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JUSTIFICATION OF THE INNOVATIVE DESIGN OF THE SKIP WINCH WITH A BODY MOVED BY A COUNTERWEIGHT GRAVITY DRIVE

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The article has to grapple with the problem of creating an economically efficient and environmentally friendly technological process for a development of solid minerals in open-pit mining. In many mining countries of the world today, the depth of many open pits is already 400–600 m or more. At the same time, the cost of transporting 1 ton of rock mass when operating a quarry whose depth is 400 m is 65–70 % of the total cost of extracting 1 ton of minerals.

The object of research is technical devices for transport of rock masses in the technological process of development of solid useful deposits in open pit mining.

The main reasons are the need to construct transport routes for them by withdrawing the sections of the rock mass on above them, as well their lifting capacity is limited because of they all do use highly energy-intensive machines for transporting rock minerals. In article has been justified a skip cable winch supplied with a wheels moving along on a railroad way by using only a gravitational counterweight device for transporting rock mass from a place of their formation to Earth surface. There have been created a prototype of a planar skip winch with four cables for practical implement in open-pit mining. The theoretical and experimental investigations of the prototype have being confirmed its performance. The created skip winch will accomplish its performancing without using any energy machines even under adverse climate conditions. Its affected would allow to make an open-pit effectiveness to soar and environmentally do friendly because of there are all but excluded any transport vehicles whether on gasoline or diesel oil

Keywords: open-pit, a skip winch, hydraulic counterweight, railroad wheel, prototype cable-driven robot

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1. Introduction

A solid minerals extracted from the Earth's interior in the course of a year in all mining countries of the world has a really immense value for whole worlwide civilization. At present, mammoth of the volume of rock mass is extracted during the development of solid mineral deposits in open-pit mining. It should be noted that the process of ramping up the volume of open-pit mining will take place in conditions of significant complication of mining geological and economic-geographical factors, The high cost of mining 1 ton rock mass is central to a traditional technologies of solid mineral deposits development crisis. Nowadays the depth of some quarries in various countries has already reached 500 to 600 meters (Sokolovsko-Sarbaevsky quarry, Kazakhstan, Bingham Canyon, USA, Udachny quarry of the Udachinsky mining and processing plant (joint stock company ALROSA, etc.). While a financial wastes on a developing only a once deposit of solid minerals steppe increase approaching a few billion in today's dollars. There are several vast shortages in that technology processes. But the main reasons is due to construct transport routes for automobile transports which in nowadays are the most widely expanded across all of exists vehicles for transporting rock mass by deleting an apart of the rock mass on above them. Nowadays the open-pit mining has a deepening shortage of transporting a rock masses. But, more specifically, there isn't enough of such transporting: no-frills, limitless lifting capaciting and transporting rock mass from a place of their formation to Earth surface without using any energy machines. But few transport systems performance anything like it anymore. Last time the economics of the transporting rock mass and the local rules that shape it do incline business affairs that an automobile, convey and other exists traditional transports have been squeezed out by a skip winch devices. A skip which have to grapple with the problem though it is limited by necessary using energy intensity lifting equipments and a granulometric composition requirements for a transported rock mass. The main shortage with concerning of a skip winches are using by them an expensive and energy-intensive hoisting machines for transporting rock mass. As well their operation and maintenance are also associated with a high financial cost. While the price of 1 ton of rock mass is expected to soar. The absence of effectible a skip winch is central to the word wild open-pit mining crisis.

Thus, the problem of transporting rock masses will likely worsen and specialists are scrambling to find a quick solution. It is predicted that there will be further a price of transporting 1 ton rock mass increase. So, it is extremely immense to find out immediately-term solutions to address the crisis. Therefore, a designing innovate skip winch having limitless lifting capacity for transporting rock mass in any value of sizes from a place of their formation to Earth surface at the development of solid mineral deposits in open-pit mining without using any energies machines as well any transport vehicles whether on gasoline or diesel oil at all various climatic conditions is an relevant.

2. Literature review and problem statement

The main production processes for the implementation of open mining of deposits of solid minerals are:

1) the destruction of sections of the rock mass;

2) loading of rock mass into appropriate vehicles;

3) transportation of the rock mass from the location of its formation in quarries to areas of the earth's surface located near the design contours of quarries, using various traditional methods:

a) road transport;

b) rail transport;

c) conveyor transport;

d) transportation of rock mass by skip hoists using lifting machines;

e) combined transport of rock mass (railway and road transport of rock mass; automobile and conveyor transport of rock mass, etc.).

In [1], formulated requirements for a new type of rock mass transportation system in open pits, the implementation of which would ensure open-pit mining of a mineral with a minimum production cost of 1 ton of a mineral. These include:

1) transportation of the rock mass along the transport route, the length of which is maximum from the quarry section where it was formed, to the area of the earth's surface located near the design contour of the quarry, the angle between the longitudinal axis of the non-working wall and the horizontal is the value of the limiting angle stability of the non-working side of the quarry;

2) ensuring a significant value of its carrying capacity, and, accordingly, the value of productivity equal to 10–30 million tons / year of one transport system, while the value of its carrying capacity should not be dependent on the value of the height of the rock mass, i.e. on the value of the depth of the mined quarry;

3) exclusion of the production operation, which consists in the destruction of oversized pieces of rocks in open pits, for their transportation from the bottom of open pits to areas of the earth's surface located near the design contours of open pits;

4) exclusion (100 %) of atmospheric air pollution located in the depleted spatial operated quarries by any harmful gases and dust during the transportation of rock mass from the bottom sections of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries.

Studies related to the design of such a system have not been carried out. From the analysis, according to the above requirements, of all traditional existing types of rock mass transportation from the bottom areas of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries, it follows that none of them fully complies with these requirements. And, therefore, the use of any of the traditional types of transportation of rock mass from the bottom areas of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries cannot ensure the open development of deposits of solid minerals with the lowest possible cost of production of 1 ton of minerals and/or minerals. However, studies on the development and creation of a similar system for transporting rock mass in quarries, the implementation of which would ensure the extraction of a mineral by an open method with a minimum production cost of 1 ton of a mineral, have not been carried out.

The key feature of mineral deposits is their exhaustiveness and the inability to restore resources. An vital role in the open-pit and underground method of mining deposits are the means to accessing to the deposit of rock massive and then its lifting to the earth's surface, that determine the initial stage of the mining operations. This necessitates the rational management of deposit resources, especially the minimization of resource losses during exploitation.

The article [2] considers the solution of a very urgent problem of effective completion of mineral reserves in quarries, the period of time and operation of which has ended or the operation of which is planned to be completed in the near future due to the extraction of minerals or minerals with unsatisfactory technical parameters. Economic indicators, that is, first of all, the value of the cost of production of 1 ton of minerals or minerals is large. In particular, attention was paid to the advantages and disadvantages of access by means of an audit, decline, and a vertical and inclined shaft. Given the relationships among the various stages of mining works, it was found that the number of active levels depends on the volume of production and the adopted mining methods. In addition, attention was drawn to the fact that the access to deposits at increasing depth is related to the intensification of natural hazards that affect the access structure. The problem of developing and creating a technical device for transporting rock mass for open-pit mining of solid mineral deposits with the lowest possible production cost of 1 ton of a mineral or minerals was not considered.

The object of research [3] is the technological processes of the development of deposits and the extraction of solid minerals by underground and open-pit methods. The work is aimed at increasing the efficiency of explosive energy use, improving the technological processes of mining operations in coal mines and open pits of mining enterprises. There was a search for innovative solutions that are expedient to apply at the present time. In the course of the analysis, the work shows ideas, methods of coal mining, systems for the development of coal seams, methods of destruction of rocks, microbiological reclamation and other new technologies and devices. However the daunting problem of a transportation of the rock mass from the location of its formation on a bottom of quarries to areas of the earth's surface located near the design contour of that have not being described.

In the article [4], in order to increase the efficiency of drilling and blasting operations and, accordingly, reduce the cost of transporting 1 ton of rock mass and improve the ecology of the intrapit space, studies were carried out to develop a mathematical model for assessing the kinetics of deformation and destruction of a section of a rock mass in operated open pits. Special attention is paid npt only to development at a rock mass but also to reuse of its and as well to an efficient ventilation system of excavation areas.

In the article [5], a mathematical model was developed to justify the choice of existing traditional technical devices for transporting rock mass. An extremely important aspect when making a decision to continue exploitation is the model of the deposit along with the estimation of the amount of resources that will be extracted to the ground surface by means of access workings.

Therefore, much attention is paid to the development and improvement of technology, methods and means of protecting the development workings behind the working faces [6].

However, the above-mentioned works [4–6] did not study the selection and justification of an innovative design of a technical device for transporting rock mass in quarries, the operation of which would ensure the extraction of a mineral by an open method with a minimum production cost of 1 ton of a mineral.

Transportation of rock mass in a quarry is the main and most labor-intensive production process for the extraction of a mineral or minerals in the development of open-pit mining of solid mineral deposits. As the depth of the quarry increases, the value of the share of financial costs when transforming the rock mass in the quarry reaches 70 % of the value of the total financial costs spent on the extraction of minerals or minerals on the magnitude of the degree of influence on the change in the values of technical and economic indicators of transporting the rock mass and the depth of implementation mining operations. Thus, when using all known traditional modes of transport of rock mass, the values of all technical and economic indicators of mining or minerals worsen with an increase in the depth of a quarry:

1) the value of the speed of movement of any transport mechanism decreases when moving rock mass, for example, a dump truck;

2) the exchange of vehicles is carried out inefficiently in adverse conditions;

3) the value of the duration of the period of time for the movement of the rock mass from the area of the bottom of the quarry to the area of the earth's surface, located near the design contour of the quarry, increases;

4) the value of the cost of transporting 1 ton of rock mass increases;

5) the value of the productivity of rock mass transportation decreases;

6) the conditions for the placement of transport communications are deteriorating;

7) the value of the degree of safety of transportation of the rock mass decreases, especially under adverse climatic conditions, for example, snowfall, rain, ice, storm, snowstorm, etc.;

8) the ecological situation in the quarry is deteriorating sharply.

In open-pit mining of solid mineral deposits, the second most important operation is the transportation of rock masses by conveyor belts. In quarries with a depth of 200 m and more, about 20–25 % of the volume of rock mass extracted from quarries is transported in the mining countries of the world [7]. The main disadvantages of conveyor belt transport of rock mass:

1) the cost of transporting rock mass is high due to the high cost of the conveyor;

2) the high consumption of electricity when transporting 1 ton of rock mass.

The transportation of rock masses by means of inclined elevators is widely used in the development of solid mineral deposits by the underground method in all mining countries of the world. In the development of solid mineral deposits by the open pit method, the transportation of rock masses in quarries by inclined elevators is rarely used because of the relatively low productivity of inclined elevators. This situation is due to the fact that inclined elevators are manufactured with drum conveyors that can move hoisting vessels – troughs containing the rock mass – with one or two hauling ropes [8]. The use of quarry hoists with a load capacity of 30–180 tons in the transportation of rock masses in quarries makes it possible to achieve a significant profit in the extraction of minerals and or mineral resources and significantly improve the environmental situation in quarries. The use of traditional methods of transporting rock mass, for example, road transport, in open-cast mining, largely depends on climatic conditions, for example, hurricane, rain, downpour, frost, blizzard, snowfall, ice, heat, etc. It should be emphasized once again that an increase in the carrying capacity of traditional rope hoist skips, equal to 40–50 tons or more, is impossible due to the technical features inherent in this type of transport of rock mass in quarries. First of all, this is the limited strength of steel ropes and the low value of the traction force of modern lifting machines. Therefore, with an increase in the depth of operated quarries, equal to 300–400 m or more, skip rope hoists become cumbersome, it is required to use steel traction ropes, the diameter of which is large, and as a result, the productivity of skip rope hoists decreases sharply.

The German company Thyssen Krupp Resource Technologies GmbH is developing a transport system that is intended to transport rock masses in a technically and economically more efficient manner and with significantly less environmental impact than transporting rock masses with dump trucks, if all other factors remain the same [9]. In the skip system, the dead weight of one skip body is fully balanced by the dead weight of the second skip body, which are connected by ropes. Therefore, during the operation of the skip system drive system, whose main component is the lifting machine, no additional energy is consumed when the empty skip body is moved along the rail transport route. The skip body, which is used for transporting rock masses with the Thyssen Krupp conveyor skip system, has a load capacity of 136 tons. It is 4 m wide, 13 m long and 5 m high. The mass of the skip is approx. 90 t. The Thyssen Krupp conveyor-skip system for transporting rock masses during open-pit mining operations offers high operational readiness for transporting rock masses in operating open-pit mines, as it retains its full operational capability even under adverse climatic conditions.

The main disadvantage of transporting rock masses by hoists in all mining countries of the world is the obligatory use of expensive and energy-intensive hoisting machines that transport troughs with rock masses whose volume is insignificant. Also, the depth of the operated quarry, where the rock masses are transported by the hoisting machine, is small, for example, up to 400 meters. This circumstance is due to the fact that the rope capacity of the drums of conventional hoisting machines is small.

Currently, about 65–70 % of the aggregate extracted from quarries is transported by trucks. When using conventional vehicles to transport rock mass (road, rail, conveyors, combined conveyors, skip loaders, etc.), the cost of extracting 1 ton of rock mass is high and approximately amount to about 10–15 USD (in 2017). For example, in open pits with a depth of 500 m, the cost of mining parts of the rock for the construction of transport routes above the surface of the rock is 5–7.5 billion USD. In addition, there are the costs of operating transport vehicles and repairing them, as well as repairing roads, etc. The high cost of transporting 1 ton of rock mass for skip haulers and conveyors is due to the use of energy-intensive lifting machinery and stringent granulometric requirements for the transported rock mass. The complexity and, in some cases, the impossibility of transporting the rock masses by conventional means of transport (under unfavorable climatic conditions: Snowfall, heavy rain, rain, hurricane, blizzard, etc.). Severe deterioration of environmental conditions in a quarry due to the emission of dust and harmful gasses (oxides, nitrogen, methane, hydrogen sulfide, etc.). The value of labor productivity of a worker when using road transport is insignificant. When the mining depth exceeds 600 m, the use of road transport is not economically viable because the value of the cost of mining 1 ton of rock mass is higher than the value of the cost of mining 1 ton of rock mass underground, if all other factors remain the same. Another main disadvantage of open mining of solid minerals with conventional mining vehicles is poor ecology in the quarry due to dust emissions, various gasses and other particles of solid inclusions, which are harmful to human health in the mined space of the quarry [10].

From the functional and economic analysis, according to the above criteria for evaluating the effectiveness of existing devices for transporting rock mass from the bottom sections of the operated quarries to the areas of the earth's surface located near the design contours of the operated pits, it follows that none of them fully meets these requirements. And, therefore, the use of any of the traditional types of transportation of rock mass from the bottom areas of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries cannot ensure the open development of deposits of solid minerals with the lowest possible cost of production of 1 ton of minerals or minerals.

The article [10] presents a mathematical model for choosing a promising «look» of a skip hoist for transporting rock mass, based on the principles of system analysis and synthesis of complex structures according to the criterion «efficiency – cost». The solution of the problem of economic assessment of options for the «look» of the skip hoist is carried out by the method of two-level optimization according to the algorithm of multi-criteria analysis of alternatives.

One of the current sustainable trends and patterns in the field of open-pit mining of solid mineral deposits is the creation of automated scheduling systems for the operation of mining and transportation machinery using satellite technologies.

The paper [11] criticizes the existing approach to control the technological process of solid mineral deposits development without taking into account the stochastic conditions of mining and transportation machinery operation. The article substantiates the idea to include in the information system for management of the technological process of development of deposits of solid minerals subsystems for management of mining transport machinery and environmental safety of the mine area, taking into account the stochastic conditions for their functioning.

So, an extremely important aspect when making a decision to continue exploitation is the model of the deposit along with the estimation of the amount of resources that will be extracted to the ground surface by various means of its transporting. The article [12] stated that access layout optimization can be treated as a network flow and should consider shortening the length of excavation and reducing the transportation distance. In [13] found that mine planning takes into account three phases: development layouts, production scheduling and equipment selection.

In [14] determined that in order to make the deposit available, it is worth using computer-aided design, with the help of which it is possible to select the place of the deposit opening. The article [15] pointed to the optimal access point, considering the net present value, and thereby optimizing the process control system for open pit mining of solid mineral deposits.

The problematic aspects of these automated process control system for the development of solid mineral deposits in a quarry, which require additional considerations, are the following: the impossibility of achieving the minimum cost of transporting 1 ton of rock mass using conventional methods of transporting rock mass. A significant amount of financial loss due to downtime of mining, loading, and transporting equipment due to the inability to control their operating parameters depending on the stochastic conditions resulting from the interaction of their working bodies with a section of the rock mass to be destroyed.

The article [16] noticed that improving the efficiency of the access workings execution is possible by automation and robotization. In recent years, there has been a growing trend in introducing equipment with parallel structure mechanisms to the global market, leading to significant improvements in technical and operational performance. As part of this trend, there has been a development of cable parallel robots by replacing the rigid links with flexible cables [17]. Leveraging these advancements, it is beneficial to consider these circumstances when designing a skip cable hoist. This type of hoist allows for unlimited size of the skip body, which carries the rock mass, to move along a rail transport track using a drive (counterweight), without the need for a lifting machine. Moreover, the mass of the counterweight can be adjusted by varying the volume of liquid inside a tank located within its body, thereby preventing any sagging of the cable or cables used in the skip hoist.

In present, there has been a trend of introducing equipments that have produced on base with cable-driven parallel robot to the world market, which have improved their technical and operational performances. To expand the service area of parallel robots, their rigid links are replaced by flexible ones (cables), as a result, cable parallel robots are obtained [17]. Above mentioned circumstances that inhering only a cable-driven parallel robot would be advisable to implement while its developing for transporting rock mass without any lifting machine by using only a hydraulic counterweight in the way of its drive unit. At the same time, there are a possibility of managing with a mass of a hydraulic counterweight by adjusting a volume of any liquid containing inside a tank arranged into its body that is facilitated eliminating an appearance of any sagging with a cables of a skip winch.

The analysis of technical and economic indicators indicates that traditional rock mass transportation methods in operational quarries are suitable for efficiently extracting mineral deposits in medium to large open pits. However, the operation of quarries often leads to an increase in the cost of extracting one ton of minerals. Therefore, specialists have established criteria for a new rock mass transportation approach in open pit mining. This approach aims to enable the extraction of minerals using an open method while minimizing the production cost per ton of minerals. The main requirements for open pit mining of mineral deposits include:

1) develop mineral deposits in open pits with a significant inclination between the longitudinal axis of the non-working side of the quarry and the horizontal plane. This inclination should be maximized to minimize the amount of overburden that needs to be removed during mining operations;

2) efficiently transport the rock mass along a transportation route that maximizes the distance from the area within the quarry where the rock mass originated to the surface area near the designated contour of the quarry. The angle between the longitudinal axis of the non-working wall and the horizontal line should adhere to the limit angle of stability to ensure the structural integrity and stability of the non-working wall of the quarry;

3) ensure a substantial carrying capacity of 150–300 tons for skip hoisting installations, which directly translates to a productivity level of 10–30 million tons per year for each skip hoisting installation. Importantly, the carrying capacity of the skip should not be dependent on the lifting height of the rock mass or the depth of the quarry. This allows for efficient and consistent transportation regardless of the depth of the quarry or the amount of material being lifted.

4) carry out technical and economically efficient transportation of rock mass in one step, the volume of which is unlimited, in quarries, the depth of which is any, for any angle between the longitudinal axis of the surface of the non-working side of the quarry and the horizontal;

5) exclude the performance of a production operation, which consists in the destruction of oversized pieces of rocks in open pits, for their transportation from the bottom of open pits to areas of the earth's surface located near the design contours of open pits;

6) ensure the minimum value of the degree of material dryness and the minimum value of the degree of energy intensity when transporting the rock mass from the bottom of the quarries to the areas of the earth's surface located near the design contours of the quarries;

7) ensure the minimum amount of capital investments and operating costs of financial resources in the transportation of rock mass in operated quarries;

8) exclude (100 %) the air pollution of the atmosphere located in the depleted spatial operated quarries by any harmful gases and dust when transporting the rock mass from the bottom sections of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries;

9) carry out technical and economically efficient transportation of rock mass from the bottom areas of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries, under any weather and climatic conditions without projects;

10) to ensure complete safety of transportation of rock mass from the bottom areas of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries, under any conditions.

Upon analyzing the operation of all existing traditional rock mass transportation methods from the bottom sections of operational quarries to surface areas near the designated contours, it is evident that none of them fully meet the specified requirements. Consequently, the utilization of any traditional transportation method in such circumstances cannot guarantee cost-effective open development of solid mineral deposits per ton of minerals and/or minerals.

Given these circumstances, there is an immediate and pressing need to develop new types of rock mass transportation specifically tailored to the unique conditions of operational quarries, especially considering the continuous increase in their depth. These new transportation methods should be adapted and optimized for efficient movement of rock mass from the bottom areas of operational quarries to surface areas near the designated contours.

In known works, the problems of increasing the efficiency of transporting rock masses by existing traditional transport systems, improving transshipment operations with rock masses between various traditional transport systems, as well as problems of rock destruction have been investigated. In-depth research has been carried out in the field of creating information systems for automating the control of traditional mining and transport machines in the technological process of developing deposits of solid minerals in an open way. Due to insufficient theoretical elaboration, the problem of creating a new type of rock mass transportation from the bottom areas of the operated quarries to the areas of the earth's surface located near the design contours of the operated quarries, adapted and/or adapted to the specific conditions of the operated quarries, the depth of which is constantly increasing, and corresponding to the above criteria remains to be fully resolved.

In the article [10], specialists developed a mathematical model for choosing a promising «look» for a skip hoist for transporting rock mass, based on the principles of system analysis and synthesis of complex structures according to the criterion of «efficiency – cost». The solution of the problem of economic assessment of options for the "look" of the skip hoist is carried out by the method of two-level optimization according to the algorithm of multi-criteria analysis of alternatives. On the basis of which the specialists substantiated the innovative design of the skip hoist for transporting rock mass. Some materials of this study are presented in this article.

Therefore, the article sets the task to justify an innovate design of a skip winch with a skip body of any value of its carrying capacities, moved by a hydraulic drive unit (counterweight) along a rail transport route, for highly profitable and environmentally friendly mining in quarries of a limitless depth and annual productivity.

The use of this technology will make it possible to achieve an significant economic effect per year in all countries of the world. This will drastically improve the standard of living of the population in the mining countries of the world.

3. The aim and objectives of the study

The aim of the study is to develop an innovative skip winch for transporting rock mass open-pit mining.

To achieve this aim, the following objectives are accomplished:

– to justify the innovative design of the skip winch with a body moved by a counterweight gravity drive;

– to study explore the layout of the skip rope lift.

4. Materials and methods

The object of research is technical devices for transporting rock mass in the technological process of developing deposits of solid useful deposits by open pit mining. The subject of research is skip rope hoists.

The main hypothesis of the study is possible of eliminating the «cause» of the high cost of transporting 1 ton of rock mass in open-pit mining of solid mineral deposits – eliminating the need to build transport routes and use energy-intensive lifting machinery and any vehicles. To implement the hypothesis of the study is assumed:

1. Equip the body of the skip with wheels (rollers) for transporting the rock mass along a quick-detachable rail track installed on the non-working side of the quarry.

2. The body of the skip with the rock mass moves along the rail track only with the help of only a gravitational hydraulic drive (counterweight) equipped with wheels (rollers) moving along the rail track installed on the Earth's surface near the design contour of the quarry, and the value of the counterweight mass is regulated using the volume of the working liquid in a vessel installed inside the body of the counterweight.

The assumptions made in the work for the empirical substantiation of the scientific hypothesis is created by a prototype of cables-driven robot are attached at one end to the drive on a fixed frame and at the other end to the skip body hinge and are in a tense position. Assuming that all cables, in any position, are always in a taut state, the kinematics of a cable parallel robot is similar to the kinematics of parallel robots with one-sided constraints.

The studies were carried out using the theory and practice of mining deposits of solid minerals using a quarry method, including the analysis of the technological process of transporting rock mass from quarries by traditional transport. A feasibility study of the technological process of moving rock mass in open pits using road transport, conveyor and transportation of rock mass by single-rope and multi-rope steeply inclined skip hoists, which are operated using hoisting machines, has been carried out. The technical and economic analysis of the technological process of transporting rock masses in operated quarries using road transport, conveyors, and transporting rock masses using single-rope and multi-rope inclined elevators, in the operation of which hoisting machines are used, showed that it is unprofitable to use traditional means of transporting rock masses in quarries with a depth of 600 m or more.

Based on the functional-economic approaches a skip winch has being developed by specialists for transporting rock mass in a quarry [10]. Nowadays, specialists have developed several variants of innovative, slightly inclined and steeply inclined skip winches the using of those allow transporting lumpy rock mass in one step into a skip body supplied with wheels and moving along rail road, arrangement on non-working sides of quarry, by using only hydraulic counterweight devices without using any energy intensive machines as well without with any whether gasoline or diesel oil vehicles [18].

To develop a prototype of the innovative device for transporting rock masses were used the methods for solving problems of theory of mechanisms and machine and numerical methods. A structural-kinematic synthesis and analyses of the prototype have been committed. Then have been conducted a kinematic and static studies the prototype, where its end effector performed given rotational motion.

A cable parallel robots are classified according to the kinematic criterion, where the main parameters are the number of cables m and the number of controlled degrees of freedom n of the mobile platform. In have being justified a choosing a structure of a prototype planar cable-driven parallel robot. Using the structural equation that was developed for a cable-driven parallel robots and superimposing different requirements to a forms of path moving of its end effector along on rail transport track located on a non-working side of the open-pit mining, it is possible to synthesize new constructions of a cable skip winches for transporting rock mass [17].

A prototype of cables-driven robot is attached at one end to the drive on a fixed frame and at the other end to the skip body hinge and is in a tense position. Assuming that all cables, in any position, are always in a taut state, the kinematics of a cable parallel robot is similar to the kinematics of parallel robots with one-sided constraints.

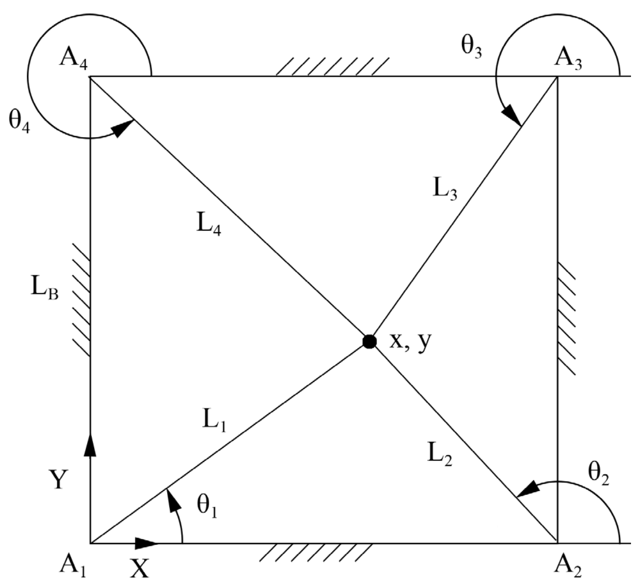

Fig. 1. Kinematic diagram of the prototype of a flat 4-cable-driven parallel robot

To solve the direct kinematics of this plane cable-driven parallel robot, it is necessary to determine the coordinates $X=\{x\,y\}^T$ its the end effector (working body) for given lengths of cables L_i – length i-th cable; x, y – coordinates of the point of the working body; θ_i – angles of inclination i-th cable, A_i – attachment points of the i-th cable to a fixed square frame with a side L_B. In the case under consideration, the positions of the attachment points, respectively A_1 (0; 0), A_2 (L_B; 0), A_3 (L_B; L_B) and A_4 (0; L_B) where i=1, 2, 3, 4.

Due to simulate the motion of a planar cable-driven robot have been chosen the dimensions a the fixed frame. The value of each side of the frame is 1000 mm. The coordinates of its end effector $X=\{x\ y\}^T$ makes a circular motion under the action of a constant external force $F_K=\{1; 1\}^T$.

The calculation of that model have been carried out in the Python programming language [19] for two types of trajectory of the end effector-circle and four-petal flower.

To solve the inverse kinematic problem, it is necessary to determine the lengths i-th cables L_i regarding attachment points $A_i=\{A_{ix}\ A_{iy}\}^T$ at given coordinates of the point of the working body $X=\{x\ y\}^T$, from Fig. 4:

$$L_i=((x-A_{ix})^2+(y-A_{iy})^2)^{1/2},\ i=1,\ ...,\ 4, \quad (1)$$

angle θ_i determined by the formula:

$$\theta_i=\tan^{-1}(y-A_{iy})/(x-A_{ix}),\ i=1,\ ...,\ 4. \quad (2)$$

To control the stepper motors of cable-driven parallel robot, it is necessary to determine the value angles of rotation of the drums the winch β_i, $i=1, ..., 4$, expressed as a function of the position the end effector $X=\{x\ y\}^T$. Taking account that all 4 drums of the winch have the same radius r the values of all these β_i equal to zero when the end effector is located in the geometric center of a square fixed frame. The initial lengths of the cables determine to $L_{0i}=\sqrt{2L_B}$, the change in the value length of the i-th cable is $\Delta L_i = L_{0i} - L_i$. The values angles β_i are determined by the formula $\beta_i = \Delta L_i / r$.

Consequently:

$$\beta=\begin{Bmatrix}\beta_1(X)\\ .\\ .\\ \beta_4(X)\end{Bmatrix}=\frac{1}{r}\begin{Bmatrix}L_{01}-\sqrt{(x-A_{1x})^2+(y-A_{1y})^2}\\ .\\ .\\ L_{04}-\sqrt{(x-A_{4x})^2+(y-A_{4y})^2}\end{Bmatrix}. \quad (3)$$

In the development of a control system for a prototype of a cable-driven parallel robot for automation of technological process transportation rock mass in open-pit mining, the results obtained in the course of research that related to the study of its structure, the solutions of direct and inverse problems of kinematics of the prototype were used to be [17]. Individual results were published in the articles [19–21].

5. Research results of the justification of innovative design

5. 1. Justification the innovative design of the skip winch with a body moved by a counterweight gravity drive

The main structural elements of a skip winch (robot) [18] are represented in Fig. 2–4. Fig. 2 shows an overall view of the design of the transport system for deep quarries. The body of the skip 1, equipped with a braking device and/or braking devices (not shown in the figures) to slow down the movement of each individual skip 1, consists of a single integral structural device. Each individual skip body 1, in which a mixture of minerals (aggregate) 2 and/or a mixture of aggregate 2 is transported, is used in the extraction of a mixture of aggregate and/or in the transport of the necessary machines and mechanisms 3 operated at the bottom of a quarry during the extraction of aggregate 2 (excavator, trolley, electric self-propelled shovel loader, etc.), and is equipped with a foldable side wall 4 and/or foldable side walls 4 (Fig. 2–4). It is equipped with supports 5, e. g. railroad wheel sets, rollers, etc., having different wheel diameters on opposite sides (Fig. 2–4). On the supports (wheels) 5 of the trough body 1, the support 5 has a rim with a double rim on one side and a smooth rim on the other side. When approaching the siding, the support wheel 5 with double rim ensures that the skip body always moves on a certain track, which is determined by the wheel with double rim. The skip body 1 with the support wheels 5 moves along the rails 6 and/or 7 laid out on the surface of the non-working side of the quarry, each of which can have a straight and/or concave and/or convex and/or convex-concave and/or straight-concave-convex longitudinal axis (Fig. 2–4).

The reloading device 8 is located on the bottom of the quarry at the place where the rock mass 2 is formed, for example, in an excavated trench (not shown in Fig. 2–4), the bottom of which is above the height mark, the value of which is equal to and/or greater than the height of the dragline body, and the reloading device 9 is located on a plot of the earth's surface near the construction contour of the quarry (Fig. 4). The skip 1 is set in motion by the actuators 10 and/or 11 (Fig. 4), each of which is a counterweight device that moves, under the effect of gravity generated by any liquid 12 contained in the container of the counterweight device 10 (11), without the use of a lifting machine, along a special overpass 13 that has the ability to adjust the angle β – the angle of inclination of its longitudinal axis with the horizontal axis (not shown in the Fig. 2–4). The movement of the cable 14 and/or 15 that moves the body of the dump lorry 1 is reversed. Its direction changes every time the dump lorry body 1 reaches the end of the rail (transport track) 6 and/or 7. A portion of the traction rope 14 and/or 15 with a braking device and/or braking devices (not shown in Fig. 2–4) is attached to the body of the skip lorry 1, and the portion of its other end 14 and/or 15 is arranged on the head frame of the rope pulley 16 and/or 17 (Fig. 4) and connected to the counterweight 10 and/or 11. The hauling rope 14 and/or 15 is provided with a protective device to protect its outer surface from moisture and icing (not shown in Fig. 2–4).

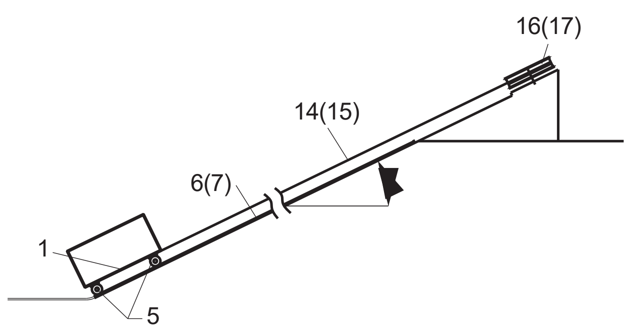

Fig. 2. Construction of a transport installation for a deep quarry

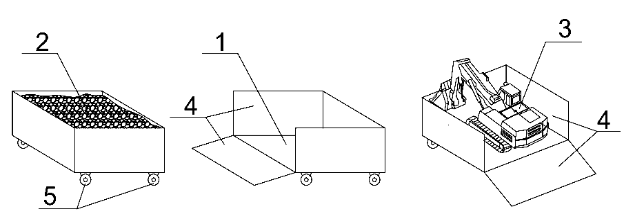

Fig. 3. Skip winch structure with support wheels and hinged side panels

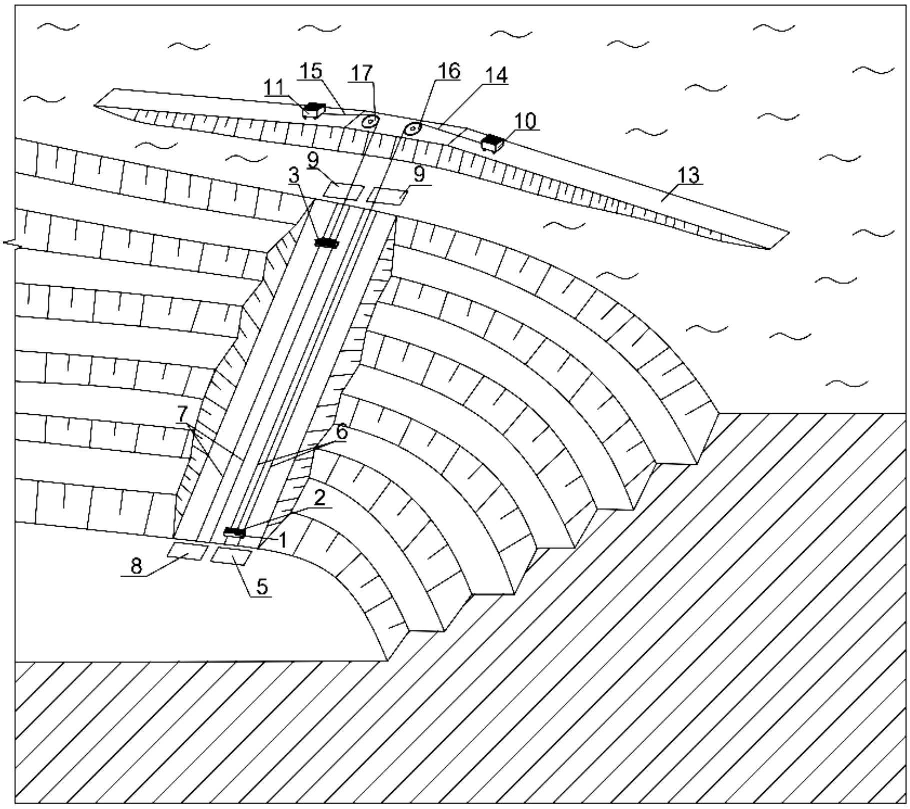

Fig. 4. General design of the transport plant for transporting rock mass from deep quarries

The transportation system for deep quarries works as follows. According to one of the options for development of solid mineral deposits in an open pit, an empty skip body 1 equipped with braking devices (not shown in Fig. 2–4) is placed along the outer surface of the pit bottom near a certain section of the side surface of the rock layer mined in the pit. While the side wall 4 of the body 1 of the transporting device is removed, the section of the rock mass in the quarry facing the layer to be mined is removed to fill the free space of the body 1 of the transporting device with a mixture of rock mass pieces (Fig. 3) created during the destruction of a certain section of the rock mass of the mined layer of the rock mass in the quarry by an explosion of explosive charges placed in blast holes. Subsequently, the body 1 of the transport device containing a mixture of pieces of the rock mass 2 moves with the help of supports 5 along the rail transport route 6 and/or 7 to the reloading device 8 and/or 9, which is located on the ground surface in the vicinity of the construction contour of the quarry, by moving the traction rope 14 and/or 15 with a protective device of its outer surface from moisture and icing (not shown in Fig. 2–4). The movement of the traction rope 14 and/or 15, which moves the body of the trough 1, is reversed. Its direction changes whenever the body of the skip 1 reaches the end of the rail (transport track) 6 and/or 7. A portion of the hauling rope 14 and/or 15 is attached to the body of the skip 1, and the portion of its other end 14 and/or 15 is attached to a roller head frame 16 and/or 17 (Fig. 2–4) by a braking device and/or braking devices (not shown in Fig. 2–4) and is connected to a counterweight 10 and/or 11 that moves under the action of gravity generated by any liquid 12 located in the tank of the counterweight device 10 and/or 11, without the use of a lifting machine that moves along a special overpass, the angle of inclination of its longitudinal axis β being adjustable with the horizontal axis (not shown in Fig. 2–4). In order to stop the trough 1, the operator releases the handle of the pincer (not shown in Fig. 2–4) of the traction cable 14 and/or 15, which is rigidly attached to the trough of the trough 1, while the cable 14 and/or 15 continues to move without stopping.

5. 2. Study the layout of the skip rope lift

In the development of a control system for the prototype of a skip winch for automation of the technological process of mining deposits of solid minerals in open-pit mining, used to be the results obtained in the course of research related to its structure analyses, of solving a kinematic and inverse problems [17]. Individual results were published in the article [19] and [20–21].

There have been given a trajectory of motion of the end effector of a prototype of skip winch represents in the form of a circle have shown in Fig. 5 and it is described following equations:

$$\begin{cases} x = 200 \cdot \cos 0.5\pi t, \\ y = 200 \cdot \sin 0.5\pi t, \\ 0 \le t \le 6. \end{cases} \tag{4}$$

The obtained kinematic and dynamic parameters of the prototype of the 4-cabel-driven parallel robot type 2T are shown in Fig. 5, 6.

Due to the complexity of installing the position sensor of the end effector, which is needed to create position feedback here use stepper motor encoders.

Fig. 7 shows a block diagram of a control system the prototype a planar cable-driven parallel robot. This feedback circuit will only work well if sufficient tension is maintained on all cables at all times.

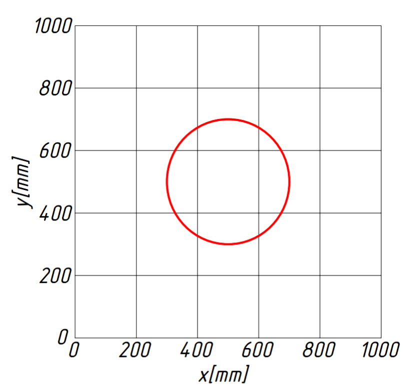

Fig. 5. Graph of the given trajectory of end effector a prototype 4-cabel-driven parallel robot in form a circle

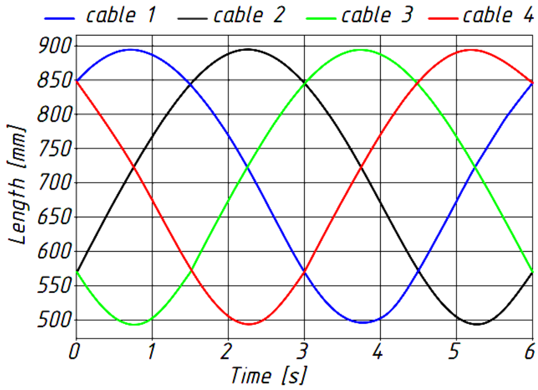

Fig. 6. Graph of changes in the value of lengths of cables of a prototype a 4-cable-driven parallel robot

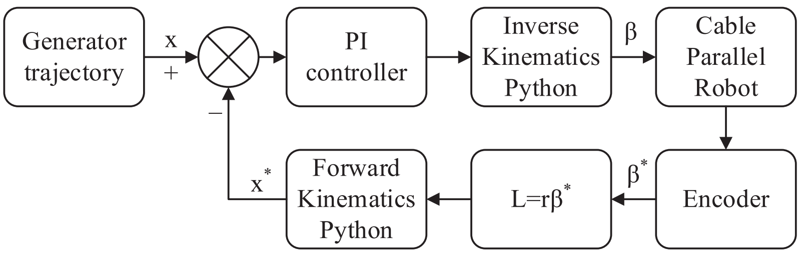

Fig.7. A block-diagram of the control system the prototype a planar cable-driven parallel robot

By defining the values angles β_i^*, $i=1,...,4$ (3) through the encoders of the motors, and then comes on the heels renewed the corresponding value lengths L_i the cables. By solving the direct kinematic task for this cable-driven parallel robots are find the positions of its end effector $\mathbf{X}^*$. Due to reduce the values errors $e=X^*-X$ of its positions are used the PI-controller.

For the build of a prototype of a planar cable-driven parallel robot, a configuration of its system was developed, taking into account the convenience and clarity when demonstrating its work to students. The configuration of the system of the prototype of the planar cable-driven parallel robot is shown in Fig. 8. Here the following initial data are selected: dimensions of the fixed frame 1×1×0.2 m, payload 0.5 kg, maximum end effector velocity 1.5 m/s.

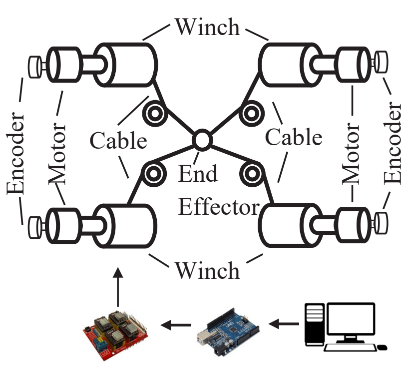

Fig. 8. The configuration system of the prototype planar cable-driven parallel robot

Affording to the configuration of the planar cable-driven parallel robot system shown in Fig. 8, four winches need to be developed. Fig. 9 shows the design of the developed cable-driven parallel robot's winch. Each of which consists of a drum mounted on a shaft with two bearings at both ends. The drum is connected to the Nemal7-l7HS8401S stepper motor through a coupling. An encoder is attached to the end of the drum.

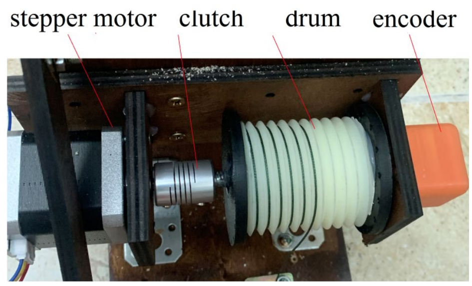

Fig. 9. Design of the winch the cabel-driven parallel robot

The stepper motor controller is based on the Arduino Uno controller with a CNC Shield v3 expansion board and stepper motor drivers using the Arduino GRBL software. With the help of the Arduino controller, the cabel-driven parallel robot is controlled by the computer via the USB port [19].

The prototype of the planar cable-driven parallel robot is shown in Fig. 10. The technical parameters of the prototype of the that are shown in Table 1. Table 2 shows the technical parameters of the planar cable-driven parallel robot stepper motor.

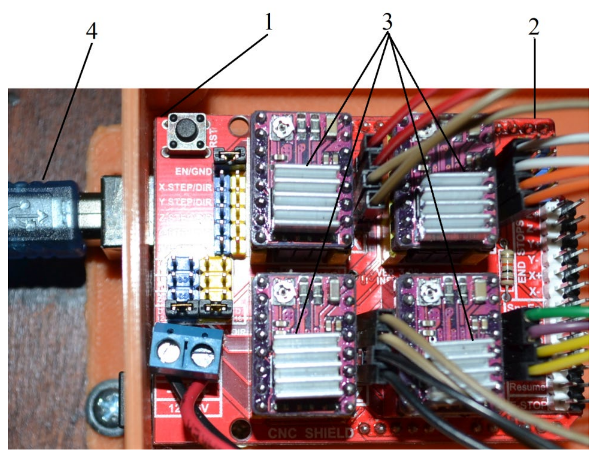

Fig. 10. Stepper motor-controller:
1 – Arduino Uno controller; 2 – CNC Shield v3 expansion board; 3 – stepper motor drivers; 4 – USB cable

Table 1

Initial parameters of the prototype of the parallel 4-wire robot type 2T for the calculation of its kinematic and dynamic parameters

Length of planar CDPR (cable-driven parallel robots)	1 m
Height of planar CDPR (cable-driven parallel robots)	1 m
Payload	0.5 kg
Pulley radius	0.02 m
Drum diameter	0.05 m
Stepper motor	Nema17–17HS84011S
Speed	0.5 m/s
DOF	3DOF
Setting time	4 sec

Table 2

Technical parameters of the planar CDPR (cable-driven parallel robots) stepper motor

Step angle (deg)	1.8
Motor length (mm)	48
Rated current (A)	1.7
Phase resistance (ohm)	1.8
Phase inductance (mH)	3.2
Holding torque (N-cm Min)	52
Detent torque (N-cm Max)	2.6
Rotor inertia (g-cm^2)	68
Lead wire (No.)	4
Motor weight (g)	350

For testing, the design of the prototype planar cable-driven parallel robot has a back wall (Fig. 11), on which white paper is attached, for drawing the specified trajectories with the end effector.

Checking the work of the prototype of that was carried out when the end effector was drawing the trajectory of a circle with a radius of r=200 mm, by the equation (4), described above.

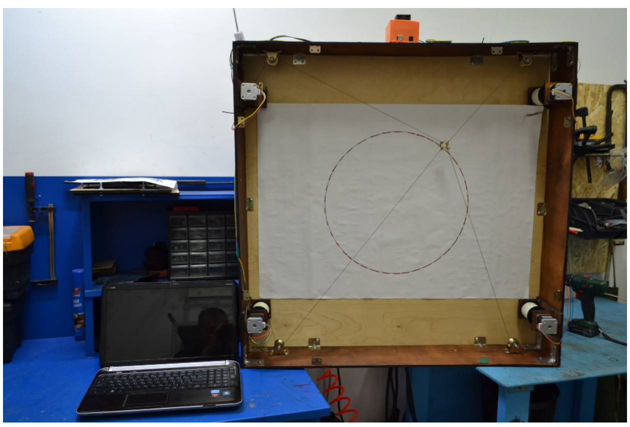

Fig. 11. The trajectory of motion of the end effector of the prototype a planar cable-driven parallel robot in the form of a circle

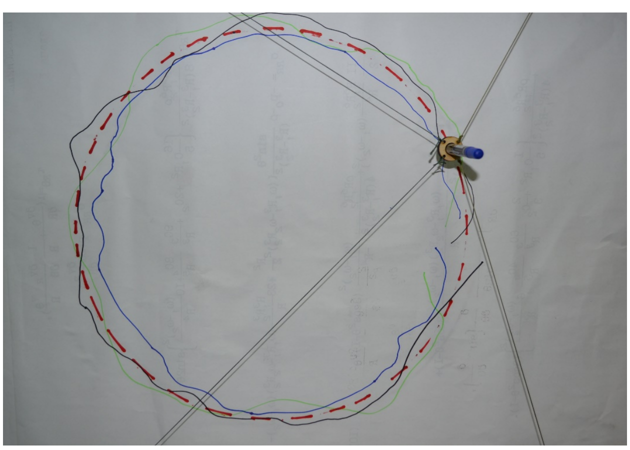

Fig. 12. Results of testing the prototype of cable-driven parallel robot for drawing the specified trajectories with its end effector

To draw the given trajectory, a marker was attached to the end effector of the planar cable-driven parallel robot prototype. The graphs for these three tests that have been carried out are represented in Fig. 12. Within of three options the red color trajectory more closely have being approached the given trajectory.

Determine the maximum deviations of the radii of the circles from the radius of the ideal circle by the formula:

$$\Delta r_i^{\max} = \left| r - r_i^{\max} \right|,$$

$$\Delta r_1^{\max} = 27 \text{ mm}, \ \Delta r_2^{\max} = 21 \text{ mm}, \ \Delta r_3^{\max} = 17 \text{ mm}.$$

To determination the average value of the maximum deviations of the radii of the circles from the radius of the ideal circle by the formula:

$$\overline{\Delta r}_{av}^{\max} = \frac{1}{3}\sum_{i=1}^{3} \Delta r_i = 21.67 \text{ mm}.$$

The average value of the maximum deviations of the radii of the circles from the radius of the ideal circle is 10.8 % of the length of the radius of the ideal circle, which indicates the insufficient accuracy of the work of the prototype.

6. Discussion of the results of creating high-performance and environmentally technology

In this study, the task is to develop a transport device that provides a significant reduction in the cost of transporting 1 ton of rock mass in the open mining of solid mineral deposits. In the article [10], an innovative structure (appearance) of a skip hoist was substantiated, which provides a significant reduction in the cost of transporting 1 ton of rock mass in the development of deposits of solid minerals in an open way. At the same time, the transition from the existing image (initial state) of the rock mass transportation system to its new image (promising) image was defined as the ratio of its productivity to the costs invested in achieving it with the least possible expenditure of resources on a conditional example. The substantiation of a rational version of the appearance of the rock mass transportation system is based on the basic principles of system analysis and synthesis of complex structures according to the «cost-effectiveness» criterion. A rational option is such an option (alternative) that allows to get the desired result at the lowest cost of the possible (calculated) options. The solution of this multi-criteria problem of assessing and choosing a promising «shape (structure)» of a transport device to ensure the lowest possible cost of transporting 1 ton of rock mass in quarries is reduced to optimizing the objective function $U(x)=\sum w_i x_i$ utility of an alternative, expressed as a linear combination of convolution values of a system of particular criteria x_i, into a generalized criterion of the desired effect (efficiency), where w_i – weight (importance) of the i-th criterion assigned by the experts. To determine the weights of each of the criteria x_i their weights w_i are selected from 0 to 1. In this case, the assessment of alternatives falls within the boundaries of the scoring scale in which the criteria are measured. At the same time, an alternative is declared as a solution to the multicriteria problem, the objective function $U(x)$ of which is the largest number of «norm», defined as the main indicator of efficiency (for example, reliability, productivity, etc.)

of the rock mass transportation system. Assuming that the ratio between financial costs and the objective function (reliability, performance, etc.) of the transport system is given by a linear function, then the solution of this minimax problem is expressed in minimizing financial costs. As a norm, the percentage ratio of the initial structural indicators of the appearance of the rock mass transportation system to its target parameters x_i is determined, taking the norm of the final state of the system as 100 %. Then, knowing the unit price X_i of the parameter (criterion) and the given level of funding, the required funding and the required time to achieve the goal of forming a new image of the rock mass transportation system are calculated. The structure of the appearance of the rock mass transportation system is changing due to ongoing activities aimed at increasing the value of one or another of its parameters X_i (criterion). The solution of the problem is reduced to the «restructuring» of the structure of the state of appearance, trying as much as possible to bring it closer to the final, target state. After that, the rate of deviation of the initial state of the rock mass transportation system from its final, target state, expressed as a percentage, is calculated. The final solution of the problem comes down to finding the maximum value of the norm of deviation of the achieved parameters of the state of the system for a given level of funding. The results of calculations on a conditional example showed the possibility of using it to improve the elements of the structure of the prospective appearance of the rock mass transportation system. In a conditional example, the structure of the achieved innovative image of the rock mass transportation system has changed significantly, the value of one parameter x_i (in the example it is at number 8), which is only 33 % at the initial state, has reached almost 80 %. At the final stage, the calculation is detailed, where the achievements for each calculated indicator x_i are determined relative to the final, target parameter, the state of the innovative appearance of the rock mass transportation system.

In this article, after substantiating the structure of an innovative skip hoist, its innovative design has been developed. An overview of the design of an innovative rope hoist (robot) with trough is shown in Fig. 1 [18]. Fig. 1 shows the structure of a transport device for a deep pit. Fig. 2 shows the structure of the skip body with support wheels and its foldable side walls. Variants of the design of the transport paths, which are the main structural elements of a skip winch for transporting rock mass can be built on the surface of the non-working side of the quarry, the longitudinal axis of those are straight and/or concave and/or convex and/or convex-concave and straight concave-convex, etc. Each individual skip body in which a mixture of minerals (aggregate) and/or a mixture of aggregate used in the extraction of a mixture of aggregate and/or in the transportation of the necessary machines and mechanisms used in the extraction of aggregate at the bottom of the quarry (excavator, trolley, electric self-propelled shovel loader, etc.) is transported is equipped with a foldable and hinged side wall and/or hinged side walls (Fig. 2–4). The skip body is equipped with supports, e. g. railroad wheelsets, rollers, etc., having different wheel diameters on opposite sides (Fig. 2–4). The skip body with supports moves on rails that are laid on the surface of the non-working side of the quarry and each may have a straight and/or concave and/or convex and/or convex-concave and/or straight-concave-convex longitudinal axis (Fig. 2–4). Fig. 3 shows the general structure of a transport unit for transporting rock masses from deep quarries with a special gravity counterweight (drive). A gravity drive (counterweight) is used to drive a cable hoist with a skip. This circumstance provides a highly productive, highly efficient, reliable and environmentally friendly technology for transportation of rock masses from deposits of solid minerals in open construction.

On based the investigation were established that main reasons of a high cost transporting 1 ton of rock mass in open-pit mining are the need to construct transport routes for them by withdrawing the sections of the rock mass on above them, as well their lifting capacitie is limited because of they all do use highly energy-intensive machines for transporting rock minerals. In article has been justified a skip cable winch supplied with a wheels moving along on a railroad way by using only a gravitational counterweight device for transporting rock mass from a place of their formation to Earth surface. By the way, the value of the counterweight mass is adjusted using a volume of the working liquid in a vessel installed inside the body of the counterweight.

In order to justify the main hypothesis of the study have been developed a prototype of the innovative device for transporting rock masses. A prototype skip loader was developed and the operability of its prototype control system type 2T was confirmed. Fig. 1 shows a structural-kinematic diagram of the prototype type 2T rope elevator. Fig. 5–12 show diagrams of the changes in kinematic and dynamic parameters of the prototype rope hoist.

A structural-kinematic synthesis and analyses of the prototype have been committed. Then have been conducted a kinematic and static studies the prototype, where its end effector performed given rotational motion. There are have been given a trajectory of motion of the end effector of a prototype of skip winch represents in the form of a circle have shown in Fig. 5 and it is described following equations (4). The obtained kinematic and dynamic parameters of the prototype of the 4-cabel-driven parallel robot type 2T are shown in Fig. 5, 6.

Fig. 7 shows a block diagram of a control system the prototype a planar cable-driven parallel robot. This feedback circuit will only work well if sufficient tension is maintained on all cables at all times. For the build of a prototype of a planar cable-driven parallel robot, a configuration of its system was developed, taking into account the convenience and clarity when demonstrating its work to students. The configuration of the system of the prototype of the planar cabel-driven parallel robot is shown in Fig. 8. Here the following initial data are selected: dimensions of the fixed frame $1\times1\times0.2$ m, payload 0.5 kg, maximum end effector velocity 1.5 m/s.

Affording to the configuration of the planar cable-driven parallel robot system shown in Fig. 8, four winches need to be developed. Fig. 9 shows the design of the developed cable-driven parallel robot's winch. Each of which consists of a drum mounted on a shaft with two bearings at both ends. The drum is connected to the Nemal7-l7HS8401S stepper motor through a coupling. An encoder is attached to the end of the drum.

The stepper motor controller is based on the Arduino Uno controller with a CNC Shield v3 expansion board and stepper motor drivers using the Arduino GRBL software. With the help of the Arduino controller, the cable-driven parallel robot is controlled by the computer via the USB port.

Fig. 9 is represented a winch of the prototype a cable-driven parallel robot.

The prototype of the planar cable-driven parallel robot is shown in Fig. 10. The technical parameters of the prototype of the that are shown in Table 1. Table 2 shows the technical parameters of the planar cable-driven parallel robot stepper motor. A prototype of cables-driven robot are attached at one end to the drive on a fixed frame and at the other end to the skip body hinge and are in a tense position. Assuming that all cables, in any position, are always in a taut state, the kinematics of a cable parallel robot is similar to the kinematics of parallel robots with one-sided constraints.

For testing, the design of the prototype planar cable-driven parallel robot has a back wall (Fig. 11), on which white paper is attached, for drawing the specified trajectories with the end effector. Checking the work of the prototype of that was carried out when the end effector was drawing the trajectory of a circle with a radius of $r=200$ mm, by the equation (4), described above. To draw the given trajectory, a marker was attached to the end effector of the planar cable-driven parallel robot prototype. The graphs for these three tests that have been carried out are represented in Fig. 12. Within of three options the red color trajectory more closely have being approached the given trajectory.

The results that have obtained in process of its performance simulating allow to confirm a main hypothesis of the study concerning the possibilities of squeezing out the fundamental «causes» of a high cost of transporting 1 ton of rock mass in open-pit mining of solid mineral deposits inherent to all of exists transporting systems – eliminating in need to build transport routes as well in using whether energy-intensive lifting machinery or any vehicle trucks. The average value of the maximum deviations of the radii of the circles from the radius of the ideal circle is 10.8 % of the length of the radius of the ideal circle, which indicates the insufficient accuracy of the work of the prototype.

The main limitations is the fact that at the moment only experimental studies of the prototype cable skip hoist have been carried out. Further, a full-scale experiment is required at a specific mining enterprise. Understanding the scale of the problems to be solved that will arise when implementing this technology in practice, let's plan to create a collaboration of leading scientists and specialists from countries of the World, for example, Ukraine, China, India and other countries.

The main disadvantages of the study is that assumptions made in the work for the empirical substantiation of the scientific hypothesis are based only for a prototype of cables-driven robot are attached at one end to the drive on a fixed frame and at the other end to the skip body hinge and are in a tense position. The assuming that all cables of a prototype in any position, are always in a taut state, that circumstance also is limited that study, because of its kinematics are similar to the kinematics of parallel robots only with one-sided constraints. As well in the development of a prototype has not been studied an influence any contributions of changing a value tensions its cables on the accuracy while reproducing by the end effector a given trajectory. While developing the control system for the prototype 4-rope skip hoist type 2T [17, 19], its performance was confirmed. However, the positioning accuracy of its working body (body) turned out to be insufficient. For example, the value of the maximum deviation in absolute value of the trajectory of movement of its worker from a given trajectory of a circle of radius $r=200$ mm was $D_{av}^{-\max}=21.67$ mm and the positioning error of the working body of this robot reached almost 11 %. The reasons for such a significant positioning error are the lack of a rigid basing of its working body, errors in the control system, including random and systematic errors in the evaluation of experimental data.

The research results presented in this article are only a part of it. In this sense, they have a limiting character. In the future, it is planned to present research materials on the problems of improvement of drilling and blasting technology, including the method of destruction of rock masses in a quarry by explosions of explosive charges formed in horizontal, slightly inclined boreholes, and improvement of the technological process of loading rock masses into a prospect without the use of large excavators with the help of towing equipment.

7. Conclusions

1. In this study have been designed an innovate skip winch having limitlessness lifting capacity for transporting rock mass in any value of sizes from a place of their formation to Earth surface at the development of solid mineral deposits in open-pit mining without using any energies machines as well any vehicle trucks whether on gasoline or diesel oil and do performancing at all various climatic conditions. For a conditional example, the structure of the achieved innovative image of the rock mass transportation system has changed significantly, for example, the value of one of the parameters (productivity), which is only 33 % in the initial state, has reached almost 80 %.

The results obtained will make it possible to the creation of an innovative technology for the development of solid mineral deposits in the open method for use in various conditions of mining and geological deposits in all climatic conditions of open pit mining (snowfall, blizzard, ice, rain, heavy rain, fog, etc.).

2. A prototype of a skip winch has been built. Checking the work of a prototype was carried out by drawing a trajectory of a circle the end effector. In the course of experiment it was found that the deviation of a trajectory from an «ideal» given circle occurs as a result of a sudden less of tension in any cable. The average value of the maximum deviations of the radii of circles from the radius of the «ideal» circle is around 11 % of length of the radius of the «ideal» circle.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

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