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ALTERNATIVE ENERGY SOURCE IN THE USE OF VEHICLES

Specialization: **3340.01-Electrotechnical systems and complexes**
Field of science: **Technical sciences**

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of the dissertation for the degree of
Doctor of Philosophy

ABSTRACT

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The dissertation work was performed at Sumgayit State University.

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INTRODUCTION

Relevance and development of the topic. The development of the population and scientific and technical progress on earth continuously is increasing the demand for electricity. Currently the use of carbohydrates extracted from the earth for the production of heat and electricity creates major problems from an environmental point of view. Intensive consumption of organic fuels (coal, oil, gas, etc.) leads to sufficient depletion of their reserves. It means that people are faced with the problem of developing and practical study of a new, efficient source of heat and electricity.

Based on IRENA's database, 70% of the world's population is expected to live in cities by 2050. At the same time, it is estimated that the demand for passenger transportation will increase twice. Considering all this, the need for climate-friendly proposals and projects, problems of how to save energy and costs are emerging, and in addition to these, not using sources that can be considered harmful to the environment, projects to reduce energy costs in transport management based on new technologies are among the most urgent issues.

The topic of increasing the efficiency of various types of vehicles, saving fuel was reflected in the scientific articles of CIS experts and scientists A.A.Maron, E.B.Spector, A.B.Myatej, S.I.Khudorojkon and Azerbaijani scientists Z.N.Musayev, E.M.Farhadzade.

However, despite the preparation of various constructions in this direction, the development and improvement of the technology of using the mechanical energy generated during braking as AES for the purpose of increasing the efficiency of public transport vehicles and saving fuel is an urgent issue. The solution of these issues shows that the dissertation work is relevant.

Object and subject of the research: Collection of mechanical energy generated during braking in the operation of public transport vehicles, conversion into electrical energy, storage and use as AES.

Aims and objectives of the research:

In order to increase the efficiency of vehicles, during brake converting the mechanical energy generated into electrical energy, collecting, forming of the device construction, which ensures its use as an AES, building mathematical and computer models for the study of its management and control processes. To achieve this goal, the following issues need to be resolved:

1. To propose and analyze the functional scheme of gathering, converting into electrical energy and storing the mechanical energy generated during braking during operation in public transport vehicles;

2. Based on the principle and technology of converting the mechanical energy generated into electrical energy while making brake in public transport vehicles during exploitation;

3. During exploitation in public transport vehicles collecting mechanical energy generated in braking into electric energy, storing, and using it as AES;

4. To design a device that allows the collection of mechanical energy generated during the operation of public transport vehicles, its conversion into electrical energy, storage of electrical energy, and its use as an AES;

5. To evaluate with experimental studies the process of collecting electric energy due to the electromechanical conversion caused by braking during the operation of vehicles on the route;

6. Development of the functional algorithm of the technical interface that ensures the collection, conversion, storage and use of the mechanical energy generated during braking during the operation of public transport vehicles and checking with experiments;

7. Control the process of movement of the vehicle along the route, braking, stopping at parking lots, converting mechanical energy into electrical energy and charging batteries, modeling its management and connecting it with the computer network.

Research methods: The following methods were used to solve the research questions arising from the purpose of the dissertation work:

1. Analytical and practical studies;

2. Mathematical and computer modeling;

3. Analytical and logical methods of applied mathematics;

4. Model studies and comparison of obtained results with theoretical propositions on dissertation.

Basic theses for defense:

In accordance with the set goal, the following main issues were resolved in the dissertation work:

1. Comparative analysis of the principles, methods and models of obtaining electrical energy from the mechanical energy generated during braking during the operation of existing public transport vehicles;

2. Determining the source of mechanical energy generated in the braking process and economically justifying and selecting the constructive parts of the structural scheme of the proposed facility according to the project of the public transport system;

3. The process of transporting the mechanical energy generated in the braking process by removing it from the wheel system;

4. Taking into account the mechanical energy losses generated in the braking process, the quality performance of its transportation process;

5. Uploading the mechanical energy generated in the braking process to the mechanical energy collection;

6. The process of transferring the mechanical energy generated during the braking process from the mechanical energy collection to the energy conversion zone;

7. The process of converting the mechanical energy generated in the braking process into electrical energy by electro-mechanical method and filling it into battery banks for future use;

8. Modeling the movement of public transport along the route, the transformation of mechanical energy generated in the braking process into electrical energy and the energy collection algorithm, management and control process.

The scientific novelty of the research:

1. In order to increase the efficiency of vehicles, the construction of the device that ensures the conversion of mechanical energy generated during braking into electrical energy, collection and use as AES has been developed;

2. Up to 70% of the mechanical energy generated during braking during the operation of public transport vehicles has been converted into electrical energy;

3. The movement of public vehicles on the route, the number of stops, the duration of stopping at the stops was determined, and the algorithm of the process of collecting the electric energy generated as a result of recuperation during braking into the batteries was established;

4. The graph scheme of the algorithm of the recuperation process in the public transport vehicles along the route has been established, and mathematical and computer models have been established for the study of management and control processes.

Theoretical and practical significance of the research: As a result of the implementation of constructively set issues, achieving the process of electromechanical conversion of the mechanical energy generated in the braking process during the operation of public vehicles makes it possible to obtain sufficient electrical energy. The electrical energy received as a result of the electro-mechanical conversion of 70% of the mechanical energy generated in the braking system of public vehicles can be considered as an alternative energy source. By using the electricity from the braking system, which is economically efficient, as an AES, the control of public transport is achieved.

Approbation and implementation. 19 scientific articles have been published on the topic of the dissertation. 9 of them are articles, 10 are conference materials, (3 conference materials are published abroad, 3 articles are in journals recommended by the Russian Higher Attestation Commission, and 1 article is a journal quartile without co-author **(Q1), Elsevier publication Scopus, Web of Science** and **E-library**. 8 of the works are not co-authored.

The name of the institution where the dissertation work was completed. The dissertation work was completed at the Department of Electromechanics of Sumgayit State University. The device formed on the basis of the construction developed in the thesis work was tested at the Repair center under the authority of the Sumgayit Motor Transport and Passenger Transport Department under the Head of the

Sumgayit City Executive Authority, and an Application Act was obtained, as well as the results of mathematical and simulation modeling Baku No. 6 conducted with computer experiments on route indicators.

The total volume of the dissertation with a sign indicating the volume of the structural sections of the dissertation separately. The dissertation consists of an introduction, 4 chapters, main results and a list of used literature. The work consists of 153 pages, including 46 figures, 3 tables and a 145-number bibliography. The volume of the structural sections of the dissertation separately: introductory part 18963 marks; Chapter I 31849 signs; Chapter II 40770 signs; Chapter III from 61358 signs; Chapter IV 18489; the main results consist of 3907 marks and the total volume of the dissertation with marks: 175336 marks.

DİSSERTATİON CONTENT

The relevance of the topic of the work is motivated, the object and subject of the research are investigated, the purpose and tasks of the work are determined, the methods of the research are indicated, the main propositions defended are explained, the scientific innovations obtained, the practical importance of the work and the application of the results are considered, the appropriability and brief content of the work are given in the **Introduction.**

In the first chapter, existing models for the use of recuperative braking using systems and networks of various constructions, based on modern technologies, in order to increase the efficiency of vehicles and save fuel during operation, were examined based on comparative analysis, and the construction of a newly developed electromechanical conversion device was presented. Initially, the amount of energy to be taken into account during braking in a bus, which is an inner-city means of transport, is estimated in accordance with the truth, and in this case, the beginning and the end of the issue are approximately determined. Based on this definition, the necessity of the work is determined - complete information about all sections of constructive work is processed, and the obtained profit is analyzed. In the process of data collection, how often the vehicle moves in which place, their number in the area where these vehicles are located, and at the same time the power characteristics are obtained. In studies, the usefulness of the project is determined approximately. In its initial form, the sequence of operations is approximately as follows:

- volume of mechanical energy in short-term full braking conditions (this volume is proportional to the speed S, mainly related to the effect of braking mechanisms in the braking system). The volume of mechanical energy is defined as follows:

$$P_{mech.}=f(t) \quad (1)$$

The maximum value of mechanical energy P_{max} corresponds to the time t=0 (pictures 1, 2). In fact, both P_{mech}t parameters also depend on the weight of the vehicle and braking mode.

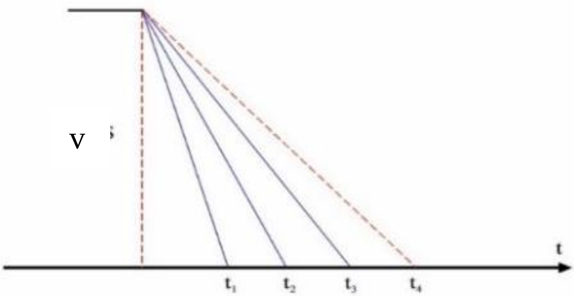

Figure 1. Time dependence of vehicle speed at full braking
v - speed of the vehicle, t-time

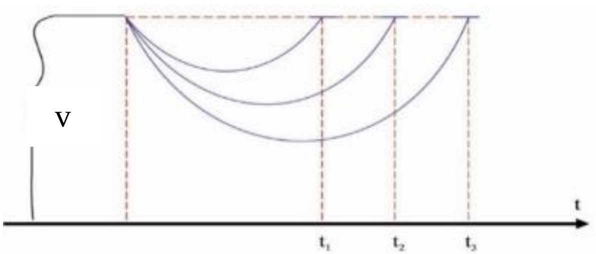

Figure 2. Acceleration in mild form braking time dependence
v - speed of the vehicle, t-time

In the second chapter, the issues of choosing technical means for gathering and converting the mechanical energy generated in the braking system of public transport vehicles into electrical energy and establishing the structural and constructive scheme of this device were considered. As a result of the analysis, it was determined that when looking at public transport vehicles (especially the bus industry), frequent braking (either slowing down or stopping) in their working mode attracts attention. Of course, braking in all cases requires some fuel loss. When the braking system is activated, sending the energy directed to the stopping direction of the vehicle to any system is aimed at increasing the useful work coefficient.

The structural scheme of the electromechanical conversion system is shown in figure 3.

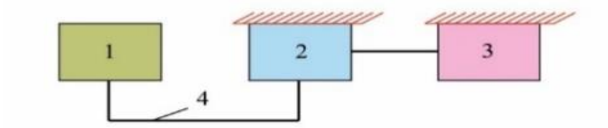

Figure 3. Structural diagram of the electromechanical conversion system

1- wheel assembly of vehicles; 2-mechanical energy collector; 3-electric generator; 4-tros

There are two areas in the system – space which performs their functions. The first area is the brake element of the rear wheels, which includes two supports and a cable that carries mechanical energy to the collecting element, and the second area is a system that converts mechanical energy into electrical energy through electromechanical conversion.The processes involved in the construction of the proposed electromechanical conversion device are as follows:

When vehicles are commanded to stop or slow down, a mechanical connection between the rotating wheel structure and the brake disc is created. Depending on the degree of filling of the mechanical energy collector, the braking disk rotates (maximum rotation $\pi/2$ - if there is no energy reserve in the collector); the springs of the mechanical energy collector are compressed and increase the energy reserve (volume).At the end of the braking process, the brake disk is released and the cable returns its return through the return spring additionally placed in the mechanical energy set; the next gathering takes place; on subsequent braking, the mechanical energy collector starts again. The next parallel influencing process is the process of converting the accumulated mechanical energy into electrical energy. The basis of the mechanical energy harvester is the disc system, which is connected to the disc on which the spring system is fixed, the free-moving clutch with the cable, the main support and the gear holder. Under the influence of the cable moving through the braking disc, the element of the mechanical energy collector rotates at a certain angle, as soon as the braking disappears, the cable and the braking disc return to their original position with the return spring (the spring is counted only for the return of the braking disc and cable). The disk of the accumulator loaded with mechanical energy enables the operation of the electric generator. A gear system was applied to bring the rotation frequency of the electric generator to a certain value. The energy is collected due to the compression of the springs in the mechanical energy collector.The length of movement created by opening the springs does not match the length of movement that can operate the generator. Therefore, opening the springs through a system of gears creates a high-frequency rotation. The moment created by the mechanical energy collector and the moments that ensure the normal operation of the electric generator are equal to each other in the maximum volume of the collector, and the maximum moment exchange takes place when the battery banks are fully connected.After the battery banks are fully charged, electric power is supplied to the starter motor (which performs the functions of starting and leading motor) with the driver's command, and the vehicle continues its movement without ICE (Internal combustion engine).

The importance of two constructive elements in the transport of mechanical energy has been shown:

1) getting an operation for transporting mechanical energy from the braking system;

2) launching of construction for mechanical energy transfer.

The working principle of the proposed electromechanical conversion device is related to the functions performed to stop the vehicle at stops or reduce its speed. In this process, the mechanical energy generated during braking is transferred to the brake disc.

According to modern technologies, the brake disc is attached to the body of the vehicle.In the design of the presented device, the brake disc has a design that can rotate up to π/2 angle along the axis of the rear axle.It should be noted that the possibility of increasing or decreasing the value of the turning angle depends on the structural characteristics of the vehicles[1].

The angle of rotation depends on the following factors:

- from the capacity of the public transport;
- from the speed of public transport;
- from the braking intensity of the public transport vehicle;
- from the amount of real collected energy in the mechanical energy collector, etc.

In order to collect the mechanical energy generated during braking in the vehicle, in the braking system of each wheel, it is necessary to place an additional element between the body surface and the brake disc, so that the mechanical energy generated during braking is converted into a movement element, so that the effect of this movement will represent mechanical energy relatively and it will be possible to exclude it from the wheel system as a moving element. The amount of mechanical energy accumulated in this element is close to 90-95%. The movement of the presented structural element on the shaft under conditions of maximum force should not exceed an angle of approximately π/2 (the maximum rotation of the element during sharp full braking is up to π/2).In order to transport the mechanical energy from the element located in the wheel brake system to the point of use, the system used in the process of delivering the energy to the place of use without loss should be such that the energy loss is small. Of course, the process can be performed using hard or soft transmissions: in individual areas, steel bars with diametrical or triangular-quadrangular cross-section, chain steel ropes, cables with a soft construction can be used.In the proposed structure, the use of screw springs working for screw compression and tension in the

1.Базров Б.М. Основы технологии машиностроения / Уч., Б.М. Базров. - М.: - Инфра-М, - 2019, - 492 с.

"Mechanical energy set" is considered appropriate[2].According to the standard (ГОСТ 13766-68), the 1st class bow of grade №575 is selected. For this spring, F_3=10510.5H; d=15 mm; D_x=105 mm; The hardness of one winding C_1=610 H/mm;

During the process, at any cross-section of the spring, the force F is directed along the axis, and at the same time, a moment M=FD/2 is created in the direction perpendicular to the axis of the spring. The force F is divided into $F_1=F\cos\alpha$ - transverse (projection of the force on the x-axis) and $F_2=F\sin\alpha$ longitudinal (projection of the force on the y-axis).M isrotational and bending moments occur along the axis of the spring coil and perpendicular to it (Fig. 4).

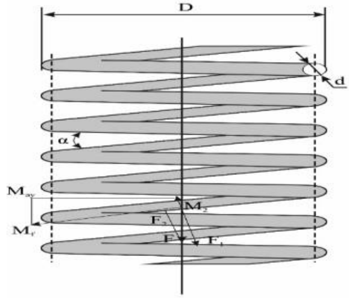

Figure 4. Resulting in the operation of the selected spring construction directions of forces

Rotating moment $M_r=FD\cos\alpha/2$; Bending moment $M_b=FD\sin\alpha/2$.Calculations show that the tangential value of shear stress is much lower than the tangential value of rotational stress. Therefore, if the torque cosa=1 is taken to simplify the spring report, $M_r=M_b=FD/2$ olar. The structural scheme of the designed electromechanical conversion device is shown. The diagram shows the cross-sectional views of the structural elements used in the construction (Figure 5).

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[2] Джэф Дэниэлс. Современные автомобильные технологии. Машиностроение, - 2017, - 238 с

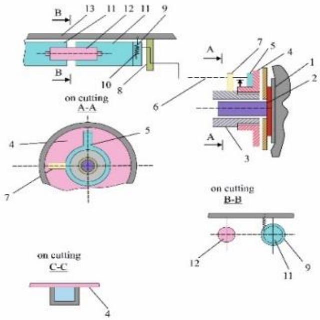

Figure 5. Structural scheme of the electromechanical conversion device

1-rear wheel; 2-axis; 3-shirt; 4-brake disk; 5-protrusion; 6-rope; 7,8-support; 9-free movement clutch; 10-return spring; 11-mechanical energy collector; 12-electric generator; 13-board

Approximately 85-90% of the energy generated in braking through the cable from all wheels enters the mechanical energy collection. 10-15% of this energy is spent on the brake disc and tensioning during cable operation. A small part of the energy generated during braking is spent on the indicated disk, and the rest is spent on the movement of the cable located in the brake zone of the main wheels. The cable transports the braking energy to the brake disc and the main energy collection point - the mechanical energy collection (Fig. 6).

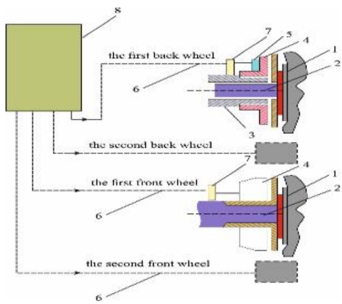

Figure 6. The scheme of transporting the energy generated during braking to the energy collection

1-wheel; 2-axis; 3-shirt; 4-brake disk; 5 side exit; 6-rope; 7-trunk; 8- collection of mechanical energy

The construction of the device created on the basis of the working and structural elements used in the process of converting the mechanical energy generated during braking into electrical energy and their performance is shown (Fig. 7).

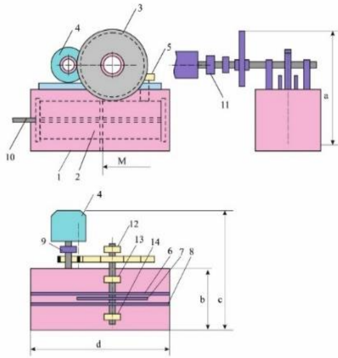

Figure 7. Constructive performance of the device that converts the mechanical energy generated during braking into electrical energy

1-trunk; 2-working spring; 3-gear wheel; 4-generator; 5- gear crawler; 6,8-frame of the crawler; 7-sliding gear transmission; 9-free movement clutch; 10-rope; 11-clutch; 12,13,14-pillows. a,b,c,d dimensions are known after complete design.

The collection of mechanical energy generated during the operation of the vehicle during braking, the process of conversion into electrical energy, the placement of the mechanical energy collector in two planes, the determination and study of the characteristics of the spring were carried out **in the third chapter.** Stabilization in the process of converting the mechanical energy generated in braking, analysis of the losses in the generator, establishing the building Coefficient of Performance (c.o.p) of algorithm, summarizing total c.o.p and saving produced electrical energy and using it such as problems have been resolved.

The designed construction is a complex of technical equipment, which includes a reducer placed between a set of mechanical energy and an electric generator system, and an electric generator that converts the transferred mechanical energy into electric energy. The conversion efficiency of mechanical energy into electrical energy is 80÷90% when performed with a generator. Autonomous small powerful converter consists of the following elements: mechanical power transmission, reducer, generator, accumulator battery (Figure 8).

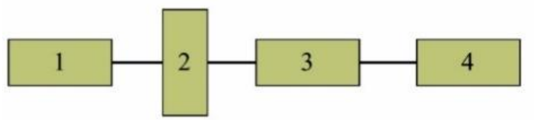

Figure 8. Electromechanical conversion device basic structure scheme

1-mechanical power transmission, 2-reducer, 3-generator, 4-accumulator batteries

The transmission, which is in contact with the spring of the mechanical energy set, transmits the mechanical energy to the reducer. The reducer connects the mechanical power transmission with a certain frequency of rotation, which enters through gears of different diameters, with the generator, where electricity is produced. The generated electricity is stored in batteries. If there is any important equipment in large powerful special cars with a complex structure, it is required to convert the voltage stored in the battery into an alternating current.

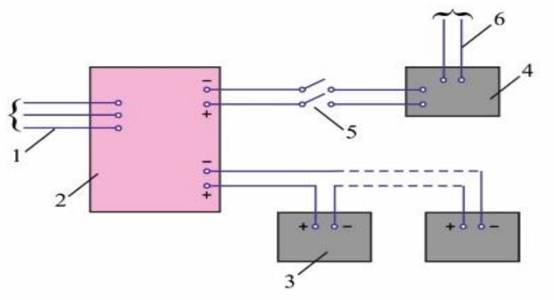

Figure 9. Scheme of the electrical power network

1- generator connection wires (synchronous and asynchronous generators), 2-controller distributor, 3-battery banks,
2- 4-inverter, 5-switch, 6-alternating current source

The features and characteristics of the existing generators in the designed structure were investigated depending on the work process in the unit. It is more convenient to use a direct current generator in the device, because no conversions are allowed in this type of system[3]. Normal operating conditions are at (1÷3) kWt power, which is favorable for the designed construction (Figure 10).

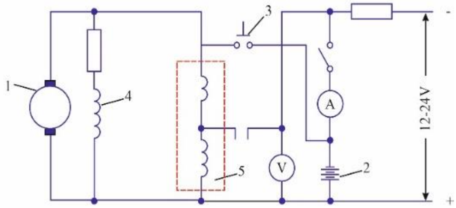

Figure 10. Constant current load switching scheme
1-generator, 2-battery, 3-ignition button; 4-loop of influence, 5-reverse current relay

Ensuring uninterrupted operation of the generator is related to the duration of energy transmission. In order to increase the length of the spring while maintaining the power spent on it, it is necessary to place N springs in a series and round. Considering that the load ($P_{account}$) within the acceptable limits is unequal for each step of the spring, and in this case it is necessary to have an external load (0.8÷0.9) P_{edge} - to ensure the operation of the spring according to the linear characteristic. According to the calculated load spring characteristics are shown in figure 11.

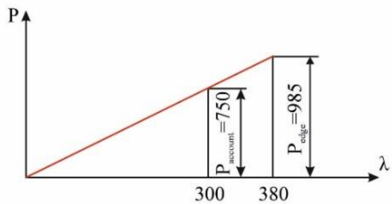

Figure 11. Characteristic of the developed spring according to the calculations

[3] Усольцев А.А. Электрические машины. Санкт- Петербург: НИУ ИТМО,- 2013, - 416 с

The collection of mechanical energy occurs due to the compression of the springs in the process. The working time of the mechanical energy in opening the spring is one of the main parameters in the designed device. To increase this parameter, it is necessary to increase the length of the spring. The length increase after the spring is fully compressed and opened:

$l = l_a - l_y$ where l_o- the fully unfolded length of the spring; l_l - full compression of the spring under load, as a result mechanical load collected in compression:

$$\sum P_{mech.c} = NP_{mech.l} \quad (2)$$

where $P_{mech.l}$ - mechanical load of a spring connected in series; N is the number of springs connected in series.

After the load is removed from the area of influence of the compressed springs due to the load $P_{mech.c}$, the spring's opening effect is transferred to the energy conversion system. That is

$$\sum P_{mech.c} \approx \sum P_{mech.o} \quad (3)$$

where $P_{mech.o}$ is the load obtained in opening the springs when the compressive load is removed.

Figure 12. The spring connection scheme is given as follows.

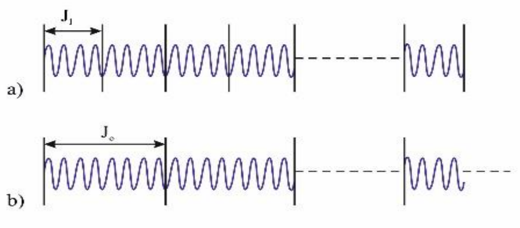

Figure 12. Spring connection scheme

a) Collection of the spring due to the effect of the load;

b) Opening of the spring after the load is removed

In order to increase the volume of energy collection in the mechanical energy collector and to extend the time of transmission to the electric generator system, and to increase the length of the space where the springs are located, the springs are also placed on the second plane. In any case, the load transmitted by the cables will be equal to the sum of the mechanical loads of the first and second wheels

($P_{mech.}t_1$, $P_{mech.}t_2$). First, this will happen within the rotation angle of the brake disc. Design works are being carried out in order to collect the brake energy of the front wheels.

$$P_{mech.c} = P_{mech.t1} + P_{mech.t2} \quad (4)$$

One of the main elements here is the acquisition of the volume of the mechanical energy collector. If the system of springs connected in series of the mechanical energy collector is placed in several parallels, a constructive approximation must be made for tensioning the cables, that is, the ratio between the rotation angle of the brake disc and the rotation angle of the gear half disc should be 1:1 and the ratio 1: K (K>1) should be changed. Therefore, the following ratio should be obtained:

$$K = \frac{\alpha}{\pi / 2} \quad (5)$$

where α is the turning angle of the gear half disk, $\pi/2$ is the maximum (accepted) turning angle of the braking disk.

Constructively, as a result of calculations and considerations, it was decided that the ratio K= l÷2 is satisfactory. Accepting the ratio K >2 leads to some complexity in the structure, which increases the cost of the structure. During the design, a free-motion clutch was used in the construction to use the energy generated by the springs connected in series and compressed by the braking energy towards opening. Thus, the compression process in the springs of the mechanical energy collector is concentrated in one effect zone of the coupling, and the effect of the torque is concentrated in the other element[4].

The process of transferring motion to the electric generator is performed by means of a large gear ratio:

$$k = k_1 \cdot k_2 \quad (6)$$

where k_1 is the ratio of the diameter ($d_{f.s.m}$) of the gear half disk of the mechanical power distributor to the diameter (d_s) of the gear wheel on

[4] Молотников В.Я. Механика конструкций. Теоретическая механика. Сопротивления материалов / Учебное пособие. В.Я. Молотников. – СПб.: Лань, - 2012, - 608 с

the shaft of the free movement clutch; k_2 is the ratio of the diameter of the transmission gear wheel (d_t) to the diameter of the gear wheel (d_g) placed on the shaft of the electric generator:

$$k_1 = \frac{d_t}{d_v} = \frac{400}{50} = 8;\ k_2 = \frac{d_{ö}}{d_g} = \frac{400}{50} = 8$$

So the total transmission number will be: $K = K_1 K_2 = 8 \cdot 8 = 64$

In Figure 13 the process of collecting the mechanical energy generated during braking and the load accumulation graph as a function of time are given.

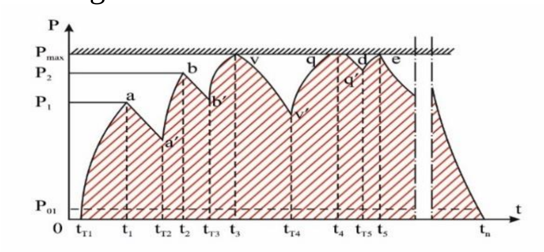

Figure 13. Mechanical energy accumulation over time dependency graph.

t_1, t_2, t_3, t_4- times when braking stops;

t_{T1}, ..., t_{T5}- braking start times.

The process is performed as follows:

In the first braking (t_{T1}), the force compressing the springs is transmitted through the cable. Due to the direct effect of the cable on the springs, the 1st compression arm moves and moves slightly in the direction of compression of the springs (in the time distance t_{T1}-t_1), the braking process stops at the moment t_1 (point a). From this moment, that is, from time t_1, force is transmitted in the direction of the generator, so that the compression force of the springs gradually decreases.

The next braking moment is t_{T2}, where the springs are compressed again; new mechanical energy enters the system. The access period is from t_{T2} t_2.

Thus, during braking, the compression of the springs, that is, the process of gathering mechanical energy takes place (t_{T1} - a), (t_{T2} - b) and so on. After braking stops, the consumption of mechanical energy (a - a', b - b', etc.) affects the cycle.

If there is no braking for a certain time, the mechanical energy will be completely converted into electrical energy (at the end of the opening of the spring, in the range where the force approaches zero), the rotation frequency of the electro generator will also approach zero, and the electric motive force will not be induced (field - P_{01}).

In order to obtain the power graph of the mechanical energy collector, it is necessary to sequentially analyze N number of springs with the same characteristics connected in series. The total length of the springs together can be determined by taking into account that the fully extended length of the spring and the mechanical coupling element are also carried out:

$$L_{gen} = L_{sp} \cdot N + \Delta\alpha \quad (7)$$

where l_l is the full length of the spring element; N - number of springs; Δa - the thickness of the mechanical connection element.
The length of the working part of the spring:

$$L_i = \Delta l \cdot N \quad (8)$$

Where $\Delta l = l_l - l_c$ the working length of a spring; - l_0 =595 mm the length of a spring without load; - l_3 = 303 mm the length of a spring when fully compressed, $\Delta\alpha$ = 30 mm is accepted.

In general, all the necessary elements are determined by building a characteristic for the length of the bow. The *P=f(l)* graph of the spring system is given in figure 14.

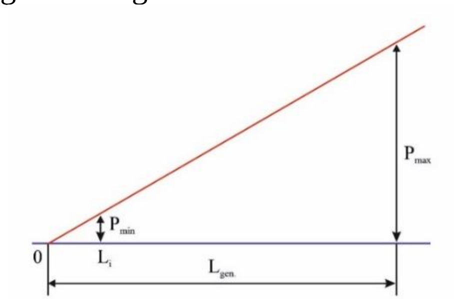

Figure 14. The spring system of the mechanical energy collector power graph P=f(L)

L_{gen} - the last limit of the working length of the spring; L_w - the length corresponding to the minimum operating torque of the generator.

The set parameters of the schedule for the calculated and accepted spring for a type of vehicle:

L_l=595mm; Δl=30mm; *L_{gen}=1815mm;*
P_{min}.=128kq;N=2x6 *P_{max}=1150kq*
pieces;

During the operation of the mechanical energy collector, the length l_i is precisely determined by taking into account the frictional forces and losses of the elements working in the device.

The torque $M_{c.o.m.e.}$ of the mechanical energy collector increases starting from zero. When this increase reaches the P_{min} value, the gear unit and the electric generator start working. During the next period of time, the braking torques (M_c) enter the collector, which is collected with the reserve torque. Moment in the general case

$$M_{c.o.m.e} \pm M_t$$

collected in the collector. As some time passes, $M_{c.o.m.e.}$>$M_{c.o.m.e.l}$ During the next braking process, the torque M_c enters the accumulator. On the other hand, during the operation of the electric generator, the equality of torques is required:

$$M_{c.o.m.e} \pm M_s \approx M_{g.sh} \pm \Delta M_s \quad (9)$$

Here, $M_{g.sh.}$ is the torque on the shaft of the electric generator; ΔM_s is the stabilizing moment.

In a mechanical energy harvester, the torque changes over time.

Several methods are used in a complex way to stabilize the rotation frequency of the electric generator. The main factor in the selection of methods is that the torque generated by the mechanical energy collector is reduced to the total transmission number ($K_{gen.}$) on the shaft of the electric generator:

$$M_{g.sh} = \frac{M_{c.o.m.e}}{K_{gen}} \quad (10)$$

where Kum is equal to the product of transmission numbers between the cable, the freewheel coupling and the shaft of the electric generator and the system:

$$K_{gen} = K_c \cdot K_{f.w.c} \cdot K_{s.g} \quad (11)$$

where K_c is the transmission number of the torque transmitted by the cable;

$K_{f.w.c.}$ - transmission number in the free movement clutch; $K_{s.g}$ - transmission coefficient between the shaft of the electric generator and the system. The following methods are used for stabilization:

1. The effect of the dependence of the electric motive force of the electric generator on the frequency of rotation.

$$e_{e.g.} \equiv B \cdot v \quad (12)$$

where B is the value of induction in the generator; v is the rotation frequency of the rotor.

There is an interaction between B and v: with an increase in B, e_{eg} increases and, accordingly, the load of the electric generator increases, as a result of which there is a decrease in the rotation frequency, thereby the load I_{eg} decreases.

2. Stabilization of the rotation frequency of the electric generator by a mechanical method (introduction of a fan specially calculated taking into account the rotation frequency into the construction of the generator). Then $M_t=M_{eg}+M_{sh}$. The ventilator's mechanical characteristics $M_v=f(v)$ are given in figure 15. The ratios $M_3>M_2>M_1$ differ from each other in the characteristics.

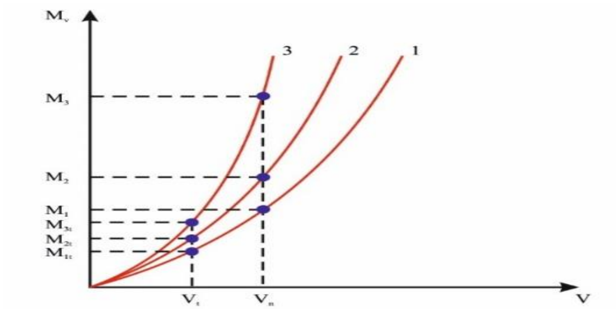

Figure 15. Fans of different structural sizes mechanical characteristics

Conducted calculations and analysis of data from intensive urban traffic show that with the above methods it is possible to maintain the balance of moments with an error of ±10%.

3. Stabilizing the rotation frequency of the electric generator by changing the number of battery banks.

During the process, the losses in the mechanisms and connections used in the device lead to a decrease in the useful work coefficient. If we take into account that the c.o.p. of each mechanism used in the construction is $\eta=1-\varphi$ becomes.

Where φ is the loss coefficient in the mechanism and c.o.p. (utility factor - coefficient of peformance) varies between zero and unity within a suitable limit of $0 \leq \eta < 1$.

Taking into account that the mechanical energy collector in the device consists of springs connected in parallel from the four-wheel system, in special cases, when $\eta_1 = \eta_2 = \eta_3 = const$ for the cases of parallel connection of springs

$$\eta = \frac{\eta(A_{s1}+A_{s2}+A_{s3}\cdots A_{s.n})}{A_{s1}+A_{s2}+A_{s3}+\cdots A_{s.n}} \quad (13)$$

Consistently useful work coefficients for suitable mechanisms are defined as:

$$\eta_1 = \frac{A_1}{A_h}; \eta_2 = \frac{A_2}{A_1}; \eta_3 = \frac{A_3}{A_2}; \ldots\ldots \eta_n = \frac{A_n}{A_{n-1}} \quad (14)$$

If we take into account that the overall useful efficiency of the device is equal to the product of the c.o.p.

$$\eta_{gnr.} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_n = \frac{A_1}{A_h} \cdot \frac{A_2}{A_1} \cdot \frac{A_3}{A_2} \cdots \frac{A_n}{A_{n-1}} = \frac{A_n}{A_h} \quad (15)$$

Based on the result $\eta_{gnr.} = \frac{A_n}{A_h}$ it can be noted that it gives the efficiency of the work received in the last placed mechanism in the series connections[5]. As a result of the conducted studies and calculations, the unit's c.o.p. (15) was determined as follows:

$$\eta_{gnr} = \eta_r \cdot \eta_s \cdot \eta_{g.c} \cdot \eta_{f.w.c.} \cdot \eta_{g.c.} \cdot \eta_{s.s.}^3 \cdot \eta_{\ e.gen.} = 0{,}6941$$

During the project, one or two battery banks are placed on board the vehicles, depending on their capacity. The main value that characterizes the accumulator is its volume, which determines the number of ampere-hours of electricity; at normal discharge current, the battery can supply power to the consumer.

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[5] Тимофеев Г.А. Теория механизмов и механика машин. Изд- во: МГТУ, -2017, - 568 с.

These are to start the internal combustion engine of the vehicle and provide electricity to the consumers while it is not working. Below is an initial draft of how this consumption will be implemented. For this purpose, the structural scheme of the given process is given in figure 16.

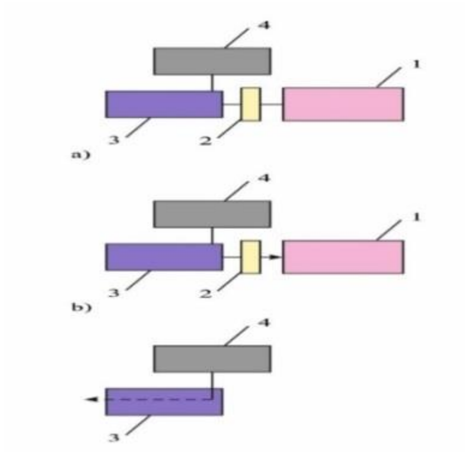

Figure 16. Electric energy drag to mechanical energy structural scheme of the transformation

1- ICE (Internal combustion engine); 2-connecting element; 3-speed box; 4-electric motor

First of all, the operation is carried out by the driver of the vehicle: in the operation of the gearbox, the 1st gear is engaged and the electric motor is started (the choice of the electric motor is performed before the design of the control system).

The rotation frequency of the electric motor must match the rotation frequency of the ICE, its variation range, so that there is an approximate adaptation at different speed steps. For this, the selection of elements included in the control system of the ICE motor should be adapted to the mode. ICE is activated after the electric energy capacity in the battery banks drops below the allowable limit.

The fourth chapter deals with a mathematical analysis of the technology of converting the mechanical energy generated during the braking process into electrical energy and the principle of charging the produced energy into the battery during the movement of the intra-city passenger bus along the route was carried out, an electronic database of the results obtained by computer experiments was created in the MS Excel program, and graphs were constructed based on the spreadsheet.

Experiments were conducted in the MATLAB program, conclusions were obtained using the method of logical productions, the graph scheme of the algorithm of the recuperation process in public transport vehicles along the route and mathematical and computer models were built for the study of management and control processes.

In order to ensure experimental tests of the recuperation process on a public transport vehicle, i.e. charging the battery with the required amount of electric energy, the following initial data are determined:

The full duration of the experiment is expected to be 15 hours (6:00 a.m. to 9:00 p.m.);

If we consider that the capacity of the battery used in public transport is 75 A*s and the voltage is set to 12 V, the power spent on charging the battery in 1 hour is 0.90 kW.

According to the regulations, the distance between stops is considered as follows:

$$500 \leq l_{b.s.d} \leq 600 \qquad (m)$$

The average speed of the public transport vehicle between stops must be ensured according to the following condition:

$$50 \leq V_{int.} \leq 60 \qquad (km / hour).$$

The length of the route of transport No. 6 moving through the city of Baku

$$l_m = 45\ km$$

The number of public transport stops

If we take $n_{b.s.} = l_m / l_{b.s.d.}$, then $n_{b.s.} = 75$.

If we take into consideration that the stopping time of public transport at each stop should be up to 1.2 minutes to ensure the recuperation process, then if it stops at each stop for 72 seconds, the total amount of electric energy accumulated in the battery during the stopping time for 15 hours is determined. To conduct experiments, the number of stops on the route (45000 m) and the distances between the stops are determined.

Accumulation of electrical energy into the battery

Table 1

Number of stops on route No. 6 ($n_{b.s.}$) Distance between stops	($l_{b.s.d.\_i}$ (m)) Distance between stops	Duration of parking vehicle (t_i – (*min*))	(t_i –(min)) Capacity of the total electric energy collected in the accumulator wattage (kWh)
75	600	0.96	1,08
79	570	0.92	1,089
85	530	0.85	1.085
90	500	0.8	1.08

Experiments were conducted using the MATLAB software package to determine the number of cycles on the route and analyze the energy capacity of the battery by constructing a graph of the dependence of the number of stops on the distance between the stops on the route No. 6, charging the battery of a public transport vehicle with electricity (Fig. 17.).

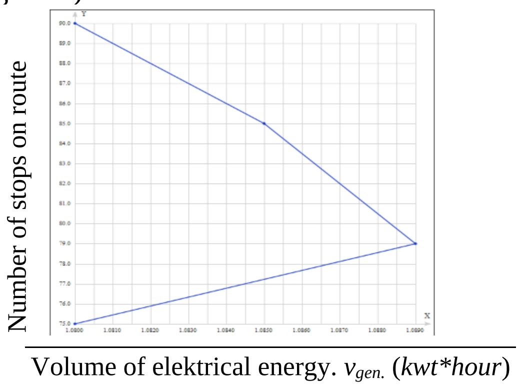

Figure 17. Graph of the dependence of the total electrical energy capacity collected in the battery on the number of cycles of the vehicle on route No. 6

If we take into account that the total distance of public transport along the route is l_{gnr}=45000 m, then according to the following expression, the volume of electric energy collected in the battery is determined as follows:

$$v_{gnl} = \frac{l_{gnl} t_i v_{1hour}}{l_{b.s.d\_i} t_{1min.}} \quad (16)$$

where $t_{1min.}$ -1 is the number of seconds in a minute; t_1 - traffic stop time, $l_{(b.s.d.)}$ - distance between stops, v/ hour = 0.9 kW*hour - is the amount of electric energy collected in the battery in 1 hour.

According to Table 4.1.1, computer experiments were conducted and graphs were constructed for the transportation and stopping of public bus No. 6 on the route (pictures 18 a, 18 b).

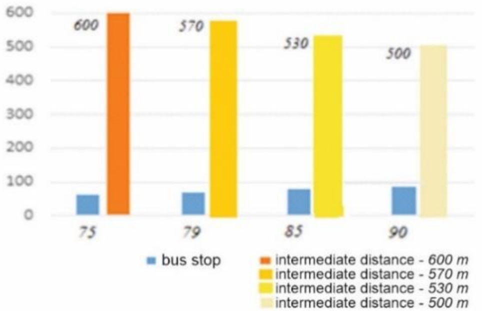

Figure 18 a. Number of stops between stops distance dependency graph

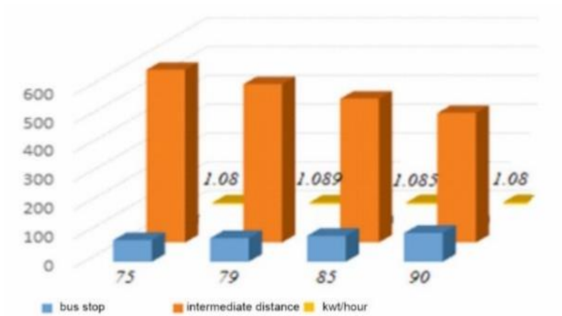

Figure 18 b. The volume of electric energy charged to the bus battery according to the route characteristics

Using the MATLAB software package, it is justified as a result of experiments that when the distance between stops of public transport is 500 ÷ 600 m and when the stop of the bus changes between 0.8 ÷ 0.96 min, it takes one cycle (45 km) to charge the electric energy to the battery, and in this time period the battery has 1.08 Energy is charged in kWh. By conducting computer experiments, it was determined that the charging of electric energy to the battery of a vehicle depends on the following parameters:

- the number of stops on the route ($n_{b.s.i}$);
- distance between stops ($l_{b.s.d.i}$);
- vehicle parking time ($t_{b.s.i}$).

The above parameters can be given as multiples:

$$n_{b.s.i.} \in \{n_{b.s.1}, n_{b.s.2}, \dots, n_{b.s.k}\};$$
$$l_{b.s.d.i.} \in \{l_{b.s.d.1}, l_{b.s.d.2}, \dots, l_{b.s.d.n}\}; \qquad (17)$$
$$t_{b.s,i} \in \{t_{b.s.1}, t_{b.s.2}, \dots, t_{b.s.k}\};$$

where k=1, l_{gnl} / lb.s.i ; $t_{b.s.k}$ - the duration of public transport vehicle parking at parking lot number k.

In order to solve the problem in real time, adequate control by identifying the states (initial and final states of the parking lot) determined by the elements of the *"If"* implication of the production model and whose states are limited by the sensors of the local network UniFi installed in the stops of the public transport vehicle (bus No.6) an algorithm that ensures the formation of signals is established.

Production system "situation → action", "cause → result", etc. from the algebra of first order predicates in the form of pairs

$$f = < xi, vj, \&, v, \rightarrow > \qquad (18)$$

It consists of knowledge bases and a control block. Formally, the operation of the production system for any technical system

$$x\ (t+1) = f\ (x(t), U(x)) \qquad (19)$$

can be written as Here x(t) is the current state of the fact base; x(t +1) is the state of the fact base after applying the production rule U(x).

The expert subsystem, which provides the analysis of the management procedures of the recuperation processes while moving along the route, the construction of the logical algorithm, control, decision-making and synthesis, consists of a technical and software interface interconnected with the control object (Fig. 19).

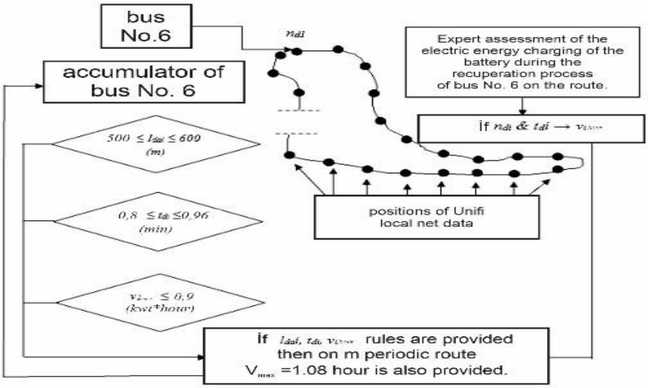

Figure 19. Modeling of maximum electric energy charging during the recuperation process of the battery of bus No. 6 on the route

The structure of the knowledge base for managing the transportation, stopping and recuperation of the bus operating on route No. 6 is as follows:

$$P_i: \wedge_{j=1}^{n} X_j \rightarrow U_k \& P(S); \;\; i = \overline{1,m}, \;\; s = \overline{1,l}, \qquad (20)$$

where m is the number of rules of the main knowledge base, n is the total number of elements of the "If..." implication of the production; k = 4 – number of execution devices; l - is a function of transition to the formed stack knowledge bases.

The elements of the "If..." implication of the productions of the main knowledge base are described as a labeled vector in the base:

$$X_j = \left[x_j^1, x_j^2, \dots, x_j^n\right] \qquad (21)$$

The elements of the Xj - vector are determined by the following condition:

$$x_j^r = \begin{cases} \text{if production elements are active} \\ \text{if production elements are not active} \end{cases}$$

In the decision-making block, the stack on the elements of the vector Xj entered from the knowledge base and the vectors uj entered from the control object

$$F = \overline{x_j} \vee \overline{v_j} \qquad (22)$$

operation is performed, if the condition F=1 is satisfied, the execution of the "Then..." implication of the production of the knowledge base is allowed, and after the decision is made, the processing of the selected production of the stack knowledge base according to the value of the transition function P(s) of the production is performed.

As a result of the experiment, on the basis of four productions, the result of charging the battery with electric energy during the movement of bus No. 6 on the route for one cycle was determined and can be written as follows:

$$V_{gnr} = \sum_{i=1}^{4} V_1 = 1{,}084\ (kWt * hour)$$

The total distance traveled by the bus along the route is determined as follows:

$$L_{gnr} = \sum_{i=1}^{4} L_i = 45\ km$$

based on the results, a diagram of the control algorithm of the recuperation process during the movement of bus No. 6 along the route is established (Figure 20).

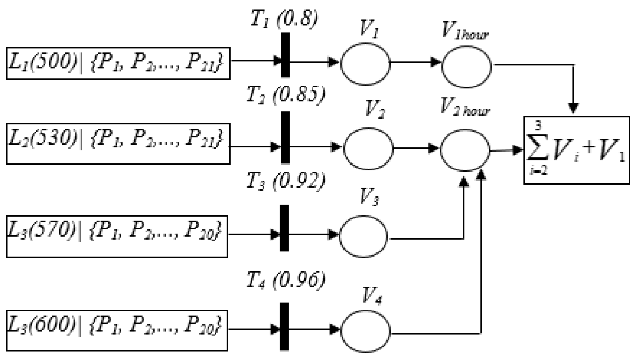

Figure 20. Diagram of the management of the recuperation process during the movement and stopping of bus No. 6 on the route

The graphical change of the recuperation process during the movement and stopping of bus No. 6 on the route was checked in the

MATLAB - software package, and the graph was constructed as follows (Figure 21).

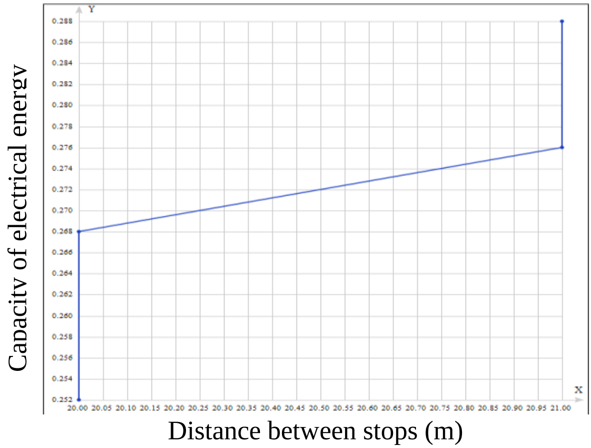

Figure 21. Graphic change of the recuperation process during the movement and stopping of bus No. 6 on the route

A real object based on a logical and graphical modeling algorithm established for the control, management and connection of the recuperation process to the local corporate network - more efficient movement of the bus along the route, determination of the duration of its parking at the stops, filling of the required electric energy into the battery in a short period of time and using it as an AES becomes possible.

82 nodal points corresponding to 82 stops are determined on the 45 km route of bus No. 6.

IP addresses 192.168.1.1÷192.168.1.82 IP are defined to ensure mutual information exchange by connecting within the corporate local network. The registration data of 82 transmitters is transmitted to the local network.

The table for determining IP and node points based on the address fields and working memory areas of the stops:

Table 2.

№	UniFi transmitters at the stops of bus route No. 6	The address allocated to the bus stop in the corporate network	Address of stops	Percent area allocated to each bus stop in the corporate network (%)
1	$A6_{v1}$	192.168.1.1	0.0.0.1	1.22
2	$A6_{v2}$	192.168.1.2	0.0.0.2	1.22
		.	.	.
		.	.	.
		.	.	.
82	$A6_{v82}$	192.168.1.82	0.0.0.82	1.22

The percentage area allocated to each stop of the route is determined according to the following condition:

$$N_{b.s.i} S_{\%i} \approx 100\ \%$$

where $N_{b.s.i}$ = 82 is the number of stops on the route, $S_{\%i}$ is the percentage area of the network allocated to each stop as shown in the productions.

$$P1(21)+P2(21)+P3(20)+P4(20)=82\ ;\ S_{\%i} \approx 1{,}22\ \%$$

The use of subnet masks to identify the 82 nodes of the network is defined by binary notation. To ensure the efficiency of a TCP/IP local network, routers are used to exchange data packets.

THE MAIN RESULTS OF THE DISSERTATION WORK

1. A large number of literature studies were carried out, a comparative analysis of information and modeling technologies used in the management of the recovery process of existing facilities and vehicles suitable for the dissertation work was carried out, and as a result, the purpose of the dissertation work and the main research issues were determined.

2. The structural scheme of the device that collects mechanical energy generated during braking during the operation of the public transport vehicle, converts it into electrical energy, stores it and uses it as AES was proposed and analyzed, the functional analysis model of the device was established, its working principle was determined, the selection of structural elements, mechanical the principle of energy transfer from the wheel system to the mechanical energy assembly, the material consumption of the springs that form the basis of the mechanical energy assembly, and the determination of their geometrical dimensions were solved, and as a result, the structural structure of the device was worked out.

3. In the proposed device, the technology of collecting and converting the mechanical energy generated during braking in public vehicles carrying passengers in the city into electricity was analyzed, the transmission mechanisms used in the device and the working principles of existing generators were investigated, the issues of choosing a suitable electric generator were solved, the characteristics of the mechanical energy collector under load were established, public transport methods of stabilization in the process of collecting mechanical energy generated during braking and converting it into electrical energy were determined, the device's losses were analyzed, and the coefficient of useful activity of device (η =0.6941) was determined as a result..

4. In the proposed device, the technology of collecting and converting the mechanical energy generated during braking in public transport vehicles carrying passengers in the city into electric energy was analyzed, the transmission mechanisms used for the transmission

of motion in the device, the placement of the mechanical energy collector in two planes and the working principles of the existing generators were investigated and a suitable electric generator was selected. Stabilization methods have been determined in the process of collecting mechanical energy generated during braking and converting it into electrical energy in public transport vehicles. Device's losses and coefficient of performance (c.o.f) are analyzed and assigned.

5. The issues of selection and research of accumulators for storing the electricity produced in the device that converts the mechanical energy generated during braking during the operation of city passenger transport vehicles into electrical energy with an electromechanical conversion system and provides its use as an AEM have been resolved. The proposed device makes up 2-3% of the weight of the vehicle, it does not cause any harm to its construction by taking into account the operational requirements, reliability, and working modes.

6. The developed structure allows for the simplicity of its own and management, by converting the mechanical energy received from the economically efficient braking system into electrical energy, increasing the efficiency of its vehicles, saving fuel and driving public transport such as AES. As a result of conducted research and tests, up to 70% of the mechanical energy generated during braking in the operation of vehicles has been converted into electrical energy and it has been confirmed that the energy obtained can be used as AES.

7. The device proposed in the thesis work was developed according to the selected parameters and tested in operational conditions and allowed to obtain quite acceptable results. It should be noted that the results of scientific-theoretical studies, methodical recommendations in the presented dissertation work can be successfully applied in the future in the creation of new devices and in the process of operating similar devices for the purpose of saving fuel in the operation of transport and using them as AES.

THE MAIN RESULTS OF THE DISSERTATION ARE REFLECTED IN THE FOLLOWING PUBLISHED SCIENTIFIC ARTICLES:

1.Balayeva, Ə.H., Nəqliyyatın tormozlanma prosesində alternativ enerji mənbəyi // - XXI Respublika Elmi Konfransı, BDU, - Bakı: -2017, -s. 117-119.

2.Мусаев, З.Н., Балаева, А.Г., Альтернативная энергия при торможении городских транспортных средств // - X международная научно-практическая конференция молодых ученых, том 1, - Уфа: - 2017, с. 293-294.

3.Balayeva, Ə.H., Nəqliyyat vasitələrinin tormozlanmasından alınan alternativ enerji sərfiyyatı haqqında // - XXII Respublika Elmi Konfransı, ADPU, -Bakı: - I cild, - 2018, -s. 208-210.

4.Фархадзаде, Э.М., Мусаев, З.Н., Балаева, А.Г., Конструктивные особенности накопителя механической энергии торможения // - Международная научная конференция, СГУ, - Сумгаит: - 2018, -с. 298-300.

5.Musayev, Z.N., Balayeva, Ə.H., Nəqliyyat vasitələrinin tormoz rejimindən enerji mənbəyi kimi istifadə // - SDU, Elmi Xəbərlər, №1, cild 18, - Sumqayıt: - 2018, -s. 77- 79.

6.Fərhadzadə, E.M., Musayev, Z.N., Balayeva Ə.H. Nəqliyyat vasitələrində alternativ enerjinin toplanması mexanizmi // - AMEAFİ Energetikanın problemləri, №2,- Bakı: - 2019, -s. 57-61.

7.Musayev, Z.N., Balayeva, Ə.H., Alternativ mənbə-güc toplusu // - Beynəlxalq konfrans. ADNSU, - Bakı: - 2019, -s. 195-196.

8.Musayev, Z.N., Balayeva, Ə.H., Nəqliyyat vasitələrində enerji çevrilməsi prosesində stabilləşdirmə // - ATU, Elmi əsərlər, №1, - Bakı: - 2019, -s 44-48.

9.Musayev, Z.N., Balayeva, Ə.H., Nəqliyyat vasitələrinin istismarı zamanı enerji itkisinə qənaət // - Respublika Elmi Konfransı, SDU, - Sumqayıt: - 2019, -s. 211- 214.

10.Фархадзаде, Э.М., Мусаев, З.Н., Балаева, А.Г., Новый источник альтернативной энергии // - Технология машиностроения, №6, - Москва: - 2019, -с. 26-30.

11.Мусаев, З.Н., Балаева, А.Г., Возврат потерянной механической энергии в тормозной системе транспорта // - IV Национальной научно-практической конференции, Том 2, КГЕУ, - Казань: - 2019, -с. 251- 255.

12.Balayeva, Ə.H., Tormoz mexaniki enerjisinin çevrilmə məkanına nəqli prosesi // - SDU, Elmi Xəbərlər, cild 20, №1, - Sumqayıt: - 2020, -s.97-99.

13.Balayeva, Ə.H., Tormozlanma – elektrik enerjisi istehsalı // –ADNSU, Azərbaycan Ali Texniki məktəblərinin Xəbərləri, -Bakı: Cild 22, Buraxılış 1(123), - 2020, -s. 87-92.

14.Фархадзаде, Э.М., Мусаев, З.Н., Балаева, А.Г., Процесс возврата потерянной механической энергии // - Международной научно-практической конференции, ПГУ, - Псков: -23-24 апреля - 2020 г., -с. 86-90.

15. Балаева, А.Г. Разработка пружинного накопителя бортового рекуператора энергии торможения транспортных средств // - Международный научный журнал, Альтернативная энергия и экология, Россия, - Саров: - №1, - 2022, с.103-114.

16. Balaeva, A.G., Popova, O.I., Popova M.I., System for recovery of mechanical energy of machines // LGTU, Vesti, - RF, - Lipetsk: -Vol. 18, No. 1, - 2022, -pp. 15-24.

17. Balayeva, A.H., The use of tompoz energy as an alternative energy source in the operation of vehicles and the application of an inverter in the device // III International Scientific Conference, Current Issues of Applied Physics and Energetics, SDU, -Sumgayit: - 2022, - p.171- 178.

18. Balayeva, A.H., Features of using the mechanical energy generated during braking as electrical energy // Proceedings of the Republican Scientific and Technical Conference, Energy Efficiency and Green Energy Technologies, AMU, - Baku: - 2022, -p.145-148.

19. Balayeva, A. H., Use of mechanical braking energy in vehicles as electricity and hydrogen energy // International Journal of Hydrogen Energy, - America, Florida, - Miami: -vol. 48, Issue 80, - 2023, - p. 31023-31039.

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