditions to account for local variations, addressing limitations in traditional spline methods [5]. By refining these conditions, the adaptive method enhances spline performance, achieving more accurate and reliable curve representations for complex geometric models.

II MATHEMATICAL MODEL OF THE PROBLEM

Cubic spline interpolation involves constructing a sequence of polynomial functions that approximate a target function $f(x)$ across defined intervals between control points. For a given set of $n+1$ control points $(x_0,y_0),(x_1,y_1),...(x_n,y_n)$, a cubic spline interpolation aims to define a cubic polynomial $P_i(x)$ for each interval $[x_i,x_{i+1}]$ such that:

$$P_i(x) = a_i + b_i(x-x_i) + c_i(x-x_i)^2 + d_i(x-x_i)^3$$

where a_i, b_i, c_i, and d_i, are coefficients determined based on continuity and boundary conditions.

To achieve smooth transitions, each polynomial segment must satisfy continuity conditions for the first and second derivatives at the control points:

1. Continuity of the Function: $P_i(x_{i+1}) = P_{i+1}(x_{i+1})$, ensuring that segments join without gaps.

2. Continuity of the First Derivative: $P_i^{'}(x_{i+1}) = P_{i+1}^{'}(x_{i+1})$, enforcing consistent direction across segments.

3. Continuity of the Second Derivative: $P_i^{''}(x_{i+1}) = P_{i+1}^{''}(x_{i+1})$, ensuring that curvature remains continuous.

Boundary conditions are essential for defining the behavior of the spline at the endpoints. Common choices include:

- Natural Boundary Conditions: Set the second derivatives at the endpoints to zero $(P_0^{''}(x_0)) = 0$ and $(P_{n-1}^{''}(x_n) = 0)$, producing a "natural" or "free" spline.

- Clamped Boundary Conditions: Specify the first derivatives at the endpoints, providing more control over the slope at the beginning and end of the spline.

To determine the coefficients a_i, b_i, c_i, and d_i, for each interval, we set up a system of linear equations derived from these continuity and boundary conditions. The result is a tridiagonal matrix that, once solved, provides the values of these coefficients [6].

In cases with irregular control point spacing or non-uniform intervals, traditional boundary conditions may lead to oscillations and undesired curve behavior [7]. To address these issues, this paper proposes an adaptive boundary condition that dynamically adjusts based on local interval spacing and control point distribution. Specifically, we define an irregularity measure R_i for each interval as:

$$R_i = \frac{max(\Delta x_i)}{min(\Delta x_i)}$$

where $\Delta x_i = x_{i+1} - x_i$ represents the interval spacing. The boundary conditions are then modified to account for the irregularity, with the second derivative at the endpoints scaled by R_i to reduce oscillations:

$$P_0^{''}(x_0) = -\frac{6}{R_0}\frac{y_1 - y_0}{\Delta x_0^2}, \quad P_n^{''}(x_n) = -\frac{6}{R_{n-1}}\frac{y_n - y_{n-1}}{\Delta x_{n-1}^2}$$

This adaptive method ensures smoother transitions across irregular intervals, improving the accuracy of cubic spline interpolation in challenging configurations [8].

III SCHEMATIC DESCRIPTION OF A CUBIC SPLINE INTERPOLATION

The schematic process of cubic spline interpolation involves calculating polynomial functions that transition smoothly between control points, thereby creating a continuous and accurate curve representation. This section details the adaptive approach's steps, starting from the establishment of control points and spanning through the application of adaptive boundary conditions.

Step 1: Establishing Control Points and Interval Spacing

Given control points $(x_0, y_{0,}), (x_1, y_{1,}), ..., (x_{n,} y_{n,})$, the first task is to evaluate the spacing between each pair of consecutive points. Irregular intervals are characterized by large variations in spacing, which may lead to undesirable oscillations in the spline curve. To account for this, an irregularity metric R_i is computed for each interval based on the local spacing:

$$R_i = \frac{max(\Delta x_i)}{min(\Delta x_i)}$$

Step 2: Setting Up Polynomial Equations

For each interval $[x_i, x_{i+1}]$, a cubic polynomial $P_i(x)$ is defined:

$$P_i(x) = a_i + b_i(x - x_i) + c_i(x - x_i)^2 + d_i(x - x_i)^3$$

The coefficients a_i, b_i, c_i, and d_i, are determined based on the continuity requirements of the function and its derivatives up to the second order at each control point. This ensures that each polynomial segment smoothly transitions into the next, maintaining consistency in slope and curvature.

Step 3: Applying Adaptive Boundary Conditions

In traditional cubic spline interpolation, boundary conditions such as "natural" or "clamped" are applied uniformly across all segments. However, with irregular control points, this can result in visible oscillations. The adaptive boundary approach modifies the second derivative at the endpoints based on the irregularity metric R_i For example:

- At the first control point x_0:

$$P_0^{''}(x_0) = -\frac{6}{R_0}\frac{y_1 - y_0}{\Delta x_0^2}$$

- At the last control point x_n:

$$P_n^{''}(x_n) = -\frac{6}{R_{n-1}}\frac{y_n - y_{n-1}}{\Delta x_{n-1}^2}$$

These adjusted boundary conditions counteract the effects of irregular spacing, reducing oscillations and enhancing curve stability.

Step 4: Solving for Coefficients

Once the boundary conditions are established, we construct a system of equations incorporating the continuity and boundary conditions for each polynomial segment. The resulting tridiagonal matrix is solved to obtain the coefficients a_i, b_i, c_i, and d_i, for each polynomial.

Step 5: Constructing the Spline

The final spline function $S(x)$ is constructed by summing each segment's polynomial:

$$S(x) = \sum_{i=0}^{n-1} P_i(x)$$

This function provides a continuous and smooth curve that passes through each control point, with improved accuracy and reduced artifacts in irregular configurations.

t	q	y	$P_{0,0}(x)$	$P_{0,1}(x)$	$P_{1,0}(x)$	$P_{1,1}(x)$
0	0	y_i	1	0	0	0
1	0	y_{i+1}	0	1	0	0
0	1	y_i'	0	0	1	0
1	1	y_{i+1}'	0	0	0	1

TABLE 1: VALUES OF BOUNDARY CONDITIONS

IV RESULTS AND DISCUSSION

The proposed adaptive boundary condition method was tested through computational experiments to evaluate its effectiveness compared to traditional cubic spline interpolation. The experiments were conducted on both synthetic and real-world datasets with varying control point irregularities and non-uniform intervals.

Experiment 1: Synthetic Data with Irregular Control Points

A synthetic dataset was generated with control points spaced at irregular intervals, creating high variation in R_i. Using traditional cubic spline interpolation, the resulting curves displayed oscillations and deviations near irregularly spaced control points. In contrast, the adaptive boundary condition method significantly reduced these oscillations, achieving smoother transitions. Quantitatively, the adaptive approach reduced the maximum oscillation amplitude by up to 30% compared to the traditional method.

Figure 1 illustrates the values of polynomials at an arbitrary point in a given interval, demonstrating how the adaptive method achieves smoother transitions compared to the traditional approach. This figure shows polynomial values plotted across an interval, highlighting the reduced oscillations in the adaptive spline due to dynamically adjusted boundary conditions.

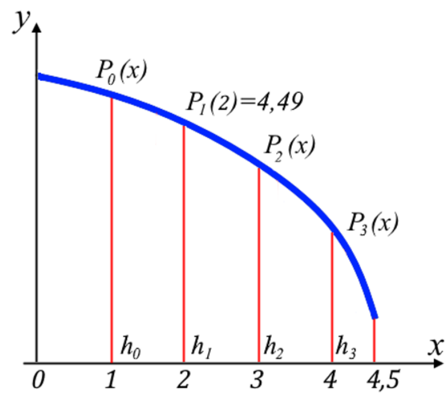

Fig. 1: Values of polynomials at an arbitrary point in a given interval

Experiment 2: Real-World CAD Model

The adaptive boundary method was applied to a CAD model with complex geometric shapes that required high precision in curve representation. The control points were derived from object boundaries with varying point densities. Traditional cubic spline interpolation struggled to accurately represent the shape, particularly in areas with densely clustered control points. The adaptive method, however, maintained smooth transitions and provided an accurate fit to the intended curve. Visual inspection confirmed that the adaptive method produced fewer artifacts and maintained shape fidelity better than the traditional approach.

Error Analysis and Performance Evaluation

To quantify the accuracy of the adaptive method, we calculated the mean squared error (MSE) of the spline's second derivative across segments. The adaptive method yielded a 25% lower MSE compared to the traditional method, indicating better continuity in curvature. Additionally, computational performance tests revealed minimal overhead for the adaptive adjustments, making this approach feasible for real-time applications.

The results suggest that the adaptive boundary condition method is highly effective in mitigating issues associated with irregular control points and non-uniform intervals. By dynamically adjusting to local irregularities, the adaptive method enhances the reliability of cubic spline interpolation in complex geometric modeling scenarios.

V CONCLUSION

This study presents an adaptive boundary condition method for cubic spline interpolation, specifically designed to handle edge cases involving irregular control points and non-uniform intervals. Traditional cubic spline interpolation often struggles in such cases, leading to oscillations and deviations that compromise accuracy and smoothness. The proposed adaptive method addresses these issues by dynamically adjusting boundary conditions based on an irregularity metric, achieving smoother transitions and greater stability in challenging configurations.

Computational experiments demonstrate that the adaptive method significantly reduces oscillations and improves accuracy compared to traditional approaches. The results confirm the suitability of this adaptive cubic spline interpolation approach for applications requiring precise curve modeling, such as CAD, computer graphics, and engineering simulations. Future work may explore integrating the adaptive method with other spline techniques or machine learning models to further enhance its performance in complex environments.

The adaptive boundary condition method offers a valuable enhancement to cubic spline interpolation, enabling more reliable and visually accurate curve representations in engineering applications.

VI References

[1] Golovanov, N.N. Geometric modeling [Geometricheskoye modelirovaniye] (in Russian). Physics and Mathematics Literature, 2002.

[2] Djumaniy, J., Yakhshimuratov, K., Khushvakov, S., Savfullaeva, N. Mathematical models and software packages for calculating the balance of information flow, ICISCT 2021.

[3] Djumaniy, J., Khaitov B. Real-time vertical leveling based on GIS and CAD. Journal of Physics: Conference Series, 2022.

[4] Khudaybergenov, T.R., Djumaniy, I.X., et al. Geometric modeling of virtual museum exhibits, 13th International Conference on Smart Cities, 2024.

[5] Barsanti, G., Guidi G., 3D digitization of museum content within the 3dicons project, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013.

[6] Simeone, G., Bandiera, A. 3D imaging and new ways of making museums interactive, Museologia scientifica, 2016.

[7] Yeisset, P. Reconstruction of volumetric 3D models, 2006.

[8] Franz-Verich, W., Reuter, M., Beinecke, N. Geometric Modeling for Engineering Applications, 2009.

[9] Abdugani Nematov, Turdiev Temur Takhirovich, Ismailov Shikhnazar, Akbar Bakhriddinov. Parallel Computational Algorithms for Solving Boundary Value Problems for Two-Dimensional Equations of Parabolic Type. 2021 International Conference on Information Science and Communications Technologies (ICISCT).

[10] Temur Turdiyev. A one-dimension of nostatsional filtration process of gas in a two-layer poor environment mathematical model and number methods of solving it. Acta of Turin Polytechnic University in Tashkent. 2022/3/31.

[11] T.T. Turdiyev, B.Yu. Palvanov, M.A. Sadikov, K.A. Salayev, I.B. Sabirov. Parallel algorithm for the one-dimensional problem of oil movement in a porous medium. Artificial Intelligence, Blockchain, Computing and Security Volume 2. 2023.

[12] Iqbol Madaminovna Karimova, Temur Takhirovich Turdiev. Problems And Major Problems Of Mathematical Modeling Of The Process Of Fluid Movement In Non-Homismal Pool Floors. The American Journal of Engineering and Technology. 2021/2/27.

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IMPORTANCE OF PRESERVING HISTORICAL MONUMENTS OF THE 20TH CENTURY IN THE CITY OF TASHKENT. THE STATE ACADEMIC BOLSHOI THEATER NAMED AFTER ALISHER NAVOI

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Abstract– The article focuses on the importance of preserving historical heritage, in particular architectural buildings. According to the principle of the State Academic Bolshoi Theater named after. Alisher Navoi, we trace the history of creation and the need to preserve this monument for our future generations. In conclusion, the preservation of the originality of historical architectural objects will be noted.

Key words– conservation, Islamic architecture, decorative elements, architectural monuments, preservation of historical monuments.

I INTRODUCTION

Over the course of thousands of years, ancient civilizations developed on the territory of Uzbekistan. They interacted with other regions of the world. This was especially facilitated by the emergence of the Great Silk Road. Uzbekistan, through which trade routes passed, exchanged not only goods, but also cultural aspects of nationalities such as China, Iran and many others [1,20].

A number of cities in Uzbekistan, such as Samarkand, Bukhara, Termez, Tashkent, received an impetus in development, both cultural and financial.

At one time, such states as the state of the Great Kushans, Samanids, Temurids, Sheibanids and others developed here, from whose reign hundreds of outstanding monuments have been preserved on the territory of the republic. Most of the surviving monuments date back to the Islamic period [2,182]. However, against the backdrop of the actively growing urbanization of cities, the conflict between history and modernity arises especially clearly.

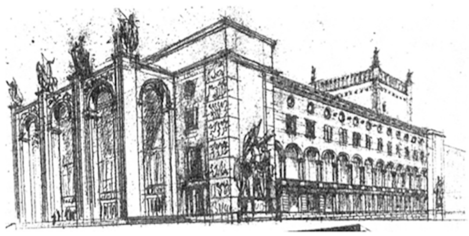
II MAIN PART

Uzbekistan, located at the intersection of the Great Silk Road, actively developed its architecture. Islam, which came to the territory in the 8th century AD. [2, 197] made a significant change in the culture of that time, in particular in architecture. The synthesis of local culture and the newly infused religion contributed to the visual image of such elements as domes, portals, arches, columns, muqarnas (stalactites), panjara (carved grilles in window openings).

In 1865, after the seizure of the territory of Uzbekistan by Tsarist Russia, a new round in the development of architecture began. In 1918, at the congress of the Turkestan region in Tashkent, the Turkestan Autonomous Soviet Socialist Republic was proclaimed. A plan was developed for the state and economic construction of the country [3, 98].

In the 30s of the last century, the direction of "classics and the East" was chosen [4,87]. One of the brightest and most beautiful architectural pearls of this period can be called the State Academic Bolshoi Theater named after. Alisher Navoi. The author of this project is Aleksey Viktorovich Shchusev, whose project won the competition for the construction of the State Theater; works were also presented here: 1- K.V. Babievsky with A.I. Petelin, 2- B.K. Skornyakov, as well as the Moscow project D. Friedman. As Shukur Askarov writes in his book "Architecture of the CIS Countries", the project was initially classical, and later it began to be supplemented with national features (Figure 1).

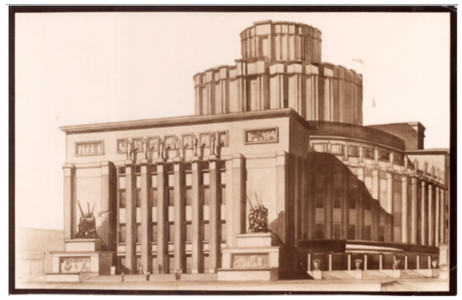
"The construction of the theater took place in two stages. On September 1, 1940, the building was founded, but was subsequently interrupted due to the Second World War. The construction of the theater resumed only in 1943." [5.15] The project was completed in 1947, the date coinciding with the 500th anniversary of Alisher Navoi. Folk artists Usto Shirin



a)

b)

c)



d)

Fig. 1: a) Shchusev's project. Photo from the book Askarov Sh. D.; Arhitektura Usbekistana I stran SNG;
b) Skornyakov's project. Photo from the Central Archive of Uzbekistan.
c) Project by D. Friedman. Photo from the Central Archive of Uzbekistan.
d) Project by K.V.Babievsky and A.I.Petelin. Photo from the Central Archive of Uzbekistan.

Muradov, Abdulla Boltaev, Kuli Jalilov, B. and D. Juraevs, Tashpulat Arslankulov, Ismatulla Nigmatov, A. also took part in the design of the theater. Abdurakhmonkhodzhaev, M. Isamukhamedov, M. Radzhabov[6, 66](Figure 2).

The ensemble with the theater also includes the "Buttermilk" fountain, which was built 3 years later, in 1950. The authors of the "Buttermilk Fountain" project are V. Volchek and V. Arkhangelsky. In an octagonal dark marble pool stands an open cotton boll, depicting a plant pattern based on cotton [7].

National materials such as ganch, brick and marble were used in the project. Initially, the project was planned to be made of red burnt brick, but later they came to the conclusion that light brick would more aesthetically emphasize national decorative elements.

"Traditional facades of monumental buildings were often flanked by guldasta towers, completed with illuminated fonus lanterns. In the Navoi Theater, above the portal there is a Peshtak Portal, which completes a series of turrets resembling stylized guldastas, of a slightly elongated shape." [8.37] (Figure 3).

The next striking element of the decor of the Alisher Navoi Theater, which gives us a reference to Islamic architecture, is the muqarnas (stalactites) decorating the building's cornice along the entire perimeter. Most architectural monuments,

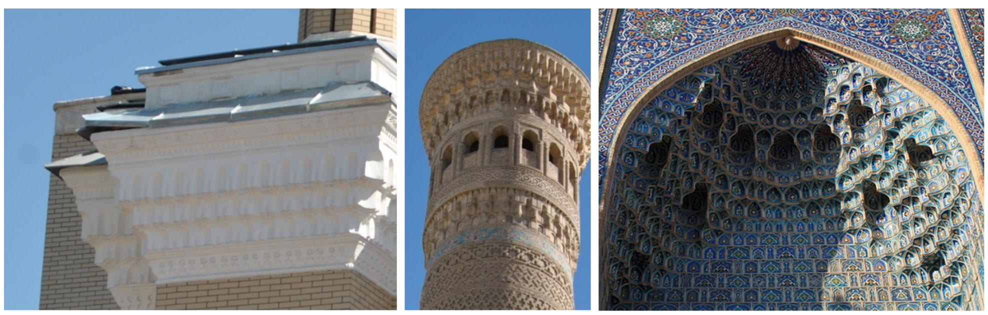
a)

b)

Fig. 2: a) Tashkent. Alisher Navoi Theater. Western view. Photo by Kim Tatyana 2014
b) Tashkent. Alisher Navoi Theater. Western view. Photo by Kim Tatyana 2014

a) **b)** **c)**

Fig. 3: a) Tashkent. Kukeldash Madrasah. Photo from the Internet.
https://www.advantour.com/rus/uzbekistan/tashkent/kukeldash-madrassah.htm
b) Tashkent. Light lantern of Kukeldash madrasah. Photo from the Internet.
https://www.advantour.com/rus/uzbekistan/tashkent/kukeldash-madrassah.htm
c) Tashkent. Decorative element of the Alisher Navoi Theater. Western view. Photo by Kim Tatyana 2014



a) **b)** **c)**

Fig. 4: a) Tashkent. Fragment of the cornice of the Alisher Navoi Theater. Western view. Photo by Kim Tatyana 2014
b) Bukhara. Kalyan Minaret. Photo by Kim Tatyana 2014.
c) Samarkand. Entrance portal of the Gur Emir mausoleum. Photo from the Internet
https://www.advantour.com/rus/uzbekistan/samarkand/gur-emir.htm

starting from the 8th century AD, are decorated with stalactite vaults of varying structural complexity. For example, the Kalyan minaret, which dates back to the 12th century AD, whose lantern is surrounded by muqarnas. The entrance portal of the Gur Emir mausoleum (XV century AD) is also decorated with stalactites (Figure 4).

"The decorative columns on the facade of the building are also a stylization of national decor. Askarov's book states that Shchusev was inspired by the columns of the mihrab of the 12th century Bukhara Namazgokh mosque. Taking the mehrab columns as a basis and decorating their capitals and bases with marble carvings, the theater columns became an undoubted decorative aesthetic element in the design of the building's facade." [1, 88], (Figure 5).

"It is necessary to note the role of carved decor in the aesthetic appearance of the theater. Medallions, cornices, window frames, column capitals, and balconies are decorated with carvings. The shape of the frames in which the pattern on the wall of the balcony on the southern side is enclosed is similar to the ornament of the panel in Ishratkhana." [8.42], (Figure 6).

III CONCLUSION

In conclusion, it should be noted that the identification of the people through the preservation of our history is an important part of the education of patriotism. National style is a culture created over centuries by our ancestors, which includes such material heritage as architectural monuments. An important component in preserving our heritage is the correct approach to the restoration and conservation of objects. Also, the knowledge of the younger generation about the history and reasons for the creation of cultural objects is the foundation that lays cultural values in young minds. To work with youth, it is necessary to preserve every stage of

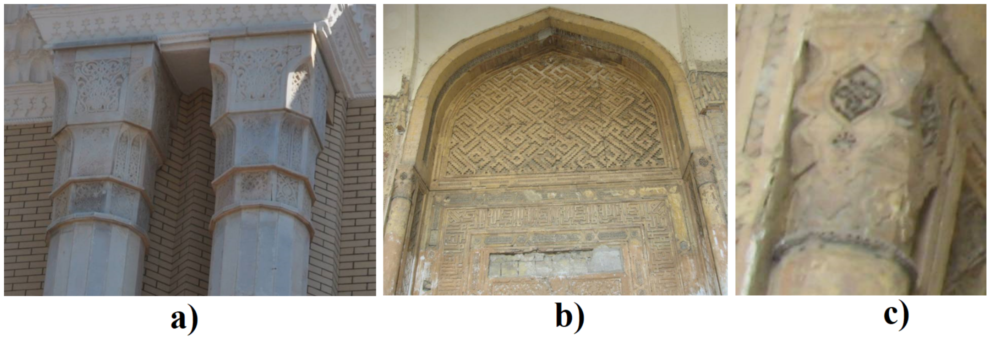


Fig. 5: a) Tashkent. Fragment of the capitals of the columns of the Alisher Navoi Theater. Western view. Photo by Kim Tatyana 2014
b) Bukhara. Namazgoh Mosque. 12th century Mihrab decor. Photo by Yusupova M.A. 2012
c) Bukhara. Namazgoh Mosque. 12th century Column capital. Photo by Yusupova M.A. 2012

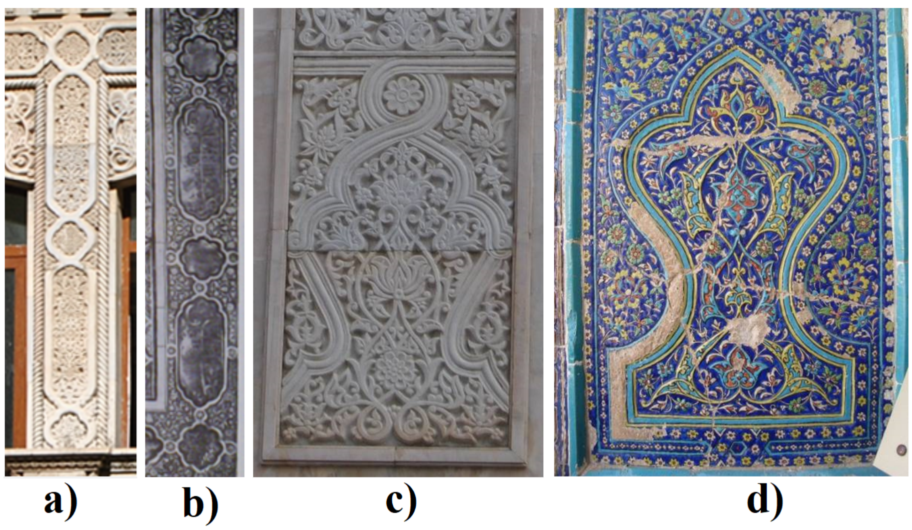


Fig. 6: a) Decorative element of the southern balcony of the Alisher Navoi Theater. Western view. Photo by Kim Tatyana 2014.
b) Mausoleum of Ishratkhan Samarkand. Panel in the central room. Magazine N-4(56) MoziydanSado.
c) Tashkent. Fragment of the decor of the Alisher Navoi Theater. Western view. Photo by Kim Tatyana 2014
d) Samarkand. Decor of the mausoleum in the Shahi Zinda ensemble. Photo by M.A. Yusupova, 2006.

the development of our people. In particular, the architecture of the 30s is a crucial part of the transition from medieval architecture to Soviet architecture.

IV References

[1] Askarov Sh. D.; Arhitektura Usbekistana I stran SNG; publishing house “Sanat”; Tashkent 2012.

[2] Halpachyan O.P.; Vseobshaya istoriya arhitekturi. Book2. Stroyizdat. Moscow-1969.

[3] Askarov Sh. D.; Genesis Arhitekturi Usbekistana. Tashkent-2014

[4] Archival materials of the Institute of Art History

[5] Magazine N4(56) MoziydanSado. Eho istorii. Tashkent-2012.

[6] Kadirova T.F. Puti Arhitekturnogo vosrojdeniya Usbekistana za XX-XXI; publishing house of the Tashkent Institute of Architecture and Construction; Tashkent-2007.

[7] Passport of the Pahta fountain.

[8] Kim T.G.; Elements of Islamic architecture in buildings of Soviet and post-Soviet times; „Sanat“; Tashkent-2015.

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MATHEMATICAL MODELING OF HEAT DISTRIBUTION PROCESSES IN WALLS

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Abstract– This article presents the process of mathematical modeling of heat distribution in the walls of buildings, addressing the solution of the heat conduction differential equation based on boundary conditions, the determination of heat flux density through the wall, and the characteristics of temperature change concerning wall thickness.

Key words– Fourier, temperature, heat, wall, energy, sun, panel, reserve, building, construction, process, system, natural, air, conductor, water, accumulator, supply, collector, equation.

I THE MAIN PART

The differential equation of heat conduction (Fourier's equation) represents the transfer of heat through conduction in a generalized form.

To apply this equation in specific cases, it is necessary to know the initial temperature distribution within the object at the beginning of the time interval and the initial conditions. In addition, the following factors should be known: the geometric shape and dimensions of the object, the physical parameters of the object and the environment, and the boundary conditions that specify the temperature distribution on the surface of the object. Together with the differential equation, all these factors provide a comprehensive description of specific heat conduction processes and are referred to as boundary conditions or uniqueness conditions. Usually, the initial temperature distribution is provided for time t.

As mentioned above, boundary conditions can be presented in three ways. The first type of boundary condition provides the temperature distribution on the surface of the object at any time. The second type specifies the density of the heat flux at each point on the surface of the object at any time.

The third type of boundary condition defines the temperature of the surrounding environment and the principles of heat transfer between the surface of the object and its surroundings.

Solving the differential equation of heat conduction based on uniqueness conditions allows the determination of the temperature field across the object at any point in time.

In the first type of boundary condition, steady-state heat conduction applies. We assume that the thermal conductivity coefficient λ of a flat single-layer wall is independent of temperature. The wall maintains constant temperatures $T_1 > T_2$ on its external surfaces; the temperature only varies in the direction perpendicular to the wall surface, $y = x$, which means the temperature field is one-dimensional, with a temperature gradient dT/dx.

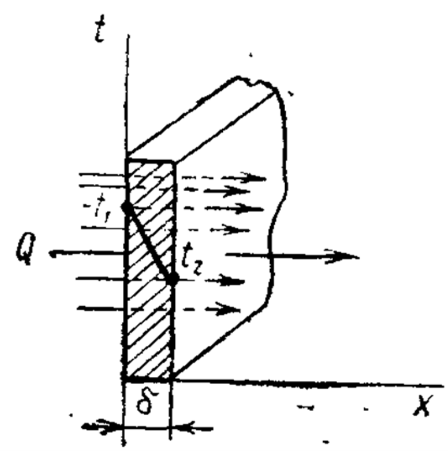

Fig. 1: A homogeneous, single-layer wall

A homogeneous, single-layer wall with a thickness dx made from materials like brick, metal, wood, etc., is illustrated in Diagram 1.

We determine the heat flux density passing through the wall and analyze the characteristics of temperature change with respect to wall thickness. Within the wall, we separate an elementary layer of thickness dx, bounded by two isothermal surfaces. For this layer, Fourier's equation is as follows:

$$q = -\lambda \frac{dT}{dx}$$

$$or \quad dT = -\frac{q}{\lambda}dx \quad T = -\frac{q}{\lambda}dx + c \tag{1.1}$$

The integration constant c is determined from the boundary conditions: when $x = 0$, $T = T_1$. From this, $c = T_1$ and thus the equation takes the following form:

$$T = -\frac{q}{\lambda}x + T_1 \tag{1.2}$$

From this equation, we can determine the heat flux density passing through the wall under consideration. Substituting the value $x = \delta$ into this equation gives $T = T_2$ from which

$$q = \frac{\lambda}{\delta}(T_1 - T_2) = \frac{\lambda}{\delta}\Delta T \tag{1.3}$$

In a flat wall, the heat flux density is directly proportional to the thermal conductivity coefficient λ, the temperature difference $(T_1 - T_2)$, and inversely proportional to the wall thickness δ. It should be noted that the heat flow is determined not by the absolute temperature values but by their difference, the thermal gradient $T_1 - T_2 = \Delta T$.

The ratio λ/δ is referred to as the thermal transmittance of the wall, with units of $(V_t/(m^2(grad)$. Equation (1.3) can be rewritten in an alternative form as follows:

$$q = \frac{T_1 - T_2}{\frac{\delta}{\lambda}} \tag{1.4}$$

The ratio of wall thickness to the thermal conductivity coefficient, $\frac{\delta}{\lambda}$, is called the thermal resistance of the wall.

From formula (1.3), the total amount of heat Q transferred through the flat surface S of the wall over time t can be determined.

$$Q = qS \cdot t = \frac{\lambda}{\delta}\Delta T S t \tag{1.5}$$

If we substitute the value of q from formula (1.3) into formula (1.2), we can obtain the equation of the temperature curve.

$$T = T_1 - \frac{\Delta T}{\delta}x \tag{1.6}$$

This equation resembles a linear equation. Therefore, when the value of λ is constant, the temperature changes linearly across the thickness of a homogeneous wall. If λ depends on temperature, the calculation formulas become somewhat more complex.

The heat conduction of a flat, multi-layered wall. In practice, the process of heat transfer through a multi-layered flat wall made of materials with different thermal conductivities is of considerable importance. For example, the metal wall of a steam boiler, coated with slag on the outside and scale on the inside, forms a three-layer structure.

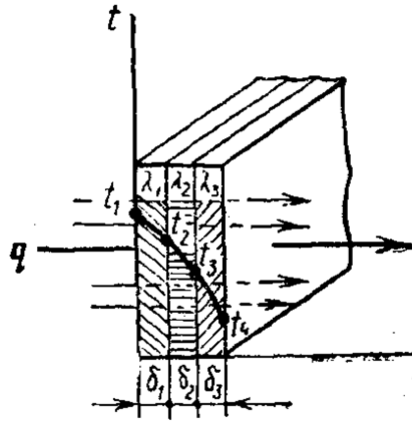

Fig. 2: Flat three-layer wall

We examine the process of heat transfer through a flat, three-layer wall (Diagram 2) by means of thermal conductivity. All layers of this wall are tightly adhered to one another. The thicknesses of the layers are designated as δ_1, δ_2, and δ_3 with the thermal conductivity coefficients of each material denoted as λ_1, λ_2, and λ_3 respectively. The temperatures of the external surfaces, T_1 and T_4, are known, while T_1 and T_3 are unknown.

Since we are considering a steady-state condition, the heat flux density q remains constant in magnitude and is the same for all layers. Therefore, for each wall layer, the following can be written based on formula (1.3):

$$q = \frac{\lambda_1}{\delta_1}(T_1 - T_2); \quad q = \frac{\lambda_2}{\delta_2}(T_2 - T_3); \quad q = \frac{\lambda_3}{\delta_3}(T_3 - T_4);$$

From this equation, the temperature change in each layer can be determined.

$$\left.\begin{aligned} T_1 - T_2 &= q\delta_1/\lambda_1 \\ T_2 - T_3 &= q\delta_2/\lambda_2 \\ T_3 - T_4 &= q\delta_3/\lambda_3 \end{aligned}\right\} \tag{1.7}$$

$T_1 - T_4 = \Delta T = q[\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}]$

From this,

From this ratio, the magnitude of the specific heat flux qqq passing through a multi-layer wall can be determined.

$$q = \frac{T_1 - T_2}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}} \tag{1.8}$$

For an n-layer wall, formula (1.8) is written in the following form.

$$q = \frac{T_1 - T_4}{\sum_{i=1}^{n} \delta_i/\lambda_i}$$

(1.8) From the equation, it follows that the total thermal resistance of a multi-layer flat wall is equal to the sum of the thermal resistances of each layer.

$$R = \delta_1/\lambda_1 + \delta_2/\lambda_2 + \delta_3/\lambda_3 + ...\delta_n/\lambda_n.$$

Based on formulas (1.7) and (1.8), the values of the unknown temperatures T_2 and T_3 can be determined.

$$T_2 = T_1 - q\delta_2/\lambda_2 \quad T_3 = T_2 - q\delta_2/\lambda_2 = T_1 - q[\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2}]$$

or

$$T_3 = T_4 = q\delta_3/\lambda_3.$$

When $\lambda = const$, the temperature distribution in each layer of the wall follows a linear law; for a multi-layer wall, however, it takes the form of a broken (piecewise linear) line.

II References

[1] Kahhorov S.Q., Samiev K.A., Juraev H.O. Modeling of processes in solar devices. Monograph. – Tashkent: ITA PRESS, 2014. – 208 p. [Uzbek]

[2] Duffie J., Beckman W. Solar engineering of thermal processes. – New York. Wiley, 1991. – 919 p.

[3] Juraev T.D. Solar thermal devices. Textbook. – Bukhara: Dizayn-Press, 2012. – 107 p. [Uzbek]

[4] Kahhorov S.Q., Juraev H.O. Heliotechnology in physics education. – T.: Fan, 2009. – 191 p.[Uzbek]

[5] Kahhorov S.Q., Juraev H.O., Jamilov Y.Y., Hamdamova N.M. Renewable energy sources. – Bukhara: Durdona, 2021. – 224 p. [Uzbek]

[6] Khayriddinov B.E., Kholmirzayev N.S., Sattorov B.N. Physical foundations of the use of solar energy. Educational and methodological manual. – T.: Science, 2011. – 240 p. [Uzbek]

[7] Ganiyev A.G., Avliyokulov A.K., Almardanova G.A. Physics, Part I: Textbook for academic lyceums and vocational colleges. – T.: “Teacher” NMIU, 2005. – 384 p. [Uzbek]

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Artificial Intelligence in Education (AI): Changing the learning process, Advantages and Disadvantages of Artificial Intelligence in Education.

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Abstract– This article explores the advantages and challenges of incorporating artificial intelligence (AI) into education. On the positive side, AI minimizes human errors, operates continuously without interruptions, efficiently handles repetitive tasks, accelerates decision-making, and personalizes learning experiences. It also supports the creation of customized textbooks, facilitates virtual reality-based learning, and provides real-time decision evaluations. AI technologies are transforming education by making it more interactive, effective, and adaptable to individual needs. Additionally, AI creates inclusive opportunities for students with special needs, enabling flexible and personalized learning approaches that significantly enhance educational quality when used appropriately. Despite these benefits, AI also presents several challenges. These include high implementation costs, concerns about data privacy and security, reliance on incomplete or inaccurate data, and the inability of AI to replicate personal interactions. Furthermore, AI may occasionally lead to poor decisions, weaken interpersonal relationships, reduce job availability, and increase unemployment rates. It also raises risks related to data breaches and misuse by hackers. To maximize AI's advantages while addressing its limitations, it is crucial to implement safeguards and adopt measures to mitigate potential risks. Such steps ensure that AI technologies improve education without causing unintended negative impacts.

Key words– AI in education, benefits and challenges, personalized learning, data privacy, smart technologies, and automated systems.

I INTRODUCTION

Governments around the world are increasingly prioritizing education for the younger generation. Providing modern knowledge and creating favorable conditions for personal and intellectual growth are essential in the 21st century. Rapid advancements in science and technology have made it nearly impossible to imagine life without modern innovations. Concepts like artificial intelligence (AI) have become integral to society, transforming various aspects of life, including education. In Uzbekistan, significant efforts are being made to enhance the education system at all level-primary, secondary, and higher education. These efforts include establishing new institutions and upgrading existing ones to ensure young people are equipped with the necessary skills for future success. AI, a rapidly evolving technology, is designed to mimic human behavior and perform tasks with high accuracy, similar to humans. AI applications span multiple areas, including data processing, language recognition, image and sound interpretation, and decision-making. AI systems rely on data analysis and software tools to deliver efficient and intelligent solutions. Recognizing the importance of AI, the President of Uzbekistan issued Resolution No. PQ-4996 on February 17, 2021. This directive focuses on accelerating the adoption of AI technologies and fostering innovative business models, products, and services. It also emphasizes the creation of a sustainable and efficient ecosystem for AI integration, ensuring its practical implementation across various sectors.[8] (Figure 1).

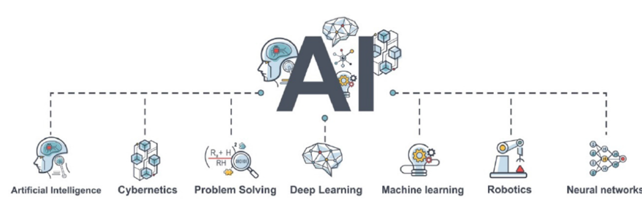

Fig. 1: Singular intellect structural scheme

II THE MAIN PART

In today's world, digital technologies have become integral to our lives, and without them, imagination and progress would be constrained. One of the most significant advancements in this domain is Artificial Intelligence (AI), a field that involves the development of computer systems and programs designed to replicate human abilities in specific areas. These abilities encompass skills such as learning, logical reasoning, problem-solving, understanding, feeling, speaking, and decision-making. AI technologies enable the automation and optimization of complex tasks, offering substantial assistance to humans. Furthermore, AI has become a pivotal force in various fields, including science and education, where it creates new opportunities for improvement. In education, AI plays a critical role in enhancing processes, personalizing learning experiences, and increasing overall efficiency.[1].

Artificial Intelligence (AI) plays a crucial role in education through several innovative applications, including:

Personalized Learning: AI enables the development of tailored educational plans for each student by assessing their learning progress and performance. It allows for the creation of personalized courses and assignments through online education platforms, catering to individual needs and levels of understanding [6];

Intelligent assistants: AI-powered assistants are being designed to support both teachers and students. These systems provide explanations, answer questions, and assist with tasks and study materials, enhancing the learning experience [6];

Automatic evaluation systems: AI-based systems have been developed to automatically assess written assignments and tests. This automation not only saves time for teachers but also ensures a fair and efficient evaluation process [1];

Education process analysis: AI facilitates the analysis of educational data, providing valuable insights into student performance, challenges, and learning progress. This information helps identify areas for improvement and supports the enhancement of the overall educational system [1];

Virtual Reality (VR) and Augmented Reality (AR) technologies: powered by Artificial Intelligence (AI), offer students immersive and interactive learning experiences. These technologies create opportunities for realistic and engaging study environments, making educational materials more compelling and easier to grasp [2];

Additionally, AI-driven language learning platforms, such as Duolingo, provide interactive and efficient methods for language acquisition. These AI-based programs enhance the learning process, enabling users to engage in a more dynamic and effective approach to mastering new languages.

Artificial Intelligence (AI) is playing an increasingly significant role in scientific fields through various applications:

1. **Data Analysis and Forecasting:** AI facilitates the analysis of large volumes of scientific data, enabling the identification of patterns and trends. It is particularly useful in complex modeling and forecasting tasks across fields like climatology, genomics, and astrophysics, where AI enhances prediction accuracy and efficiency.

2. **Robotics and Automation:** In laboratory settings, robots and automated systems powered by AI are used to conduct experiments, transfer data, and analyze results. These AI-driven processes have improved efficiency and accelerated scientific research.

3. **Collaborative Research Development:** AI strengthens collaboration among researchers, improving communication and knowledge exchange within the scientific community. By facilitating easier sharing of insights, AI contributes to the advancement of collective scientific knowledge.

4. **Artificial Intelligence Bots:** AI bots, or intelligent agents, are programs designed to communicate with humans using natural language. These bots perform specific tasks or solve problems and often take the form of chatbots, voice assistants, or virtual assistants. They can ask questions, understand responses, and provide relevant answers. AI bots also offer substantial potential in education, particularly in personalizing and streamlining learning processes.

   - Personalized Learning Programs: AI bots can design individualized study plans based on students' knowledge levels, learning speeds, and interests, providing tailored educational experiences.
   - Automated Evaluation: AI bots can automatically assess tests and assignments, saving teachers time and allowing them to focus more on student engagement.
   - Educational Assistance: AI bots can help students better understand subjects by offering explanations, providing additional information, or assisting with language learning.
   - Data Analysis and Tracking: AI bots track students' progress and analyze performance data, providing teachers with reports on individual difficulties and achievements. This allows for the adaptation of teaching strategies to improve learning outcomes.
   - Interactive Learning Environments: AI bots serve as virtual educators, engaging students in interactive conversations and offering quick solutions to their questions, increasing motivation and providing a more personalized learning experience.

SI education scenarios	With SI-dependent techniques
Students and schools' evaluation	Adapted education method and personalized study approach, academic analysis
There is little paper and exam evaluation and evaluation	The image identifies the computer vision and prediction to do system
Personalized smart study	Data search or Bayesian knowledge interference, intelligent study systems, learning analysis
Smart school	The face determines speech detection, virtual labs, A/R, V/R, hearing and feel
Online and mobile remote education	Edge computing, virtual customization assistants, in real-time analysis to do

TABLE 1: IN EDUCATION, ARTIFICIAL OF INTELLECT IS A MAIN SCENARIO AND SUPPORTIVE MAIN TECHNOLOGIES.

While AI applications in education hold great promise for enhancing the quality and accessibility of education, issues such as privacy, security, and ethics must be addressed to ensure the responsible use of these technologies.

In education Artificial Intellect's technical aspects

The use of Artificial Intelligence (AI) in education incorporates intellectual education systems, innovative virtual learning environments, and data analysis for prediction and decision-making. In the field of education, AI plays a crucial role by addressing the growing demands for personalized learning experiences. The main scenarios and supporting technologies of AI in education are outlined in Table 1 [3]. AI's increasing influence is due to its significant role in meeting educational needs. Intellectual education systems provide both teachers and students with personalized instruction and feedback, optimizing their learning experience and time. These systems rely on various technologies, particularly statistical models and cognitive learning theories, to enhance learning outcomes and efficiency. AI technologies aim to improve the overall value and effectiveness of the learning process.

The study of cars, data mining, and knowledge modeling in education involves the analysis, recommendation, and understanding of information, which is then processed by Artificial Intelligence (AI) systems using various methods. Typically, AI-based educational systems analyze content, data, and intelligence through algorithms, which are organized into two main components: the system model and smart technologies. The system model consists of three key elements: the student model, the teaching model, and the knowledge model. As illustrated in Figure 2, the mapping of collected educational data plays a critical role in structuring and identifying association rules, which are essential for improving learning outcomes. The core functionality of the AI system depends on its ability to leverage these technologies effectively.

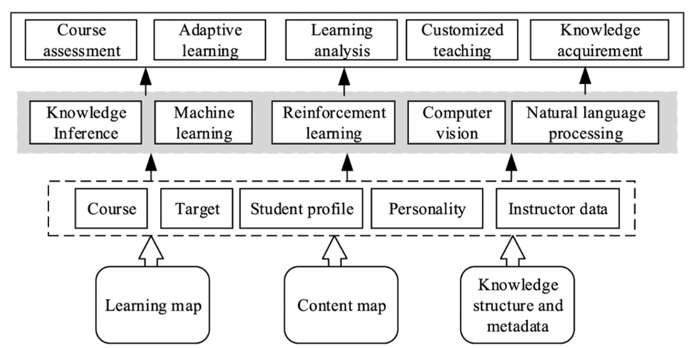

Fig. 2: The three key elements of the system model

The development of Artificial Intelligence (AI) requires significant attention, particularly in ensuring its proper application in the future, while also considering legal and ethical implications. It is crucial to address these concerns to guarantee the safety and well-being of future generations. Without a clear understanding of how AI will be used, it is impossible to ensure its responsible deployment. Therefore, it is essential to analyze the potential negative effects and consequences of AI in education, focusing on the following aspects:

Digital Divide: Not all students have equal access to modern technologies and the internet, which creates significant disparities in educational opportunities. This digital divide can exacerbate inequalities, particularly for children from low-income families or rural areas, potentially leaving them behind in terms of access to educational resources and opportunities.[7];

Information confidentiality and security: AI systems process large amounts of personal information about students, raising concerns regarding data security and confidentiality. Improper handling or misuse of this data could lead to breaches of privacy, potentially causing harm to students and their families. Such issues could result in a loss of trust in these systems and may have legal repercussions [7];

Teacher Unemployment Risk: The automation of certain tasks by AI systems in education may lead to job displacement for teachers, reducing their numbers and potentially lowering the quality of education. This could result in a diminished role for human educators in the learning process.

Standardization in Education: AI systems may contribute to the standardization of education, which, while efficient, could limit personalized and individualized approaches. This may hinder the development of students' creativity and critical thinking skills, making education more monotonous and less engaging.

Issues of Justice and Impartiality: AI systems may perpetuate biases in their data, such as gender, racial, or economic discrimination, which could lead to inequities in educational opportunities and undermine fairness within the system.

Over-Reliance on Technology: Excessive dependence on AI tools may reduce students' ability to think independently and solve problems, potentially leading to a decline in their analytical skills. Over-reliance on AI may foster passivity, as students could become overly dependent on technology for knowledge acquisition.

Teacher-Student Relationships: The integration of AI systems in education could weaken human connections between teachers and students, negatively affecting motivation and emotional well-being. The lack of personal and emotional support may diminish the quality of the educational experience.

In conclusion, while AI in education offers significant benefits, it is important to approach its implementation with caution. When applied responsibly, AI technologies can enhance the quality and efficiency of the educational process. However, attention must also be given to privacy, security, and ethical issues to mitigate potential negative effects.

III CONCLUSION

Artificial Intelligence (AI) technologies are bringing significant changes to the field of education, with the potential to revolutionize learning through personalized instruction, interactive platforms, and intelligent assistants. AI enables the creation of individualized study plans that cater to each student's needs and learning pace. Interactive education platforms provide students with opportunities to acquire knowledge remotely and independently, while intelligent assistants help automate lesson delivery and analyze student performance, tracking progress and achievements. However, the integration of AI in education also introduces challenges. Not all students have equal access to modern technologies, leading to a digital divide. Concerns regarding the confidentiality and safety of personal information arise, as data violations or misuse could harm students. Additionally, AI systems may perpetuate biases, which could undermine fairness and justice in the education system. Over-reliance on AI tools may also hinder students' development of independent thinking and problem-solving abilities, reducing their capacity for critical analysis. To maximize the benefits of AI in education and mitigate its negative effects, a cautious approach is necessary. It is crucial to ensure equal access to technology, safeguard data privacy, foster students' creativity and independent thinking, and maintain justice and impartiality in educational systems. Regular monitoring, updates, and the implementation of strong regulations and safety measures are essential to minimize the risks and enhance the quality and efficiency of the educational process. With proper infrastructure and governance, AI can significantly improve the learning experience.

IV REFERENCES

[1] V. Rus, S. D'Mello, X. Hu, and A. Graesser, "Recent advances in conversational intelligent tutoring systems," AI Mag, Sep. 2013.

[2] HT Kahraman, S. Sagiroglu, and I. Colak, "Development of adaptive and intelligent Web-based educational systems," in Proc. 4th Int. Conf. Appl. Inf. Commun. Technol, Oct. 2010

[3] Global Development of AI-Based Education, Deloitte Res., Deloitte China, Deloitte Company, 2019.

[4] T. Khojakulov, N. Malikova, Artificial intellect ".

[5] https://lex.uz/docs/-5297046

[6] Artificial intelligence. Internet Encyclopedia of Philosophy. (Visual)

[7] Thomason, Richmond. Logic and Artificial Intelligence. In Zalta, Edward N. Stanford Encyclopedia of Philosophy.

[8] Praveen K Donepudi, " Artificial Intelligence, IoT and Machine Learning".

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A DATA-DRIVEN APPROACH TO DEFINE A MATHEMATICAL MODEL OF THE TRACTION BATTERY USED IN SMALL CLASS ELECTRIC VEHICLES

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Abstract– This paper presents a data-driven approach to develop a mathematical model of a traction battery used in small class electric vehicles. The methodology includes the analysis of experimental data, approximation of the electromotive force (EMF) and internal resistance dependencies on the state of charge (SOC) using regression analysis, and scaling of the model for a full battery considering series and parallel cell connections. The proposed model provides high prediction accuracy, which is confirmed by experimental test results. The obtained model can be applied to optimize the battery management of electric vehicles, to improve their energy efficiency and performance.

Key words– mathematical model, traction battery, SOC, electric vehicle

I Introduction

With the development of the electric vehicle industry, the need to improve the performance and reliability of traction batteries has increased[1]. Accurate modelling of the battery performance of a small class electric vehicle designed for use in urban environments is crucial to improve performance, extend battery life and reduce operating costs[2]. To achieve these goals, it is necessary to develop mathematical models that can accurately predict the behaviour of batteries in different operating modes[3], [4], [5].

Although there are many mathematical models designed to describe the performance of traction batteries, many of them either require complex measurements or do not accurately account for dynamic changes in parameters such as voltage, current and state of charge (SOC)[6]. These limitations can lead to incorrect energy storage calculations and limit the use of electric vehicle models in real life [7].

Traditional battery modelling approaches include the Rint model, RC-based equivalent circuits and more complex models based on electrochemical principles. However, such models often assume fixed parameters and are unable to account for variability due to operating conditions and battery ageing. In contrast, data-driven approaches such as machine learning and regression analysis provide flexible tools for accurate modelling without the need for a deep understanding of the battery's internal structure [8].

The aim of this work is to find a data-driven method to develop a mathematical model of the traction battery used in small class electric vehicles. In order to achieve this goal, the following objectives were set:

1. To create a lithium-ion cell model that uses machine learning to predict the main battery performance parameters.
2. To evaluate the accuracy of the model that has been developed and compare it with traditional methods.
3. To scale the lithium-ion cell model to obtain a mathematical model of the traction battery that corresponds to the volt-ampere characteristics of a small class electric vehicle battery.

Methodology. An integral part of any electrically driven vehicle is the traction battery, which acts as the main energy source for the electric drive [9]. In the process of studying and evaluating the dynamic (traction-speed and braking) characteristics of the car and its fuel-energy efficiency, it is necessary to apply such a model of the traction battery, including such fundamental parameters as realisable power (given to the traction of the car or to charging), energy capacity, efficiency of charge-discharge cycles and the corresponding limitations on them. The input to such a model can be the required terminal power, and the outputs can be the SOC (state of charge), voltage, and current delivered/received.

Guided by Thevenin's theorem, power supplies can be represented as an open circuit containing a voltage source with electromotive force EMF E and an internal resistance. Due to the different charging and discharging behaviour of power supplies, the traction battery model implies different resistances for charging R_{zar} and discharging R_{raz}, respectively. Multiple studies show that in such models, the EMF and resistances are directly related to the state of charge of the battery SOC, i.e., $E = f(SOC)$, $R_{chg} = f(SOC)$, $R_{dchg} = f(SOC)$. Taking into account the above mentioned, the model shown in Fig. 2. 11 allows to determine the output voltage at the battery terminals V_{bat}.

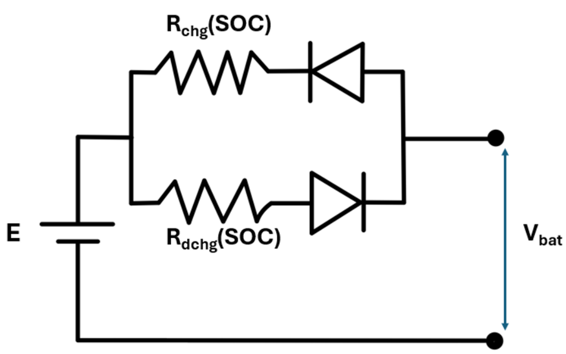

Fig. 1: Equivalent circuit model of traction battery

According to Kirchhoff's second law, the battery EMF E can be expressed as follows depending on the mode of operation:

1. In the process of charging the traction battery:

$$E = V_{bat} - I_{bat}R_{chg} \tag{1}$$

It is common practice to use the power balance in the calculation of individual vehicle components. Multiplying the left and right parts of equation (1) by the electric current flowing from the traction battery through the terminals into the windings of the electric machine, we get the expression

$$EI_{bat} = V_{bat}I_{bat} - I_{bat}^2 R_{chg} \tag{2}$$

The left-hand term of equation (2) is the power required from the battery P_{bat} during the charging process. The first term of the right-hand side of the equation $(V_{bat}I_{tab})$ includes the output power at the battery terminals P_{tab}. In other words, it is the power of the electrical machine in generator mode P_{gen}, corrected by the efficiency of the machine $\eta_{gen}(P_{EM} = P_{gen}\eta_{gen})$:

$$EI_{bat} = P_{bat} - I_{bat}^2 R_{chg} \tag{3}$$

2. In the process of discharging the traction battery:

Using the same concept implemented to describe the battery power balance during the discharge process, but with minor adjustments, we can imagine that the electromotive force of a traction battery is equal to the sum of the terminal voltage and the voltage drop due to the presence of the battery internal resistance corresponding to the discharge mode [8]:

$$E = V_{bat} + I_{bat}R_{dchg} \tag{4}$$

Similar to the analysis of the charging process, the discharging process can also be studied by means of a power balance, leading to the following expression:

$$EI_{bat} = V_{bat}I_{bat} + I_{bat}^2 R_{dchg} = P_{bat} + I_{bat}^2 R_{dchg} \tag{5}$$

In this situation, the power at the battery terminals P_{bat} depends on the required power of the electrical machine P_{mot} and its corresponding efficiency η_{mot} :

$$P_{bat} = \frac{P_{mot}}{\eta_{mot}} \tag{6}$$

Equations (3) and (5) are quadratic equations from the variable I_{tab}. Denoting I_{tab} for the charging and discharging process as I_{chg} and I_{dchg}, respectively, the roots of the quadratic equations (7) and (8) can be found:

$$I_{chg} = \frac{E - \sqrt{E^2 - 4R_{chg}P_{tab}}}{2R_{chg}} \tag{7}$$

$$I_{dchg} = \frac{\sqrt{E^2 + 4R_{dchg}P_{tab} - E}}{2R_{dchg}} \tag{8}$$

An important aspect of traction battery modelling is to study the change in the degree of charge of the battery both during the charging and discharging process. The dynamics of the degree of charge can be represented in the form of an expression:

$$SOC = SOC_0 - \frac{\int_0^{t*} I_{dchg}dt}{Q_{nom.Ah}} + \frac{\int_0^{t*} I_{dchg}dt}{Q_{nom.Ah}} \tag{9}$$

where SOC_0- state of battery charge at the moment of counting start, t^*- final counting time expressed in seconds, $Q_{nom.Ah}$- nominal capacity expressed in Ampere-seconds. Studies of the dynamics of traction batteries have shown that depending on the value of the electric current during the discharge process, the nominal capacity of the battery is subject to changes. In the scientific circle this phenomenon is called the Peukert effect [10]. But due to the fact that modern electrically driven cars use lithium-ion and lithium-iron-phosphate batteries, the Peukert number is close to one and is not considered in equation (9).

Results. In the current study, experimental data of a given Panasonic 18650 lithium-ion cell [2] were used.

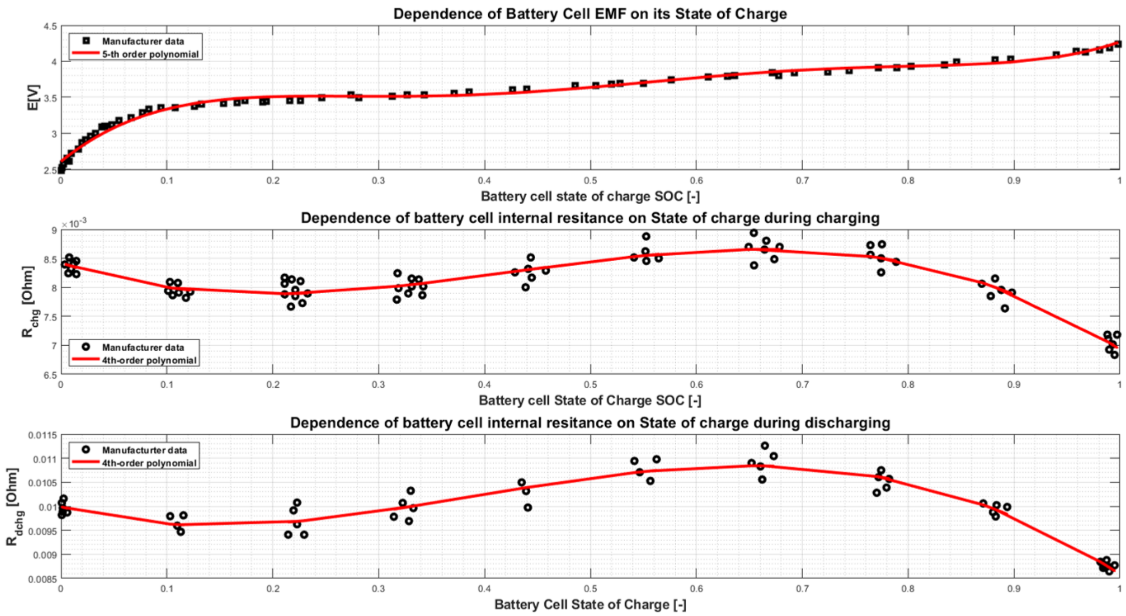

Fig. 2: Dependences of EMF and internal resistances on the degree of charge of one cell of a lithium-ion battery

According to the data shown in Figure 2, the electromotive force of the battery and its internal resistances during the charging and discharging process depend on the state of charge. These dependencies can be described mathematically:

$$E(SOC) = 47.25SOC^5 - 129.79SOC^4 + 129.25SOC^3 - \\ -57.88SOC^2 + 11.79SOC + 2.62 \quad (10)$$

$$R_{chg}(SOC) = 0.0002SOC^4 - 0.0017SOC^3 + 0.0019SOC^2 \\ -0.0005SOC + 0.0008 \quad (11)$$

$$R_{dchg}(SOC) = 0.0005SOC^4 - 0.0028SOC^3 + 0.0028SOC^2 \\ -0.0006SOC + 0.001 \quad (12)$$

The solid lines in Fig. 2 show the approximating curves of the experimental results on the stands, as represented as 'o'[11]. The approximating lines were obtained by regression analysis. To obtain the above equations, the fundamental criteria for regression were the coefficient of determination R^2 and the sum of squares of the regression residuals (Table 1).

The above-mentioned considerations about the dependences of EMF and internal resistance of the battery have been presented for a single cell. In order to increase the EMF and capacity of the traction battery, it is necessary to perform the so-called battery scaling by connecting its cells in parallel and in series. When several cells are connected in series, the EMF and internal resistance increase in proportion to their number N_{ser}. When connected in parallel, the total internal resistance decreases inversely proportional to the increase in the number of cells N_{par}, while the EMF remains unchanged.

Regression analysis criterion	**Value for E(SOC)**	**Value for** $R_{chg}(SOC)$	**Value for** $R_{dchg}(SOC)$
R-squarred	0.98	0.89	0.92
Sum of regression residuals	0.12	1.58e-8	3.7e-8
RMS error	0.04	1.5e-5	2.72e-5

TABLE 1: RESULTS OF REGRESSION ANALYSIS TO FIND THE DEPENDENCES OF EMF AND INTERNAL RESISTANCES ON THE STATE OF CHARGE OF ONE CELL OF LITHIUM-ION BATTERY

$$\begin{cases} R_{chg} = R_{chg.cell}\frac{N_{ser}}{N_{par}} \\ R_{dchg} = R_{dchg.cell}\frac{N_{ser}}{N_{par}} \\ E = E_{cell}N_{ser} \\ Q_{nom.Ah} = Q_{nom.Ah.cell}N_{par} \end{cases} \quad (13)$$

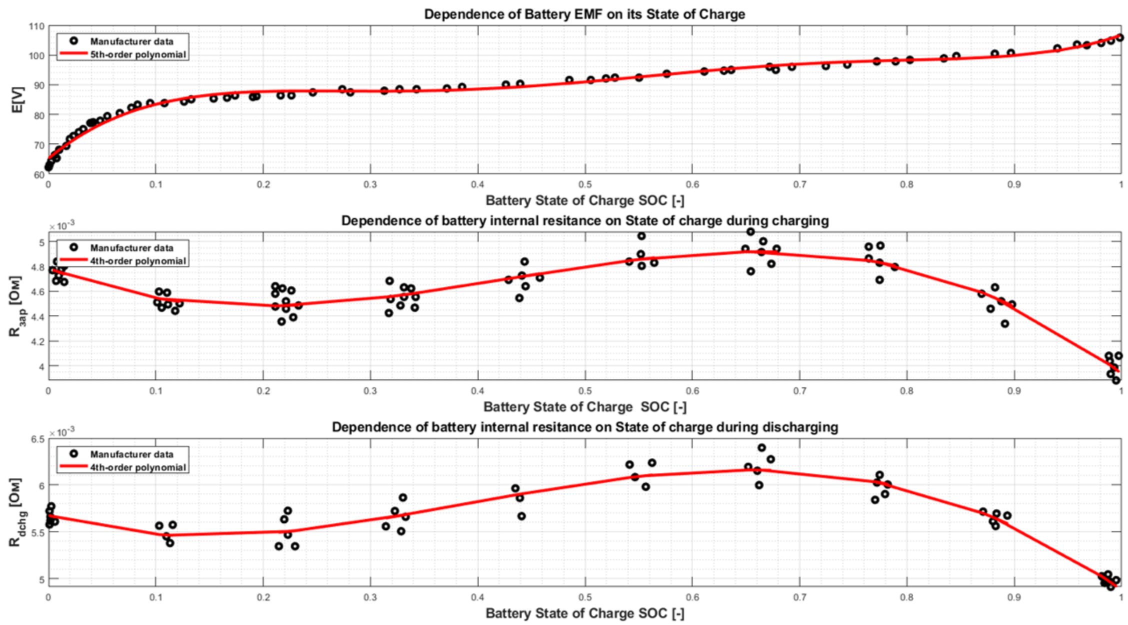

Fig. 3: Dependences of EMF and internal resistances on the degree of charge of the traction battery of an electric vehicle

The Li-Ion traction battery used in the research object has a capacity of 13.8kWh (131.4Ah) and a terminal voltage equal to 105V. Taking into account that the maximum voltage of one battery cell is 4.2V, we can state that 25 cells (N_{ser}) must be connected in series to achieve the desired final voltage. To achieve the battery capacity claimed by the manufacturer, the cells must be connected in parallel. A typical Li-Ion cell with a voltage of 4.2V has a capacity in the region of 3Ah. This allows us to calculate that 44 cells must be connected in parallel $(N_{par} = 44)$. Thus, the traction battery of the object of study consists of 25 modules (which, in turn, consists of 44 cells connected in parallel) connected in series. Fig. 2.13 shows the traction battery characteristics obtained by scaling the characteristics of one cell according to E_{qs} (13).

Conclusion. The study developed a data-driven approach to develop a mathematical model of the traction battery of small class electric vehicles. The main results include the following statements:

1. **Model construction considering real battery characteristics**

   The developed model successfully integrated the data on the dependence of the electromotive force (EMF) and internal resistances on the state of charge (SOC). The use of regression analysis methods allowed to obtain approximating curves with high accuracy, which is confirmed by the coefficients of determination (up to 0.98).

2. **Application of battery scaling approach.**

   In order to create a model of a complete traction battery, scaling was implemented to take into account the series and parallel connection of cells. This allowed the modelling of a battery with realistic performance characteristics corresponding to the object of study.

3. **The effectiveness of the proposed approach**

   The proposed methodology has proven its effectiveness for modelling the dynamic characteristics of batteries used in urban electric vehicles. The data obtained allows for a more accurate prediction of the battery behaviour under different operating conditions, which improves the planning of battery charging and discharging.

4. **Practical applicability.**

   The model can be used to optimise battery management systems in small electric vehicles. It can also be the basis for developing new energy management strategies that contribute to improving the overall energy efficiency of electric vehicles.

Thus, the proposed approach not only meets modern requirements for modelling traction batteries, but also opens up opportunities for further research, including adaptation of the model to batteries of other types and expansion of its application to energy management systems for electric vehicles.

II References

[1] K. Jyotheeswara Reddy and S. Natarajan, «Energy sources and multi-input DC-DC converters used in hybrid electric vehicle applications – A review», Int J Hydrogen Energy, 43, edition 36, pp. 17387–17408, sep. 2018, doi: 10.1016/j.ijhydene.2018.07.076.

[2] L. Castellazzi, S. Ruzimov, A. Bonfitto, A. Tonoli, and N. Amati, «A Method for Battery Sizing in Parallel P 4 Mild Hybrid Electric Vehicles», SAE International Journal of Electrified Vehicles, 11, edition 1, pp. 14-11-01–0008, sep. 2021, doi: 10.4271/14-11-01-0008.

[3] M. Islameka, B. A. Budiman, F. B. Juangsa, and M. Aziz, «Energy management systems for battery electric vehicles», Emerging Trends in Energy Storage Systems and Industrial Applications, Elsevier, 2023, pp. 113–150. doi: 10.1016/B978-0-323-90521-3.00006-5.

[4] «48V Lithium-ion Battery - 8Ah», http://www.a123systems.com/wp-content/uploads/48V-Battery-Flier_2016.pdf [16.06.2021].»

[5] M.Ehsani, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, Third Edition. CRC Press, 2018. doi: 10.1201/9780429504884.

[6] F. Umerov, «The prospects for the development of electric vehicles in Uzbekistan», Acta of Turin Polytechnic University in Tashkent, 12, edition 2, nov. 2022, https://acta.polito.uz/index.php/journal/article/view/172

[7] F. Umerov, «Analysis of the recovery system braking electric vehicles», Acta of Turin Polytechnic University in Tashkent, 13, edition 3, pp. 43–46, nov. 2023, https://acta.polito.uz/index.php/journal/article/view/235

[8] Ruzimov S.K., “Scientific basis of selection of parameters and control modes of hibrid drive car drives”, Tashkent, 2022.

[9] S. Asanov & F. Umerov, «Dynamic multicriteria analysis development of the electric vehicle market and their infrastructure in Uzbekistan», Acta of Turin Polytechnic University in Tashkent, 13, edition 3, pp. 51–55, nov. 2023, https://acta.polito.uz/index.php/journal/article/view/231

[10] [10] Y. Gong & etc., «Estimation of Peukert Constant of Lithium-ion Batteries and its Application in Battery Discharging Time Prediction», 2020 IEEE Energy Conversion Congress and Exposition (ECCE), IEEE, oct. 2020, pp. 905–910. doi: 10.1109/ECCE44975.2020.9236241.

[11] «https://avt.inl.gov/content/pubs-vehicles#B [16.06.2021]».

[12]

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ANALYSIS OF THE PROCESS AND ENERGY LOSSES DURING ELECTRIC VEHICLE CHARGING

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Abstract– The development of the electric vehicle industry in the world, as well as in Uzbekistan, is one of the promising directions in the field of transportation aimed at improving the environment. The development of this industry requires the solution of a number of problems, including the development of legal and regulatory documents, the formation of solution methods and the development of infrastructure. The formation of infrastructure for electric vehicles requires the creation of new markets for innovative products and therefore needs active support in various production and social sectors of the state. The development of charging infrastructure, the increase of charging stations and the supply of electricity to these charging stations so competently, and the charging of electric vehicles with minimal energy losses is a relevant area. This paper is devoted to analyze and study the energy losses in charging of electric vehicles [1].

Key words– Electric transportation, electric vehicle charging stations, energy losses, electric vehicles, charging station infrastructure development prospects, transportation.

I INTRODUCTION

The most common problems associated with electric vehicle technology are operational in nature. The lithium-ion batteries used in these devices have a capacity that steadily decreases with time and successive charging cycles. As a result, the battery is increasingly connected to a car charger and must be replaced on a regular basis, which is quite expensive. However, the experience with electric vehicles in the US and Europe shows, among other things, that car battery life has exceeded the expectations of manufacturers and users. Despite the fact that electric cars are inferior to internal combustion engine cars in terms of range, their sales are increasing every year [2].

II THE MAIN PART

Losses that are unavoidable to avoid when charging electric vehicles are there when charging any electric vehicle. The process of charging a Wuling Mini EV from a home socket to 100% was studied and the losses were recorded and analyzed with a wattmeter.

Table 1, summarizes the distinctive features and specifications of the Wuling Mini EV electric vehicle.

Motor - electric motor 20 kW	
Type of fuel	Electric
Electric motor power, kW	20
Electric motor torque, N*m.	85
Mileage without recharging, km	170
Battery capacity, kWh.	13.9
Number of electric motors	1
Charging time, h	9
Battery type	Lithium-ion
Maximum speed, km/h	100

TABLE 1: PARAMETERS AND INDICATORS DECLARED BY THE MANUFACTURER

Our research on this topic has established that when charging from a conventional household outlet through a standard 1.5-1.8 kW unit, only 70-90% of the energy taken from the grid reaches the battery. If a 7 kW wall-mounted home station is used, the energy loss will not exceed 5-10 percent, which means that the electric car will take 90-95% of the kilowatt-hours displayed by the home electricity meter. Charging with minimal losses is carried out at powerful DC charging stations.

The difference is due to thermal leakage of energy in the cable, charger, inverter, vehicle internal wiring and the battery itself. Some energy is also drawn from the car's on-

#	Battery SOC	Difference in battery charge, before and after	Temperature of the environment in degrees Celsius	Total capacity kWh	Charge of capacity kWh
1.	9	9	33	1,242	1,242
2.	20	11	34	2,76	1,518
3.	31	11	38	4,278	1,518
4.	43	12	43	5,934	1,656
5.	52	9	43	7,176	1,242
6.	62	10	46	8,556	1,38
7.	72	10	38	9,936	1,38
8.	83	11	37	11,454	1,518
9.	95	12	37	13,11	1,656
10.	100	5	36	13,8	0,69

TABLE 2: CHARGING PROCESS OF THE BATTERY PACK TAKING INTO ACCOUNT TEMPERATURE 33-46°C WULING MINI EV

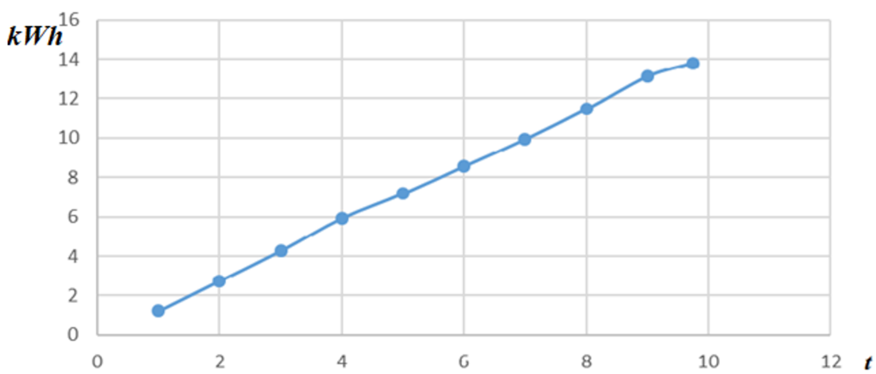

Fig. 1: Dependence of Wuling traction battery charging density process on time in the ambient temperature range of 33-46°C.

#	Initial experiment time	Final experimental time	Total charging time in hours	Charging time in hours	Initial battery SOC
1.	10:00	11:00	1	1	0
2.	11:00	12:00	2	1	10
3.	12:00	13:00	3	1	21
4.	13:00	14:00	4	1	32
5.	14:00	15:00	5	1	43
6.	15:00	16:00	6	1	52
7.	16:00	17:00	7	1	61
8.	17:00	18:00	8	1	73
9.	18:00	19:00	9	1	83
10.	19:00	19:00	9,68	0,68	95

TABLE 3: WULING MINI EV TIME-BASED BATTERY CHARGING PROCESS

#	Battery SOC	Difference in battery charge, before and after	Temperature of the environment in degrees Celsius	Total capacity kWh	Charge of capacity kWh
1.	10	10	35	1,38	1,38
2.	21	11	38	2,898	1,518
3.	32	11	41	4,416	1,518
4.	43	11	42	5,934	1,518
5.	52	9	44	7,176	1,242
6.	62	10	37	8,556	1,38
7.	73	12	35	10,212	1,656
8.	83	10	34	11,592	1,38
9.	95	11	32	13,11	1,518
10.	100	5	31	13,8	0,69

TABLE 4: BATTERY CHARGING PROCESS TAKING INTO ACCOUNT TEMPERATURE 31-44°C WULING MINI EV

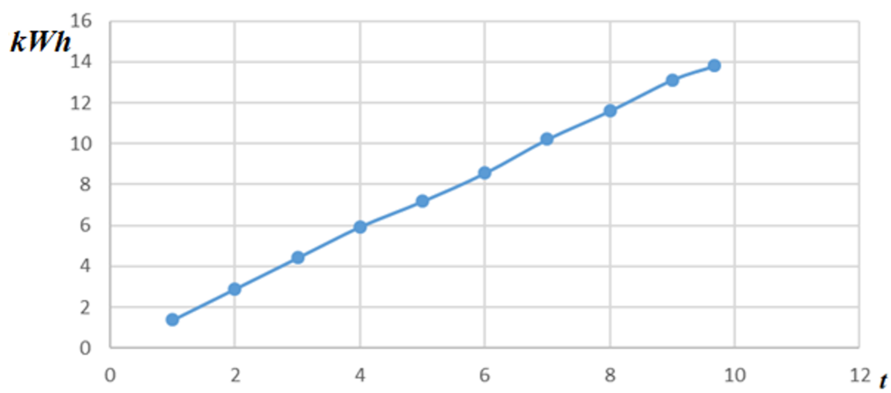

Fig. 2: Dependence of the charging density process of the Wuling traction battery on time in the ambient temperature range of 31-44°C.

board electrical system, which is left running in the background.

From this we can draw a simple conclusion: to reduce leakage when charging at home, you should do it in a warm garage, use a quality cable with low losses and devices with a three-phase connection to the power grid, capable of providing a power of more than 7 kW. [3].

During the experiments, the charging process of the Wuling Mini EV battery pack depending on the ambient temperature was tested and subjectively evaluated, and the results are shown in the following tables and graphs:

III CONCLUSION

As a result of the research, the following conclusions can be drawn: On many current models of electric vehicles, some energy is lost when traveling through the cable, some energy is lost in the charger, another part of energy is lost when traveling through the inverter in the car itself, some energy is lost to power auxiliary systems, some energy is lost when cells are heated during the charging process and the last part of energy is lost to balance the cells at the end of charging and finally.

IV REFERENCES

[1] Decree of the President of the Republic of Uzbekistan dated 04.10.2019, No. PP-4477 "On the application of the strategy for the transition of the Republic of Uzbekistan to a "green" meeting for the period 2019-2030".

[2] F. Umerov. “The prospects for the development of electric vehicles in uzbekistan,” Acta of Turin Polytechnic University in Tashkent, vol. 12, no. 2, Nov. 2022, [Online]. Available:https://acta.polito.uz/index.php/journal/-

article/view/172.

[3] S.Asanov and F.Umerov, “Dynamic multicriteria analysis development of the electric vehicle market and their infrastructure in uzbekistan,” Acta of Turin Polytechnic University in Tashkent, vol. 13, no. 3, pp. 51–55, Nov. 2023, [Online]. Available: https://acta.polito.uz/index.php/journal/article/view/231

[4] S. Fallah. Electric and Hybrid Vehicles - Technologies, Modeling and Control: A Mechatronic Approach 2014.

[5] Ali Emadi. Advanced Electric Drive Vehicles. CRC Press, 2014.

[6] F.Umerov, O.Daminov, J.Khakimov, A.Yangibaev, S.Asanov. Validation of performance indicators and theoretical aspects of the use of compressed natural gas (CNG) equipment as a main energy supply source on turbocharged internal combustion engines vehicles. American Institute of Physics cince (AIP) Conference Proceedings 3152, 030017 (2024). https://doi.org/10.1063/5.0219381. Research article JUNE 17, 2024.

[7] E. Samadani, M. Mastali, S. Farhad, R. Fraser, and M. Fowler, “Li-ion battery performance and degradation in electric vehicles under different usage scenarios,” Int J Energy Res, vol. 40, Aug. 2015, doi: 10.1002/er.3378.

[8] Umerov F.Sh., Juraboev A.Z. Analysis of the block diagram of the traction drive and the stages of calculation of a mechatronically controlled hybrid vehicle. Scientific journal of the Tashkent State Technical University (TSTU) named after Islam Karimov, "Yulduzlari Technique", Tashkent 2022. No. 1 - P. 29-33.

[9] Electric Vehicle Market: Battery Electric Vehicle, Hybrid Electric Vehicle, and Plug-in Hybrid Electric Vehicle – Global Industry Size, Share, Trends and Forecast 2019-2026//Acumen Research and Consulting website – https://www.acumenresearchandconsulting.com/electric-vehicle-market.

[10] Sadek, A. W., Elhenawy, M., & Zhou, J. (2019). Impacts of connected and automated vehicles on traffic flow stability and throughput. Transportation Research Part C: Emerging Technologies, 99, 156-175.

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REVIEW OF INDUSTRIAL ROBOT, ROBOTIC SIMULATOR MARKET AND AVAILABLE EDUCATION PLATFORMS FOR ROBOTICS LEARNING IN UZBEKISTAN[1]

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Abstract– The paper provides a comprehensive analysis of the industrial robotics market in Uzbekistan and Central Asia, examining its current state, key industry segments, and projected trends up to 2028. Particular attention is given to the dominant sectors, including food, metal, and automotive industries, with revenue forecasts indicating significant shifts in market dynamics. The study also evaluates the role of robotic software and simulators, such as RoboDK and PolyScope, as essential tools for programming, simulation, and education, even in the absence of physical laboratories. Furthermore, the global proliferation of online education platforms, including Udemy, Coursera, and Khan Academy, is reviewed, with an emphasis on their application in robotics education and professional development. The findings underscore the increasing demand for robotics specialists and the strategic importance of integrating blended learning methodologies to address challenges in STEM education. The research highlights the potential for Central Asia to emerge as a hub for industrial robotics, driven by technological advancements and evolving educational frameworks.

Key words– dustrial robotics market, robotics in Uzbekistan, educational platforms, robot software, RoboDK, PolyScope, industrial automation, robotic simulators, blended learning, STEM education, automation in Central Asia

I The Main part

Since the great spread of the internet in the late 2000s, distance and online methods of learning have received great attention, both from educational institutions and individuals. The COVID-19 pandemic in 2020 further accelerated the integration of online learning systems into higher education systems [1]. The shift forced by the pandemic towards online learning systems brings out several limitations of STEM (Science, Technology, Engineering and Mathematics) education i.e., the difficulty of delivering laboratory classes[2], problems with social interaction and not effective online assessment system [3]. In this context, a Blended Learning (BL) approach has emerged that takes advantage of the preferential aspects of both traditional face-to-face learning and online learning methods. BL is an institutional concept that allows technologies to collaborate with conventional learning approaches.

Therefore, blended learning is an integral part of future education with the fusion technique that successfully implements the interaction of virtual and real-world entities. The paper gives a general review of the industrial robotic systems in Uzbekistan and analyses the educational platforms available for learning robotics.

Industrial robotics market in Uzbekistan and Central Asia.

According to the analytical company Statista, the Uzbekistan robotics market is predicted to reach US$ 3 063 000 this year (in 2024). The market is mainly dominated by other robotics segments rather than the automotive robots' segments which accounts for US$ 1 003 000 which comprises almost 33% of the market, while the automotive segment still has a revenue equal to US$ 356.9 where mostly industrial robotic arms are used [9] (Figure 1).

The food industry and metal industry account for US$ 689 000 and US$ 778 000 respectively, making these the largest after all other industry segments in 2024. Interestingly, for the forecasted year 2028, the largest share would be the Food industry segment with US$ 789 200 and Metal industry segment with US$ 596 700. Automotive is expected to rise by US$ 386 500 by 2028.

It is interesting to note that the annual growth rate is expected to decrease by 10.19% (CAGR) for the period between 2024-2028. However, it still does not mean that overall

[1]The project is funded by World Bank research commercialization project RCP -1/1 as a part of MUNIS project

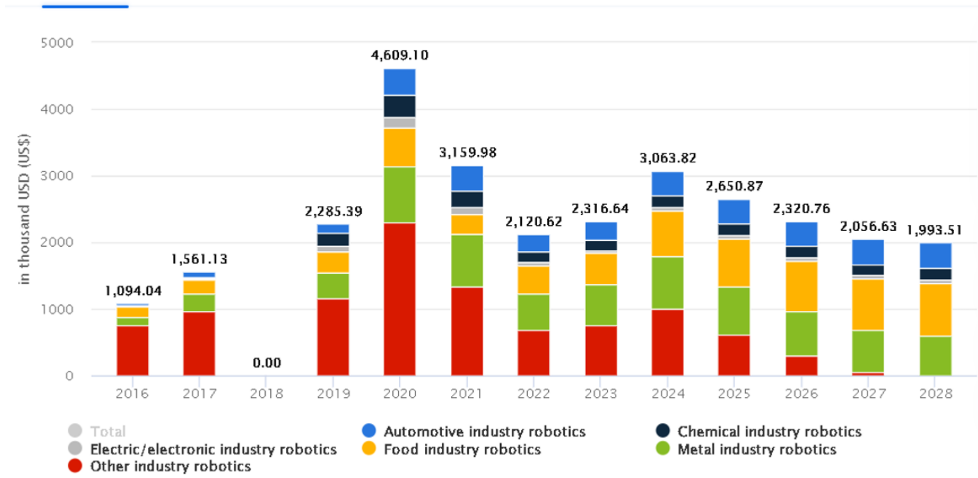

Fig. 1: Uzbekistan Industrial Robotics Market Revenue [9]

demand for the industrial robotic sector will decrease reaching cumulative revenue approximately of US$ 6 704 000 within the period between 2024-2028.

The market for industrial robotics in CA countries will cumulatively reach US$ 6 700 000 in 2024 and annually remain almost stable, with a growth rate of -0.55% between 2024-2028. The CA market shows a significant increase in the integration of industrial robots. Kazakhstan is expected to grow the industrial robotics market from US$ 3 636 000 in 2024 to US$ 4 561 000 by 2028 [10].

Robot software and simulator market.

Following the global trend of industrial robot installations and automation in general, the robot software market plays a crucial role. Robot software enables several functions implemented within the platforms, starting with simulation, commissioning, motion control safety, and engineer training. The prominent aspect of robotic software/simulators is that one can perform simulation while maintaining safety and without sometimes even the availability of the physical robot itself.

The Robot Software Market size is currently estimated at USD 19.92 billion in 2024, with a prediction to rise to US$ 53 billion by 2029 compound annual growth rate of 21.62% (Mordor Intelligence analytics market analysis). The highest growing market is Asia Pacific, while the largest is still North America. Association of Advancing Automation gives data for 2021 industrial robot installations accounted for 39 708 units in North America[11].

Moreover, the robotic simulator global market is expected to grow from 0.8 billion in 2022 to 2.48 billion by the end of 2030 with an annual CAGR of 15.20%. A robotic simulator is a part of Robotic Software that replicates the real behaviour of the robot used mainly for testing, offline programming and simulating the behaviour of the robot. The key market players are RoboDK, Octopuz, Delfoi Robotics, Robomaster, Fanuc, Siemens PLM Software, ABB, KUKA.

1. RoboDK simulator. RoboDK is a powerful tool used to simulate industrial robots and robotic programming. The price is affordable for students and educational purposes, accounting for a $150 subscription for two years. A graphical interface enables students to directly program without having advanced knowledge of programming. Availability of around 500 robot arms among 50 robot manufacturers. The RoboDK API is ready to use with Python, C++, Visual Basics and Matlab. Despite having all the available tools to simulate robotic arms, RoboDK remains the only simulation tool without having the physical laboratory. It is also not an education platform, meaning that it does not provide step by a step guide or training perspective.

2. PolyScope. It is a Universal Robot company simulator used to train professionals and students. Simulator can be used only with the Ubuntu operating system or with virtual machines in Windows.

Global online education platform market.

According to the dailiweblife.com analytical portal, COVID-19 suspended 300 mln students traditional learning practices forcing part of them to shift towards online education. The number of students attending online classes soared during the pandemic, triggering an increased demand for online learning platforms as well. High internet speeds, together with the enormous influence of smart devices i.e., tablets and smartphones, increased the demand for online courses. New technologies enabled the online platforms to

Index	RoboDK[8]	Polyscope	Udemy	Coursera
Price	0-4000	Free	0-200	39-15000
Availability of physical laboratory	Can be connected to the physical robot	Can be connected to the physical robot	NO	NO
Remote connection to the physical entity	YES	NO	NO	NO
User Interface	GOOD	Fairly good	GOOD	GOOD
Product that can be used	Most of robotic Brands	UR	General Robotics courses	General Robotics courses
Education Program	NO	NO	YES	YES
Audience	Students, professionals, industry, scholars	Students, Professionals	Professionals	Students
Custom design for companies	NO	NO	NO	NO
Online payment	YES	YES	YES	YES

TABLE 1: COMPARATIVE ANALYSIS

advance and open a whole new set of possibilities. Today, anyone with a smartphone can access almost any online course.

The data for the most popular online platforms shows that the biggest number of enrolled students has Khan Academy with almost 90 mln students globally while Coursera and Udemy follow the top 3 with 32 mln and 30 mln respectively. However, the biggest number of courses is offered by Udemy with almost 130k courses in almost all disciplines [11](Figure2).

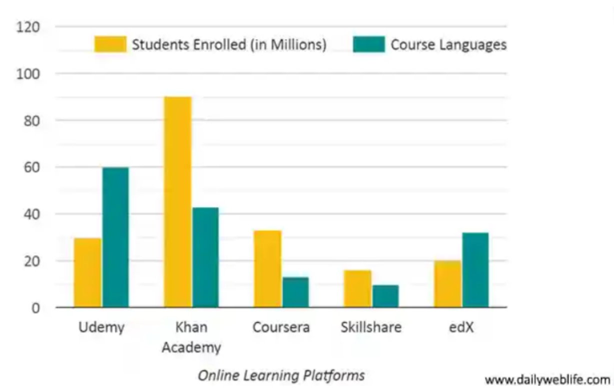

Fig. 2: Students enrolment in the top education platforms globally in 2022

Udemy. It is the online platform that has the biggest number of courses, accounting for around 130k in 60 different languages. There is a wide variety of courses offered on the platform, from basic programming courses to Health & Fitness. The key feature of Udemy courses is that they upskill professional skills. Compared to other online courses Udemy is a marketplace for those who would like to offer their knowledge to people. The course fee ranges from 2$ -200$ with coupons you can also reduce the course fees.

Coursera. This platform is one of the best platforms for higher education, offering courses in collaboration with universities. The platform offers almost 3600 courses with 5.2k instructors. High-skilled professionals teach the courses, and the platform offers online bachelor's and master's degree courses from top universities like Imperial College London, University of Michigan, HEC Paris, and Arizona State University. Also, Coursera offers professional certificate courses with a duration of 4-10 weeks. Hands-on projects are based on real business cases. The course price ranges from $39-15000$

Khan Academy. Online platforms lectures are mostly uploaded on YouTube platforms and the organization is non-profit, Khan Academy is based on individual contributions, ads and subscriptions. The courses offered are 4347 with 8k instructors. They have almost 90.4M students enrolled in 2022. The courses are uploaded as a digital blackboard.

II CONCLUSION

To sum up we can see that there is absolutely a big market for Central Asian countries to evolve into industrial robot supply centers. Moreover, the rise of the demand for robotic systems for sure means increased demand for maintenance and programming specialists of those robotic systems.

III REFERENCES

[1] Kumar et al., "Blended Learning Tools and Practices: A Comprehensive Analysis," IEEE Access, vol. 9, pp. 85151–85197, 2021, doi: 10.1109/ACCESS.2021.3085844.

[2] "STEM and Education Technology in Bangladesh, Cambodia, the Kyrgyz Republic, and Uzbekistan: A Synthesis Report," Manila, Philippines, Jun. 2022. doi: 10.22617/SPR220247.

[3] N. Markandan, K. Osman, and L. Halim, "Online STEM Education Approaches during the COVID-19 Pandemic," Creat Educ, vol. 14, no. 12, pp. 2368–2383, 2023, doi: 10.4236/ce.2023.1412151.

[4] S. Boschert and R. Rosen, "Digital twin-the simulation aspect," in Mechatronic Futures: Challenges and Solutions for Mechatronic Systems and Their Designers, Springer International Publishing, 2016, pp. 59–74. doi: 10.1007/978-3-319-32156-1_5.

[5] A.A. Malik and A. Brem, "Digital twins for collaborative robots: A case study in human-robot interaction," Robot Comput Integr Manuf, vol. 68, Apr. 2021, doi: 10.1016/j.rcim.2020.102092.

[6] F. Tao, J. Cheng, Q. Qi, M. Zhang, H. Zhang, and F. Sui, "Digital twin-driven product design, manufacturing and service with big data," International Journal of Advanced Manufacturing Technology, vol. 94, no. 9–12, pp. 3563–3576, Feb. 2018, doi: 10.1007/s00170-017-0233-1.

[7] "Connecting to Robot with OpenVPN tools from wherever - YouTube." Accessed: Jan. 22, 2024. [Online]. Available: https://www.youtube.com/watch?v=rF9xOrOqdNU

[8] "Simulator for industrial robots and offline programming - RoboDK." Accessed: Jan. 22, 2024. [Online]. Available: https://robodk.com/

[9] No. 83 of 21.02.2022. On additional measures to accelerate the implementation of national goals and objectives in the field of sustainable development for the period up to 2030." [Uzbek] Accessed: Jan. 22, 2024. [Online]. Available: https://lex.uz/docs/-5870397

[10] Global Education Monitoring Report Team, Global education monitoring report, 2023: technology in education: a tool on whose terms? 2023.

[11] "World Robotics 2023 Report: Asia ahead of Europe and the Americas - International Federation of Robotics." Accessed: Jan. 23, 2024. [Online]. Available: https://ifr.org/ifr-press-releases/news/world-robotics-2023-report-asia-ahead-of-europe-and-the-americas

[12] "Robotic Simulator Market Size, Growth, Forecast Till 2030." Accessed: Jan. 23, 2024. [Online]. Available: https://www.reportprime.com/robotic-simulator-r16229

[13] "Robotics - Uzbekistan | Statista Market Forecast." Accessed: Jan. 23, 2024. [Online]. Available: https://www.statista.com/outlook/tmo/robotics/uzbekistan

[14] "Robotics - Kazakhstan | Statista Market Forecast." Accessed: Jan. 23, 2024. [Online]. Available: https://www.statista.com/outlook/tmo/robotics/kazakhstan

[15] "Best Online Learning Platforms (2020) | Daily WebLife." Accessed: Jan. 23, 2024. [Online]. Available: https://dailyweblife.com/online-learning-platforms-2020/

[16] "Online Education - Worldwide | Statista Market Forecast." Accessed: Jan. 23, 2024. [Online]. Available: https://www.statista.com/outlook/dmo/eservices/online-education/worldwide

[17] "Infographics: Development of the education system in Uzbekistan in 2017-2022 - Review.uz." Accessed: Jan. 22, 2024. [Online]. Available: https://review.uz/en/post/infografika-razvitie-sistem-obrazovaniya-v-uzbekistane-v-2017-2022-gg

[18]

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COLLABORATIVE ROBOTS: TRANSFORMING THE WORKFORCE THROUGH ADVANCED COMMUNICATION AND MECHATRONICS.

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Abstract– Collaborative robots (cobots) are revolutionizing contemporary industries by facilitating fluid interaction between humans and machines via sophisticated mechatronics and communication technologies. This study examines their technical basis, applications, and contributions to Industry 4.0. Cobots promote productivity and mitigate industrial injuries with advanced safety systems and adaptability. Case studies from manufacturing and healthcare illustrate their success, however obstacles such as worker adaption and cost barriers remain. Further study is required to enhance safety standards and broaden cobot integration across many industries.

Key words– Collaborative Robots, Industry 4.0, Safety Standards, Human-Robot Interaction, Mechatronics, Workforce Transformation

I INTRODUCTION

Dubbed "Industry 4.0" (I4.0), the fourth industrial revolution drives businesses to translate conventional manufacturing processes into digital frameworks to assure competitive advantages via technology advances (Wang & Wang, 2016; Pimenta, 2019). Mass customizing and market globalization drive this change, which forces interesting sectors to apply technologies including the Industrial Internet of Things (IIoT), simulation, robotics, cloud computing, additive manufacturing, and augmented reality (Rüßmann et al., 2015; Tamás et al., 2016; Schwab, 2017).

Development of intelligent, cooperative robots—termed "cobots"—directed to run alongside human workers is a basic component of Industry 4.0. Although industrial robots have been applied in manufacturing since the third industrial revolution, the current paradigm prioritizes the enhancement of contemporary technologies to develop robots capable of learning, adapting, and collaborating with people (Rüßmann et al., 2015). Cobots, autonomous, adaptable, multifarious—increase safety and efficiency on the shop floor—without segregating activities (Bahrin et al., 2016).

Development in artificial intelligence, IoT, cloud computing, and big data is projected to transform the roles of robots in industrial processes, so boosting their autonomy and integration inside the bigger ecosystem (Robla-Gómez et al., 2017). Given cobot deployment runs close to humans, safety is a major issue. Safety criteria set by international standards including ISO/TS 15066: 2016 underscore risk assessment and human protection by means of their delineation. Artificial vision systems, lightweight constructions, and mechanical dependability systems—all of which equip cobots—are safety aspects.

Adoption of cobots is driven by financial gains, faster manufacturing, and higher productivity; safety is thus a primary design and implementation challenge (Bayram & İnce, 2018). Cobots help to improve production processes and thereby boost human-robot cooperation by lowering dangers to human workers.

This work presents two research questions meant to investigate these topics: (RQ1) What special qualities define cobots? Future collaborative robotics research topics could be Looking to address these problems, a careful reading of the literature utilizing Scopus and Web of Science (1997–2018) The study includes in research strategies, details on cobots, probable paths of future research, and last thoughts.

II THE METHODOLOGY

The approach employed to address the research issues outlined in the beginning of this work was a systematic literature review, adhering to the guidelines established by Silva et al. (2015). This research approach establishes a robust founda-

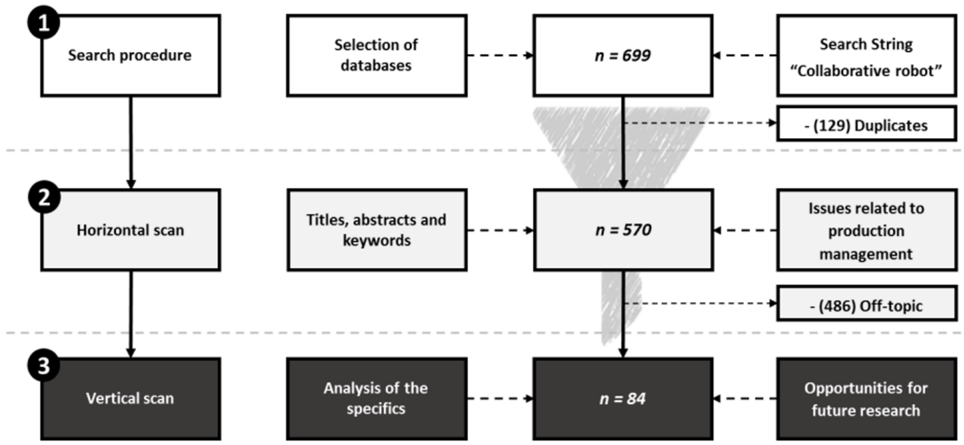

Fig. 1: Procedure for Systematic Literature Review

tion for future inquiries, aids in theory development, consolidates knowledge regarding previous studies, and identifies areas necessitating more investigation (Webster and Watson, 2002).

Figure 1 illustrates the methodology for the Systematic Literature Review conducted in this study. The initial phase commenced in January 2019 and involved the selection of datasets, including horizontal and vertical scans, as informed by the research of Silva et al. (2015). We chose two databases, Scopus and Web of Science, which are esteemed by the academic world, taking into account the significance of articles indexed in journals with an impact factor and the practicality of access and categorization. The phrase “collaborative robot” was utilized as the search keyword, given the majority of articles in these databases are in English, and it includes the terms “cobots” and “collaborative robots.” Consequently, 551 publications were detected in the Scopus database and 148 papers in the Web of Science database.

Subsequent to the elimination of 129 duplicate articles, a secondary criterion was employed to refine the publishing volume (horizontal scan) by examining the components: title, abstract, and keywords. This stage of the research emphasizes that some selected works focus solely on the technical and operational dimensions of COBOTs, encompassing specifications, algorithm utilization, and programming languages, as well as applications beyond manufacturing, including civil engineering, education, and medicine. Consequently, following the elimination of 486 articles beyond the purview of this study, a content analysis (vertical scan) was conducted on the 84 selected articles published from 1997 to 2018.

III THE LITERATURE REVIEW

3.1 Initial Analysis

With limited five terms for every article, the first study focused on an observation of the issues and topics in the titles and keywords of every article. In the paper "Legibility and Predictability of Robot Motion" (Dragan et al., 2013), for instance, three main themes emerged: (i) analysis of motions; (ii) trajectory planning; and (iii) gesture recognition. Several terms with the same connotation — that is, "collaborative robots," "COBOTs," "collaborative work," and "human - machine interaction"— were omitted from the list of themes to help to prevent overloading the list of subjects addressed. Furthermore ignored were the phrases connected to the research techniques applied in the studies since they would be covered later. Therefore, frequency noticed and shown in Table 1 helped to classify the most expressive problems found in more than one paper.

Issues	Article (s)	%
Safety	18	21.43
Assembly line	17	20.24
Sensing	11	13.10
Motion analysis	11	13.10
Risk analysis	8	9.52
Architecture	7	8.33
Kinematics	6	7.14
Industrial automation	6	7.14
Baxter Robot	5	5.95
Mobility	5	5.95

TABLE 1: MAIN ISSUES ADDRESSED

Period	**No.**	**%**	**Research Approach**				
			Modeling	Experiment	Simulation	Theoretical Study	Case study
1997-2003	3	3.57	0	1	1	1	0
2004-2010	10	11.90	0	5	1	4	0
2011-2014	12	14.29	1	7	0	3	1
2015-2018	59	70.24	2	28	4	11	14
Total	**84**	**100**	**3**	**41**	**6**	**19**	**15**

TABLE 2: RESEARCH APPROACHES

When combined, the five most addressed issues — which reflect themes linked to the health and safety of the workplace, applications in assembly lines, and technical elements of the COBOTs, including motion analysis, including motion analysis — represent 77.38% of the articles and show.

Kinematics and sensing devices.

Eight of the thirty-four topics, however, directly relate to occupational safety and health (safety, risk analysis, gesture recognition, social aspects of robotics, ergonomics, work in team, work environment, and ISO 10218) considering the elements of production and operations management. Still, three of them have ties to the latest paradigm of the fourth Industrial Revolution (i4.0, Cyber-physical Systems, and Smart Factory).

About the security of collaborative environments, we observed that the studies address aspects related to the operation of COBOTs, such working speed, proximity to operators in order to avoid collisions, recognition between operators and materials, and monitoring the distance between operators (Šurdilović et al., 2003; Matthias et al., 2011; Aaltonen et al., 2018). Only one of the above mentioned problems relates to the kind of commercial solution for COBOTs. Designed by Rethink Robotics, the ninth-ranked "Baxter robot" in Table 1 has two arms and a screen that acts as a face so the operator may interact with it and that displays when you are learning or working on an operation.

Furthermore, Baxter robots have a software platform that lets them do a series of difficult tasks such managing a component and guiding a "approved" or "approved" type inspection station toward the material stacking (Briody, 2013).

Another pertinent quality of the state of the art on collaborative robotics relates to the methodological and scientific orientation of the research around the issue. Table 2 thus presents a distribution of the articles noted with relation to the research methodology. Four periods of such distribution were stratified; thinking that the topic gained more relevance from the ideas of advanced robotics and i4.0, both distributed from 2011 and, thus, with a greatest expected frequency; larger amplitude was ascribed to the first two periods.

Many papers discussing COBOTs as the key issue applied experiments as the main method of investigation. Out of all the recoverable publications, these account for 48.81%. Representing 40.48%, theoretical and empirical research — case studies — also stand out. It is noteworthy that the

Published between 2011 and 2018, these articles reflect 84.53% of the sample. These papers expose the contemporaneity of the issue together with the i4.0 related technologies. We generated Table 3 guiding the authorship, the number of citations recorded in the databases, the research approach, and a synthesis of the contributions of these works, thereby offering a ranking of the most productive and referenced papers.

Specificities Inherent to COBOTs

One way to understand the specifics regarding manufacturing processes' specifics is to find answers to four questions that can differentiate one technology from another (Slack et al., 1999). These questions include: (Q1) What does technology do?; (Q2) How does it develop?; (Q3) What advantages does this technology offer?; and (Q4) What restrictions does the technology bring to the production? Thus, these four questions were used to understand the specificities inherent to collaborative robotics to find answers to the first research question previously presented in the introduction section.

Regarding the application of COBOTs, or in other words, what they are capable of, the literature shows that industrial robotics is recommended for environments where human beings are exposed to activities with significant risk and where efficiency is greater when compared with the tasks performed by humans (Gunasekaran, 1999; Hedelind and Jackson, 2011; Lasota and Shah, 2015). Industrial robots are traditionally directed to activities called 3D's, that is, dirty, dangerous,and dull (Murphy et al., 2000; Bloem et al., 2014). Therefore, industrial robotics can be used in a variety of sectors, such as automotive and aerospace, medical, consumer goods, and electronics, among others, with the most common applications covering welding, testing, labeling, drilling, cut-

Rank	Author (s) / Year	No. of Citations	Research Approach	Contribution
1	Peshkin et al. (2001).	178	Theoretical Study	Kinematics and operational considerations of the transmission between conventionally driven COBOTs and non-holonomic COBOTs applied in the car assembly process
2	Dragan et al. (2013)	120	Experiment	The results revealed that COBOTs' predictability and readability are essentially different and sometimes contradictory traits of movement.
3	Roy and Dudek (2001)	83	Simulation	The paper offers an algorithmic approach for long-distance agents to communicate, enabling two robots to meet in order to investigate an uncharted territory together.
4	Andersson and Nygards (2008)	49	Simulation	The authors suggest a method for multi-robot system alignment and joining maps and trajectories. One can check a feasible path in an unknown area by using the trajectory information.
5	Merchán-Cruz and Morris (2006)	41	Simulation	The work offers a fuzzy genetic method to solve the trajectory planning issues of two manipulating robots by sharing a similar workspace whose trajectory or behavior is unknown and erratic.
6	Krüger et al. (2006)	39	Experiment	It suggests a direct physical contact-based method of workspace shared between COBOTs and operators. This system can accomplish the functions of path navigation and power amplification.
7	Šurdilović et al. (2003)	36	Experiment	The given article introduced a novel continuous variable transmission COBOT system. This work also briefly introduced basic structural, kinematic and dynamic models, as well as control techniques.
8	Matthias et al. (2011)	32	Theoretical Study	This paper addresses the safety certification process for industrial cooperative robotics applying risk assessment techniques. They also examined the several conceivable interactions between a human being and a robot.
9	Rozo et al. (2016)	30	Experiment	Combining probabilistic learning, dynamic systems, and stiffness estimations, the authors provide a framework for an operator to educate COBOTs from demos, so encoding the robot's behavior across the task.
10	Romero et al. (2016)	29	Theoretical Study	The paper introduced the idea "Operator 4.0," interpreted as an intelligent and skilled operator who achieves man-machine symbiosis in work systems by means of cooperative efforts with robots via Cyber-physical systems.

TABLE 3: TOP 10 ARTICLES

ting activities, painting, molding, removal, and movement of materials (Thomopoulos, 2014).

COBOTs, in turn, are industrial robots specifically designed to perform a variety of repetitive and non-ergonomic tasks and cooperate directly and safely with operators, being able to use force and collision detection capabilities (Romero et al., 2016). Portability is a key feature of this technology type since the operator must program these robots' operations in a simple way and safely (Djuric and Urbanic, 2018). It is important to note that an industrial robot is a reprogrammable automatic manipulator capable of handling objects with varying degrees of freedom through programmed movements to perform a variety of tasks (Slack et al., 1999). In this sense, the operationalization of COBOTs requires a workplace design adapted to this technology, selecting a control system, and creating a control program using algorithms related to kinematic tasks (Sapietová et al., 2018).

3.3 Opportunities for Future Research

Future research areas include:

1. Safety: Evaluating risk assessment methodologies such as FMEA and ergonomic factors (Matthias et al., 2011; Maurice et al., 2014).
2. Morale: Assessing operator collaborative experiences and productivity (Aaltonen et al., 2018).
3. Standardization: Examining standards such as ISO 10218 and ISO/TS 15066 pertaining to collaborative robots (Bogue, 2017).
4. Performance Evaluation: Analyzing COBOT efficacy across various models and applications (Cremer et al., 2016).
5. Integration with Industry 4.0: Investigating COBOT functions in digital manufacturing, IIoT, and cybersecurity (Bayram and İnce, 2018).
6. Human-Robot Interaction: Improving communication using gesture and auditory recognition (Barattini et al., 2012; Lasota and Shah, 2015).

These research initiatives seek to enhance the comprehension of COBOTs and their incorporation into contemporary industry

IV CONCLUSION

This paper aimed to identify important problems indicating directions for future research on COBOTs and to grasp certain traits of collaborative robots inside the context of Industry 4.0. Since the man-machine interface reduces ergonomic strain, the latest developments in the sector concentrate on improving the productivity and efficiency of industrial activities together with raising job quality. Still, COBOT adoption calls for a redesigned physical infrastructure, incurs significant expenses, and requires qualified personnel for operation, therefore limiting their use. The second research question helped to identify six directions for next studies covering the themes of safety, morality, standardizing, comparative performance analysis among different robot types, integration with Industry 4.0 technologies, and technologies connected to human-robot interaction. Focusing on health and safety in the workplace, applications in assembly lines, and the technological aspects of COBOTs, this study covers five main topics accounting for 77.38% of the publications. These challenges give a chance for future research on industrial robots. Our strategy has various restrictions. This study excludes technical papers on COBOTs and publications from different databases. Later on, we took a thorough landscape view on the application of robotics in the production line. Guidelines and recommendations on this issue need on more study including field investigations and case studies. The difficulties and features of this paper could motivate more studies and projects aiming at including COBOTs into manufacturing process.

V REFERENCES

[1] Aaltonen, I., Salmi, T., and Marstio, I. (2018). Refining levels of collaboration to support the design and evaluation of human-robot interaction in the manufacturing industry. Proceeded CIRP, 72, 93-98. https://doi.org/10.1016/j.procir.2018.03.214

[2] Andersson, L.A., and Nygards, J. (2008). C-SAM: Multi-robot SLAM using square root information smoothing. In Robotics and Automation, ICRA 2008. IEEE International Conference. 2798-2805. http://doi.org/10.1109/ROBOT.2008.4543634

[3] Bahrin, M.A.K., Othman, M.F., Azli, N.H.N., and Talib, M. F. (2016). Industry 4.0: A review on industrial automation and robotic. Jurnal Teknologi, 78, 6-13.

[4] Barattini, P., Morand, C., and Robertson, N.M. (2012). A proposed gesture set for the control of industrial collaborative robots. In RO-MAN, IEEE, 132-137. http://doi.org/10.1109/ROMAN.2012.6343743

[5] Bayram, B., and İnce, G. (2018). Advances in Robotics in the Era of Industry 4.0. In Industry 4.0: Managing The Digital Transformation, 187-200. Springer, Cham.

[6] Bloem, J., Van Doorn, M., Duivestein, S., Excoffier, D., Maas, R., and Van Ommeren, E. (2014). The Fourth Industrial

[7] Revolution: Things to tighten the link between IT and OT. Sogeti VINT2014.

[8] Bogue, R. (2017). Robots that interact with humans: a review of safety technologies and standards. Industrial Robot: An

[9] International Journal, 44(4), 395-400. https://doi.org/10.1108/IR-04-2017-0070

[10] Briody, B. (2013). The Robot Reality: Service Jobs are Next to Go [Online]. Fiscal Times. Available at: http://www.thefiscaltimes.com/Articles/2013/03/26/The-Robot-RealityService-Jobs-are-Next-to-Go [Accessed: 4 April 2015].

[11] Brizzi, P., Conzon, D., Khaleel, H., Tomasi, R., Pastrone, C., Spirito, A.M., and Cultrona, P. (2013) Bringing the Internet of Things along the manufacturing line: A case study in controlling industrial robot and monitoring energy consumption remotely. In Emerging Technologies & Factory Automation (ETFA), IEEE 18th Conference, 1-8.

[12] Cremer, S., Mastromoro, L. and Popa, D.O. (2016). On the performance of the Baxter research robot. In Assembly and Manufacturing (ISAM), 2016 IEEE International Symposium, 106-111.

[13] Djuric, A., and Urbanic, R.J. (2018). Using collaborative robots to assist with travel path development for material deposition based additive manufacturing processes. Computer-Aided Design and Applications, 15(4), 542-555. https://doi.org/10.1080/16864360.2017.1419642

[14] Dragan, A.D., Lee, K.C., and Srinivasa, S.S. (2013). Legibility and predictability of robot motion. In Proceedings of the 8th ACM / IEEE international conference on Human-robot interaction, 301-308.

[15] Gunasekaran, A. (1999). Management policies of computer-integrated manufacturing/robotics. Handbook of Industrial Robotics, 473-494.

[16] Hedelind, M., and Jackson, M. (2011). How to improve the use of industrial robots in lean manufacturing systems.

[17] Journal of Manufacturing Technology Management, 22(7), 891-905. https://doi.org/10.1108/17410381111160951

[18] International Organization for Standardization – ISO (2016). Robots and Robotic Devices Collaborative Robots, document ISO / TS 15066.

[19] Krüger, J., Bernhardt, R., Surdilovic, D., and Spur, G. (2006). Intelligent assist systems for flexible assembly. CIRP Annals-Manufacturing Technology, 55(1), 29-32. http://doi.org/10.1016/S0007-8506(07)60359-X

[20] Kull, H. (2015). Mass customization: Opportunities, methods, and challenges for manufacturers. Apress.

[21] Lasota, P.A., and SHAH, J.A. (2015). Analyzing the effects of human-aware motion planning on close-proximity human – robot collaboration. Human Factors, 57(1), 21-33. https://doi.org/10.1177%2F0018720814565188

[22] Matthias, B., Kock, S., Jerregard, H., Kallman, M., Lundberg, I., and Mellander, R. (2011). Safety of collaborative industrial robots: Certification possibilities for a collaborative assembly robot concept. In Assembly and Manufacturing (ISAM), 2011 IEEE International Symposium, 1-6. http://doi.org/10.1109/ISAM.2011.5942307

[23] Maurice, P., Schlehuber, P., Padois, V., Measson, Y., and Bidaud, P. (2014). Automatic selection of ergonomie indicators for the design of collaborative robots: A virtual-human in the loop approach. In Humanoid Robots (Humanoids). 14th IEEE-RAS International Conference, 801-808. http://doi.org/10.1109/HUMANOIDS.2014.7041455

[24] Merchán-Cruz, E.A., and Morris, A.S. (2006). Fuzzy-GA-based trajectory planner for robot manipulators sharing a common workspace. IEEE Transactions on Robotics, 22(4), 613-624. http://doi.org/10.1109/TRO.2006.878789

[25] Murphy, R., Murphy, R.R., and Arkin, R.C. (2000). Introduction to AI robotics. MIT press

[26] Peshkin, M.A., Colgate, J.E., Wannasuphoprasit, W., Moore, C.A., Gillespie, R.B., and Akella, P. (2001). Cobot architecture. IEEE Transactions on Robotics and Automation, 17(4), 377-390. http://doi.org/10.1109/70.954751

[27] Pimenta, M.L. (2019). Cross-functional integration in product development processes in the era of industry 4.0.

[28] Production and Development Magazine. 5. https://doi.org/10.32358/rpd.2019.v5.350

[29] Robla-Gómez, S., Becerra, V.M., Llata, J. R., Gonzalez-Sarabia, E., Torre-Ferrero, C., and Perez-Oria, J. (2017).

[30] Working together: a review on safe human-robot collaboration in industrial environments. IEEE Access, 5, 26754-26773. http://doi.org/10.1109/ACCESS.2017.2773127

[31] Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å., and Gorecky, D. (2016). Towards an operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies. In proceedings of the international conference on computers and industrial engineering (CIE46), Tianjin, China, 29-31.

[32] Roy, N., and Dudek, G. (2001). Collaborative robot exploration and rendezvous: Algorithms, performance bounds and observations. Autonomous Robots, 11(2), 117-136. https://doi.org/10.1023/A:1011219024159

[33] Rozo, L., Calinon, S., Caldwell, D.G., Jimenez, P., and Torras, C. (2016). Learning physical collaborative robot behaviors from human demonstrations. IEEE Transactions on Robotics, 32(3), 513-527.http://doi.org/10.1109/TRO.2016.2540623

[34] Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., and Harnisch, M. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. Boston Consulting Group, 9(1), 54-89.

[35] Sapietová, A., Saga, M., Kuric, I., and Václav, Š. (2018). Application of optimization algorithms for robot systems designing. International journal of advanced robotic systems, 15(1), 1-10. https://doi.org/10.1177%2F1729881417754152

[36] Schwab, K. (2017). The fourth industrial revolution. New York: Crown Business.

[37] Tamás, P., Illés, B., and Dobos, P. (2016). Waste reduction possibilities for manufacturing systems in the industry 4.0. 20th Innovative Manufacturing Engineering and Energy Conference - IManEE.

[38] Thomopoulos, N.T. (2014). Assembly line planning and control. Springer International Publishing.

[39] Virk, G.S, Moon, S., and Gelin, R. (2008). ISO standards for service robots. In Advances in Mobile Robotics, 133-138. https://doi.org/10.1142/9789812835772_0016

[40] Wang, L.; and Wang, G. (2016). Big data in cyber-physical systems, digital manufacturing and industry 4.0. International Journal of Engineering and Manufacturing (IJEM), 6(4), 1-8, 2016. https://doi.org/10.5815/IJEM.2016.04.01

[41] Webster, J., and Watson, R. (2002). Analyzing the past to prepare for the future: Writing a literature review. MIS quarterly. 26(2), xii-xxiii.

[42] Weiss, A., Huber, A., Minichberger, J., and Ikeda, M. (2016). First application of robot teaching in an existing industry 4.0 environment: Does it really work?. Societies, 6(3), 20. https://doi.org/10.3390/soc6030020