ANALYSIS AND DEVELOPMENT OF SLOPE HOISTING SYSTEMS FOR OPEN PIT MINES

***Roman Slobodyanyuk*[1]**

[1]*France, Nancy, University of Lorraine; slobod.roman@gmail.com*

ABSTRACT. The purpose of this article is to develop and substantiate rational designs of slope hoisting systems for dump trucks in open pit mines to reduce the time losses associated with an idle mileage in the transport cycle. The basic arrangements of slope hoisting systems have been analyzed and a rational field of their application has been determined. The lack of experience in operation of slope hoisting systems with multi-rope friction winders, the possibility of reducing a friction ratio due to freezing and wetting the rope leave no chance to recognize this technical solution as a reliable. The article presents the results of the design study and determination of parameters of a hoister with a reeving system for suspension of one platform to haul down the 130-ton trucks. The developed hoisting plant consists of the following main parts two 1-6 x 5.6/0.8 single-drum hoisters; a platform for transporting the truck; a headframe for placing the deflection sheaves; two deflection sheaves; two inclined rail tracks to move the platform. The article proposes new technical solutions for hoisting plants with two platforms. The developed technology promotes improvement of the operational performance of haul trucks in open pit mines.

Keywords: slope hoisting plant, haul trucks, drum hoister, reeving system of vehicles, resource-saving technology

АНАЛИЗ И РАЗРАБОТВАНЕ НА КОНСТРУКЦИИ ЗА НАКЛОНЕНИ КЪМ КАРИЕРА СИСТЕМИ ЗА ПОДЕМ

***Роман Слободянюк*[1]**

[1]*Франция, гр. Нанси, Университет на Лотарингия; slobod.roman@gmail.com*

РЕЗЮМЕ. Целта на работата е разработване и обосноваване на рационални конструкции за кариерни наклонени кранове за самосвали, за да се намалят времевите загуби, свързани с напразния път в транспортния цикъл на самосвалните камиони. Извършен е анализ на основните схеми на кариерните подемни системи с наклон и е определен рационалния обхват на тяхното използване. Липсата на опит в експлоатацията в кариерите на подемни системи с теглителни снопове на триене, възможността за намаляване на коефициента на триене, дължащ се на замръзване и омокряне на въжето, не определят това техническо решение като надеждно. В статията са представени резултатите от изследването и определянето на параметрите на подемна машина с ремъчна спирачка на една платформа, която служи за спускане на самосвали с полезен товар от 130 тона. Разработената подемна система се състои от следните основни части: две еднобарабанни подемни машини тип 1-6х5,6/0,8; платформа за транспортиране на камиона; куп за поставяне на шайби за отклоняване; две отклоняващи шайби; две наклонени релсови линии за преместване на платформата. Предлагат се нови технически решения за подемни машини с две платформи. Разработената технология създава необходимите условия за подобряване на експлоатационните характеристики на кариерните самосвали.

Ключови думи: кариерна подемна система с наклон, транспортни камиони, барабанна подемна машина, полиспаст, технология за спестяване на ресурси

Introduction

Articulation of the problem

By the end of the 20th century, considerable progress had been made in the development and implementation of heavy hoisting plants in the underground mines. There are examples of mines with a depth exceeding 2 000 m, the lifting capacity of hoisting plants has reached over 50-60 tons. Advances in the development of mine hoisting plants have awaken fresh interest in the use of steep-slope hoisting plants in deep open pit mines (Новожилов и др., 1962; Носырев, 1972; Shilling and Adams, 1971; Васильев, 1975; Кульбида и др., 1981; Садыков, 2011). In the 60s, in the US, South America and China, more than 10 projects of slope skip hoisting plants were implemented (Новожилов и др., 1962; Shilling and Adams, 1971). In 1972, Siemag, the West German company, built the only slope skip hoisting plant in the USSR in the Sibaisky Open Pit Mine (Васильев, 1975). Along with the development and implementation of slope skip hoisting plants, a number of teams of authors elaborated an idea of using a slope hoisting plant to haul down the empty and lift the laden dump trucks in the open pit mines (Дремин и др., 1993; Листопад, 2001; Бондарєв и др.1, 2011). However, numerous projects in this regard have not been implemented. The reason for this is not only the technical complexity of slope hoisting plants, which should conform to the pit dump trucks in their parameters, but also the doubts about the economic efficiency of such plants at a state-of-the-art open pit. The systems designed for hauling down the empty and lifting the laden trucks are distinguished by high metal consumption and complexity of technical solutions on multi-rope hoisting.

Progress in mining machinery manufacturing has increased reliability of pit dump trucks and led to an increase in the reasonable distance of rock mass haulage. There are examples when the rock haulage by trucks reaches over 10 km. In these conditions, the main negative factor that needs to be solved is the idle run of trucks. One-way traffic and equal number of loaded and idle runs of trucks are the main features of truck haulage at the open pit; elimination of idle runs can be considered as the key method for improvement of truck haulage efficiency.

Analysis of recent research and publications

A great contribution to the development of the theory of slope hoisting systems was made by Белобров (2002). His work deals with multi-rope slope hoisting plants designed to haul down and lift the trucks, as well as to lift the skips of over 120 ton capacity. However, the main orientation of research was focused on lifting the cargo to the surface. In order to solve the problem, we used a multi-rope hoisting system with a large angle of the drive sheave contact (**α**=3π). With increasing **α**, the lifting capacity of the hoister is increased:

$$S_2 = S_1 e^{\alpha f}, \quad (1)$$

where S_2 is the tension of the rope lifting the laden vehicle; S_1 is the same from the side of the empty vehicle; *f* is an adhesion (friction) factor between the rope and the lining of drive sheaves (0.2 ÷ 0.3).

The hoisting plants with several drive sheaves of friction have a lifting capacity 3 to 6 times greater than single-drive machines. A weak point of this plant (Садыков, 2011) is that the hoisting ropes are subjected to multiple (up to 8-9 times) kinking on the sheaves during a lifting cycle, half of them bends in different directions, that will lead to a short lifespan of the ropes.

Siemag has developed a project for a slope hoisting plant for laden trucks, which is equipped with a single platform with a counterweight. In this project, a multi-rope hoisting system with a large angle of the drive sheave contact is also used. In the world, there are several examples of using the hoisting plants for dump trucks in the mining operations under extreme conditions - in the construction of hydraulic structures in the highlands (Nant de Drance, Tokuyama, Tateyama, Miyagase, Kaprun, etc.). The capacity of these plants does not exceed 40 tons.

Main Exposition

Statement of the problem

The purpose of this article is to develop and substantiate rational designs of slope hoisting systems for dump trucks in the open pit mines, the use of which will reduce the idle runs.

Presentation of the main study material

The main idea of this study is to increase the truck capacity by reducing the downtime associated with idle mileage in the transport cycle using the slope hoisting plants to haul down the empty trucks to the open pit. Obviously, the hoisting systems equipped with two lifting platforms alternately used for hauling down the trucks can achieve maximum economic effect.

It is known that when lifting vertically using drum winders or hoisters with friction sheaves, the vehicles move in two mutually perpendicular vertical planes: in plane, where the head sheave is located and in plane being tangential to the sheave circle (the rope leaving point from the sheave). The line of intersection of these planes coincides with the axis of the hoisting rope. When lifting vertically there are no critical difficulties with creating conditions for movement of two skips in the shaft. The skips used for vertical lifting are structurally adapted to move within a limited section of the shaft (the height of the skip is greater than its dimensions in plan).

This principle is maintained even at slope hoisting – the vehicle moves along the line of intersection of two mutually perpendicular planes, but one of them (tangent to the sheave) is located at an angle to the horizon. In this case, the design solution to arrange the movement of two vehicles (skips or platforms) associated with one or more hoisters is more difficult, especially when the trucks are lowered on the platform (the length of 130-ton truck is about 12 m, the width is 6 m, the weight is 105 t, the weight of lifting platform is 50 t). In most of proposed slope hoisting systems for dump trucks, this has led to placing the deflection sheaves on the headframes or in the hoist house, which makes these hoisting plants complex and unreliable.

A great contribution to the development of the theory of slope hoisting systems was made by *Б.А.Носырев*. In his work (1972), eight basic arrangements of slope hoisting plants are defined, the estimation is given and the rational application area is specified. Fig.1 shows the schematic diagrams of slope hoisting plants in the open pit mines, the analysis of these plants is given in Table 1. The absolute lack of experience in operation of slope hoisting systems with multi-rope friction winders in the open pit environment does not optimize the possible increase in the calculated friction factor and even more, the friction factor may be reduced due to rope freezing and wetting during the periods of rain and snow melt (Носырев, 1972).

In order to determine the main technical characteristics of the plant for hauling the empty trucks (Fig. 2), the design was elaborated for the following mining conditions: the hoisting plant is single-end type; lifting height, Hn = 400 m; a slope angle of the lifting way, α = 40 °; lifting length, L_H = 622.48 m; the type of vehicle is a platform; capacity of the platform is Q_{gr} = 105 000 kgf; mass of the platform, Q_{pl} = 50 000 kg; the purpose of the hoisting plant is men and cargo hoisting.

The maximum static load of the slope hoisting plant is 155t. At present, the mine hoisters manufactured by the industry have no capacity required to meet a target. The hoisting plant with two synchronized hoisters and a reeving system for suspension of the cargo platform is proposed, that will allow reducing the suspended load on the hoisting ropes. The suspended load is:

$$Q_0 = \frac{Q_{st}}{n \times i_n \times \eta_n} = \frac{155000}{2 \times 2 \times 0{,}99} = 39142\ kgf \quad (2)$$

where: n = 2 - number of hoisting ropes;

i_n = 2 - mechanical advantage of a tackle block (number of ropes);

η_n = 0.99 - efficiency of a tackle block on the roller bearings

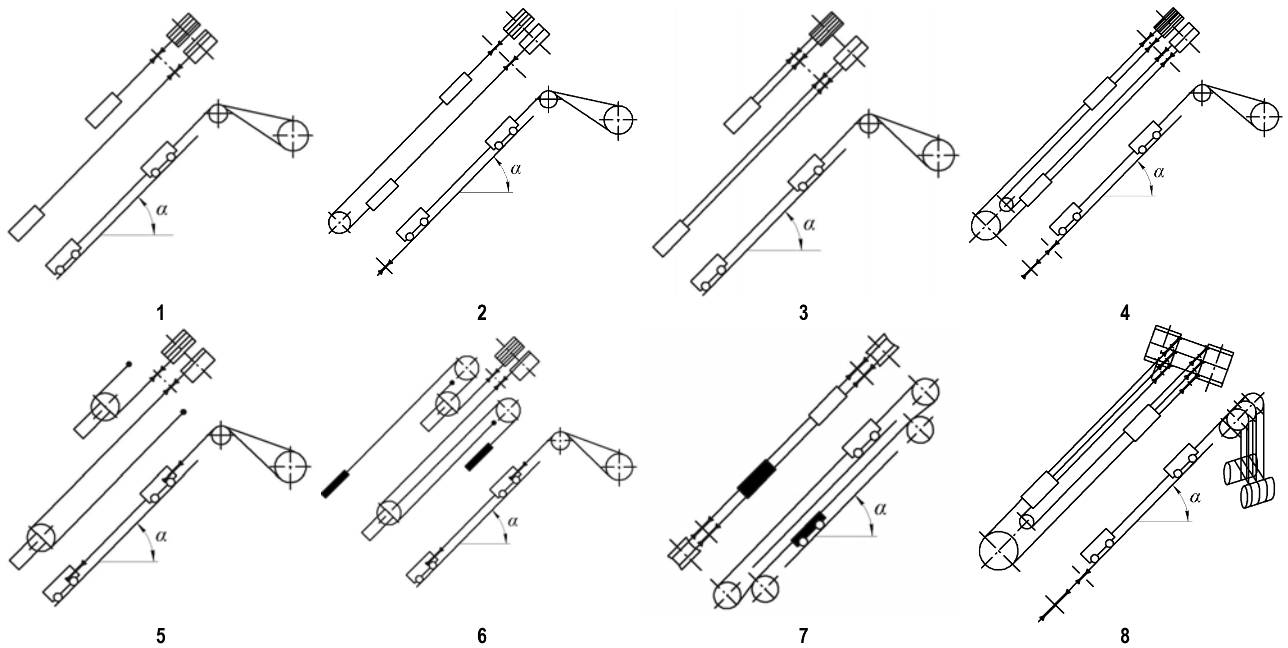

Fig.1. Diagrams of hoisting plants (Носырев, 1972)

Table 1
Analysis of arrangements of slope hoisting plants

Design features	Advantages	Disadvantages
A single-rope hoisting plant with multilayer rope winding on a cylindrical hoist drum (Fig. 1.1, 1.2), (drum hoist). Capacity is up to 40 tons.	Simplicity and reliability of the plant; the possibility of using the lubricated ropes.	The use of this plant is limited by the traction properties of the rope, the static tension of the rope line and the greatest static unbalanced circumferential force. With a greater unbalanced circumferential force, it is necessary to balance the hoisting system (Fig. 1.2).
A multi-rope hoisting plant with multilayer rope winding on the section of cylindrical drums (Fig. 1.3), (Blair hoist). Capacity is over 40 t, lifting height is over 400 m.	Simplicity and reliability of the plant; the possibility of using the lubricated ropes, the use of a winding reel of smaller diameter than in the case of friction sheaves; lower consumption of ropes.	When lifting cargo from deep levels, the improvement of energy effect may be achieved by using lower balancing ropes (Fig. 1.4).
The hoisting plants with a reeving system for suspended vehicles (Fig. 1.5, 1.6).	The harmful phenomenon of uneven force distribution along the rope lines has been eliminated; due to the high speed of the rope, it is possible to use gearless drives. The use of block hoisting arrangements is reasonable for cage hoisting plants with a low lifting speed of the cage (platform).	Complication of the vehicle construction due to placing the circumferential sheave on its frame, an increase in the vehicle weight by 10-15 tons; increased wear of the rope, because of the doubled speed of its movement and additional bending on the by-pass sheave; the use of double-length ropes.
A multi-rope hoisting plant with friction sheaves (Fig. 1.7, 1.8), (Koepe hoists). Capacity is over 40 t, lifting height is over 400 m. A hoister with one driving friction sheave provides no high traction and requires balancing ropes. In the hoisters with several driving friction sheaves, the angle of the drive sheave contact is 3π.	It can be used with long ropes; decrease in inertial masses of the winding reel; increase in efficiency of the hoisting plant; rope rupture hazard prevention when the vehicle is derailed (jammed) and re-lifted.	Limited use due to the rope stress ratios; increase in wear and corrosion of the rope due to the lack of protective lubrication; reduction of the friction factor due to rope freezing and wetting during the periods of rain and snow melt; constructive complexity of two-vehicle slope hoisting plants; the low balance ropes considerably complicate the design and reduce the reliability of the hoisting plant.

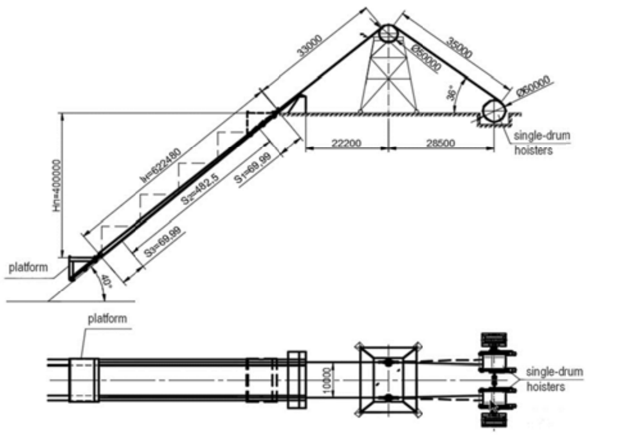

Fig.2. Diagram of a hoisting plant

As a hoister, it is rational to use the mine hoister with one cylindrical drum that has been developed by NKMZ. Based on the dimensions of the winding reel and suspended loads, the 1-6x5.6/0.8 mine hoister fits well having the following parameters: 6 000 mm drum diameter; 5 600 mm drum width; 560 kN static rope tension; 400 kN difference in static rope tension and 11 200 kNm^2 flywheel effect.

The developed hoisting plant consists of the following parts:
- two 1-6x5.6/0.8 single-drum hoisters;
- a platform for transporting the truck;
- a headframe for placing the deflection sheaves;
- two deflection sheaves (Ø 5 000 mm);
- two inclined rail tracks to move the platform.

In order to reduce the suspended load on the hoisting ropes, provision is made for two hoisters with fixing the ropes via a tackle block to the platform frame. This type of arrangement makes it possible to use commercially available hoisters. In order to distribute an even load, the operation of hoisters should be synchronized in terms of rope speed and tension. The parameters of the hoisting plant are determined by calculation as follows: the hoisting speed is 9.9 m/s, the time of one cycle is 214.2 s, the time for a truck to drive on and off the platform is 60 s, the cycles per hour are 12-15. Fig. 3 shows the diagrams of acceleration, speed and force. When the loaded platform is lowered, 1÷3 periods (Fig. 3), the values of driving forces on the circumference of the rope winders have negative values, i.e. the engines operate in a dynamic braking mode. When the platform is lifted, the drive motors operate in a traction mode, overcoming the static resistance of the hoisting system and at the same time ensuring the actual linear speed with the proper acceleration and deceleration adopted according to the requirements of design standards. The hoisting plant is equipped with two P2-800-217-8SUHL4 electric motors of 3 150 kW nominal.

The efficiency of mining operations with the use of a developed system for hauling the trucks to the working area depends on the number of downward trips per hour. The performance of the hoisting plant with one platform is sufficient to provide operation of one shovel with a 12-15 m^3 bucket capacity. In order to provide a working area of the open pit with twice as many trucks, it is necessary to build two similar single-rope hoisting plants or to develop a hoisting plant with two platforms. The main idea that needs to be implemented in the hoisting plant with two platforms is to balance the hoisting system and haul down the trucks when engines are operating in a regeneration mode.

The arrangements can be classified as per location of tracks with respect to the longitudinal hoister and the position of tracks relative to each other. We will compare the advantages and disadvantages of alternative arrangements of hoisting plants having two platforms with two independent hoisting plants having one platform. Analysis of possible kinematic diagrams allowed the following solutions to be called competitive. From the position relative to the hoister, both tracks can be located either on one side (Fig.4, 5) or on opposite sides of the hoister (Fig.6). When the tracks are located on opposite sides of the hoister, they are located in the same vertical plane, but not parallel to each other (Fig.6). In order to ensure mining technical conditions for this track location, it is necessary to provide the hoister's site on a rock pillar, protruding in plan from the general strike trend of the pit wall. This design of the hoisting plant allows to haul down the trucks at two different sections of the working area. The distance between in-pit sites of the hoisting plant can reach 600-800m. When the tracks are located on one side of the hoisting plant, they are also located in the same plane, in general, parallel to each other, but this plane can be either parallel to the pit wall plane (Fig.4)or vertical and pass through the hoisting sheaves of the hoisting plant (Fig.5).

Fig.5 shows a general view of the hoisting plant with one-sided arrangement in a vertical plane of two parallel tracks (the top and bottom tracks), where 1,2 - platforms; 3 - dump truck; 4,5 - inclined rail tracks; 6,12 - hoisting ropes; 7,13 - headframes; 8,14 – top headframe sheaves; 11,17 - bottom headframe sheaves; 9,15 – rope winding reel; 10,16 - electric motors; 18 - a hoist house (deflection sheaves on the platforms and a reeving system are not shown in the figure). Fig.6 shows a general view of the hoisting plant with an opposite-sided arrangement (in relation to a vertical plane passing through the longitudinal axis of the drum) in a vertical plane of two tracks (conditionally applied to Fig.7, left and right tracks), where 1 is platform of the right track; 2 - platform of the left track; 3 - dump truck; 4,5 - inclined rail tracks; 6,14,13,21 - hoisting ropes; 7,15,11,19 - headframes; 8,16,12,20 - headframe sheaves; 9,17 – rope winding reels; 10,18 - electric motors; 22 - a hoist house (deflection sheaves on the platforms and a reeving system are not shown in the figure).

The arrangement shown in Fig.4 differs from two independent, side-by-side located hoisting plants with one platform in that the adjacent single-drum hoisters are replaced by one double-drum hoister. The double-drum hoister serves both tracks and operates all the time in a regeneration mode, the single-drum hoisters operate alternately. In this case, the hoisting plant is equipped with three hoisters. One of the main drawbacks of this arrangement is that there is no possibility to provide a through movement of trucks, that is, when driving on or off the platform, the truck drives in reverse.

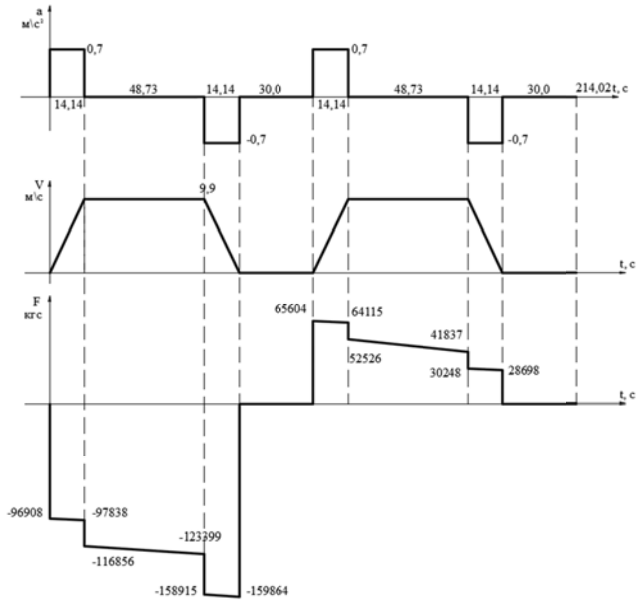

Fig.3. Diagrams of acceleration, speed and force

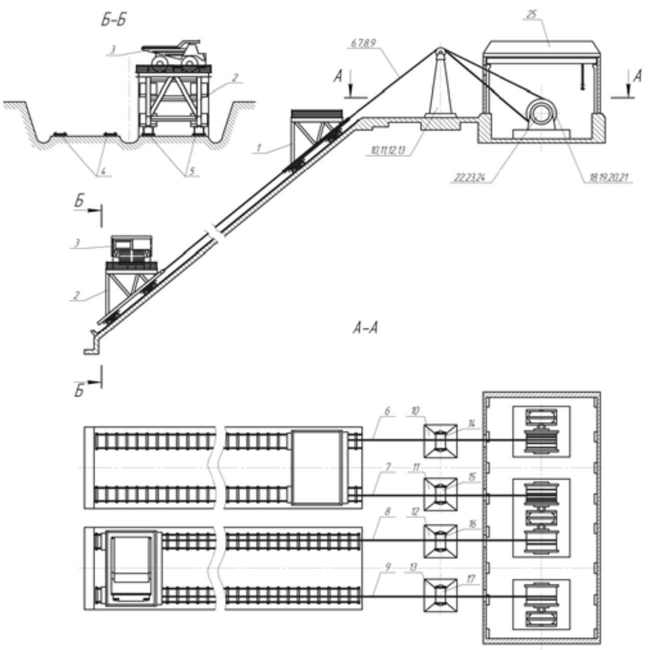

Fig.4. General view of a hoisting plant with a single-sided arrangement of two parallel tracks in a plane of a pit wall

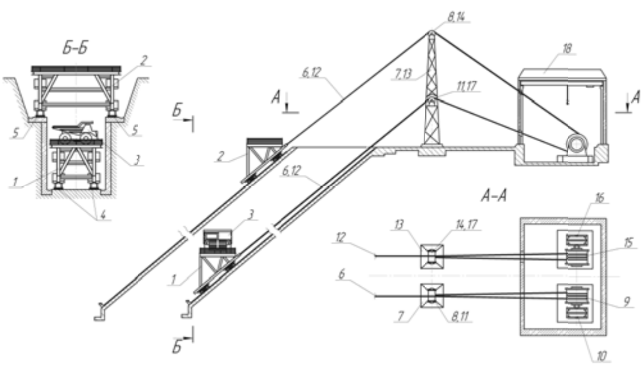

Fig.5. General view of a single-sided hoisting plant in a vertical plane of two parallel tracks

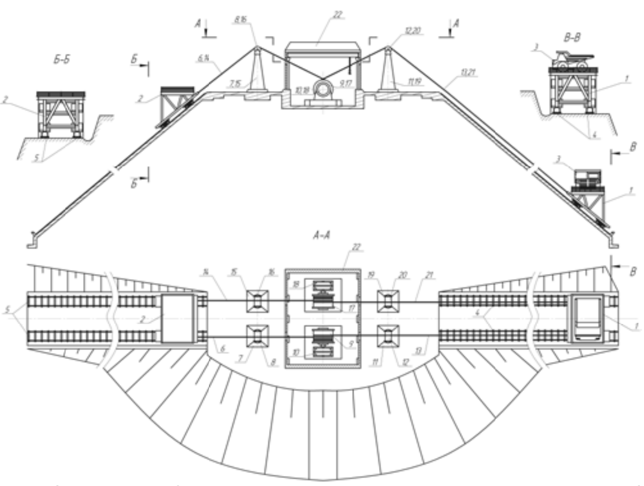

Fig.6. General view of a hoisting plant with an opposite-sided arrangement of two parallel tracks in a vertical plane

The diagram in Fig. 5 differs from the diagram in Fig. 4 in that the hoisters are statically more balanced, two ropes are wound on the cylindrical drums: when one rope reels in, another one reels out. Two hoisting plants provide hauling two platforms up and down, and operate all the time in a regeneration mode. The location of tracks in section of one step-shaped trench allows the trucks to arrive and depart without additional maneuvers. The drawback of this arrangement is the need to construct a special trench with the location of rail tracks at two levels. The upper platform is structurally more complex than the lower one.

The diagram shown in Fig. 6, in terms of arrangement of hoister operation is similar to the diagram in Fig.5. However, in this case, two tracks of the hoisting plant are located in diametrically opposite directions. This design is characterized by a safer arrangement of the truck movement on the upper loading station and provides driving the trucks off the platform in the lower position without additional maneuvers. This arrangement is characterized by a large amount of mining and capital work to prepare the sites for construction of a hoist house and a track and can be used at the open pit with a long-distance haulage.

Conclusions and trends for further research

The article presents the results of research on the development and substantiation of rational designs of slope hoisting systems for hauling the empty dump trucks in the open pit mines, the use of which will reduce the idle runs.

The basic arrangements of slope hoisting plants using drum hoisters and hoisters with friction sheaves have been analyzed. The design complexity of slope hoisting plants with friction sheaves, the rope exposure to atmospheric precipitation (wetting and frosting), the increased rope wear due to friction against the supporting rollers and sheaves cause the low reliability of the hoisting plant. The hoisters with cylindrical drums do not have the above-mentioned drawbacks.

The issue of providing the required hauling ability of the hoisting plant is proposed to be solved by using several drum-type hoisters in its construction.

The results of the design study of the hoisting plant for hauling the trucks of 130-ton capacity are presented. The arrangement of the hoisting plant with two synchronized drum hoisters and a reeving system for suspension of one cargo platform, that allow reducing the suspended load on the hoisting ropes is considered.

The developed hoisting plant consists of the following main parts: two 1-6x5.6/0.8 single-drum hoisters (manufactured by NKMZ); a platform for transporting the truck; a headframe for placing the deflection sheaves; two deflection sheaves; two inclined rail tracks for moving the platform. When lowering the dump trucks, the hoisters operate in generator mode that allows for electrical energy regeneration.

The efficiency of mining operations with the use of a developed system for hauling down the trucks to the working area depends on the number of downward trips per hour. In order to provide a working area of the open pit with more trucks, it is necessary to build two similar hoisting plants or to develop a hoister with two platforms. The article proposes new technical solutions for hoisters with two platforms, which are alternately used for hauling the trucks. The developed technology promotes improvement of the operational performance of trucks in the open pit mines.

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