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INFLUENCE OF OPEN PIT DEPTH ON THE CHOICE OF CONVEYOR TRANSPORT TYPE

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Abstract. Surface mining operations lead to an increase in the depth of open pits. As a result, there is a need to choose a conveyor transport, which allows transporting rock mass to a great height at high lifting angle. Conveyors with deep trough belts and tubular and steep incline belt conveyors are used to transport rock mass along curved and vertical routes. The use of conveyors adapted to the conditions of deep open pits allows to reduce the length of the route and to cut capital expenditures and energy costs for transporting rock mass. The main difference the existing types of steep incline conveyors is the way the cargo on the belt is kept from spontaneously moving downwards. In this work, the main types of steep incline conveyors, their advantages and disadvantages are considered. It is noted that in order to achieve maximum efficiency in transporting large pieces of rock mass in deep open pits, it is advisable to use double-circuit type "sandwich" belt conveyors, and partitions on the cargo belt. Steep incline conveyors and belts developed by Flexowell (USA), Savatech (Ukraine), Metso Outotec (Finland), ContiTech Transportbandsysteme GmbH (Germany), and steep incline conveyor with a double-circuit belt (Uzbekistan) are considered. Recommendations for choosing the type of steep incline conveyor are given. The main technical and technological parameters of tubular conveyors, which are currently in operation, are considered. It is noted that the maximum angle of inclination of tubular belt conveyors for transporting bulk cargoes depends on the coefficient of internal friction of the cargo, the coefficient of friction of the cargo on the belt and the rate of the belt filling. The ranges of change in the maximum angles of inclination of tubular conveyors are determined. Based on the analysis of the technical and technological parameters of the maximum angles of inclination of a tubular conveyor and a belt hold-down conveyor, it was found that the maximum angle of inclination of the hold-down conveyor is 5–10 degrees higher than the maximum angle of inclination of the tubular conveyor. However, the cost and design complexity of the hold-down conveyor is higher than that of a tubular conveyor. It is recommended to use tubular conveyors on sections of the route with an inclination angle of up to 30 degrees.

Keywords: open pit, steep incline conveyer, belt, angle of inclination, cargo.

1. Introduction

The continuous increase in the depth of open pits affects the operation of open pit conveyor transport and leads to the loss of its performance. Increased loads on transport systems, along with low atmospheric temperatures, increased dust content, abrasiveness and the size of cargo pieces, determine specific requirements for conveyor transport in open pits. Further intensification of mineral extraction is planned not through the construction of new mining enterprises, but by improving the existing ones, including by modernizing transport systems. These include the creation of new types of high-performance conveyors for cargo movement along inclined and steeply inclined workings, ensuring high throughput, using vehicles that ensure low dust generation, and developing transport equipment of high reliability and performance and low energy consumption. Conveyor lines, as part of a mining company's transport system, tend to be shorter in length, which makes it possible to reduce capital expenditure. At the same time, it becomes necessary to lay conveyor lines along curved and even vertical routes. One of the ways to solve this problem is to use deep trough, tubular and steep incline belt conveyors (SIC).

The use of SIC for open pit mining provides smaller dimensions and weight compared to conventional belt conveyors, reduces belt wear, reduces the number of reloading points along the track or allows to abandon them. Of particular interest are steep incline tubular conveyors for transporting rock mass without preliminary crushing. In deep open pits, it is advisable to use double-circuit belt hold-down conveyor (inclination angle is up to 30 degrees) and additional pressure of the load with the help of holding down devices that interact with the load-holding belt to transport large pieces of crushed mass.

The following parameters are taken into account when selecting the SIC: the maximum rock piece size; particle size distribution and dispersion of the rock mass. The above factors are taken into account by selecting the ratio of the maximum size of the broken rock piece to the conveyor belt speed.

Main types of SIC: hold-down conveyors; with transverse partitions and corrugated side walls; with rail partitions without side walls, bucket type belt; with deep trough belt; elevator type; with intermediate drive circuits; with tubular belt.

Analysis of modern research and publications. The main difference between the existing types of SIC is the way the load is kept on the belt from spontaneously moving downwards. There are conveyors with an increased coefficient of friction of the rock mass on the belt surface, with special supporting elements on the belt, with increased normal pressure of the rock mass on the belt, or a combination of several of these methods [1].

Limitations of SIC application in deep open pit [1]: ore extraction and overburden excavation; excavation and transportation of overburden to the surface from overburden horizons located below the railway transport area; excavation and transportation of ores concentrated under transshipment points; intensive removal of idle sides or temporarily idle sides of open pits; deposit development and transition to open pit mining to ensure cargo transport links to the surface.

The main disadvantages of SIC include [1]: the probability of the belt coming off the support rollers when using heavy pressure belts (hold-down conveyor); a decrease in the degree of the belt filling with bulk material with an increase the lift angle (belts with transverse partitions and corrugated side walls); high energy consumption during transporting the cargo and, accordingly, low lifting height (trough belt); high resistance to belt movement on rollers, expensive belt, difficulties in installation and operation (tubular belt).

The SIC is installed at the final section of open pit face on supports at a high angle without a trench. When using the SIC with a pressure belt, the costs for the supports, additional steel structures, pressure belt, holding down devices, upper branch rollers, tensioning devices, drive and service trolley are required.

Most of the energy consumed by conveyors for transporting rock mass is spent on accelerating the material as it is loaded onto the conveyor. This factor is most pronounced in the operation of SIC that transport material at an angle of 30 degrees or more.

The experience of mining enterprises shows that the most efficient option for lifting rock mass from depths of 400 m to 1000 m is to use the hold-down conveyors (with a capacity of more than 5000 tones/hour). Such conveyors are universal and unified with standard belt conveyors, have a non-standard configuration and a lifting angle of up to 90 degrees [2]. The highest efficiency of rock mass transport is achieved when using conveyors with "sandwich" of pressure belt or with partitions on the cargo belt. These conveyors have a capacity of up to 6500 tones/hour and an inclination angle of up to 53 degrees, and are operated in conjunction with main and dump conveyors on the surface. In particular, "Flexowell" Corporation (USA) developed a conveyor for lifting bulk material (sand) with pieces of ore (up to 400 mm coarse) at an angle of up to 90 degrees. The conveyor's capacity is 4000 tones/hour, with belt speed 5 m/s. The belt is mainly made of a specially profiled rubber rope with corrugated side walls and solid cross partitions.

In European countries, SICs are equipped with holding down devices in the form of elastic rollers that are permanently installed on the linear part of the conveyor. They press the side belts of the load-carrying and load-holding belts against each other, and the latter - against the transported material. The main disadvantages of SIC with holding down devices include: the possibility of cargo movement towards the tail part of the conveyor under uneven belt loading; dynamic loads when clamping devices interact with pieces of rock; reduction of the load-carrying capacity of the load-carrying belt by up to 30–40% due to the use of its side belts with a width of about 200–250 mm to press the load-holding belt with side rollers.

The company "Savatech" (Ukraine) [3] develops conveyor belts with elastic cross reinforcement with steel string (type RCN) for heavy labor conditions, tubular conveyor belts "PIPETYPE" for use in heavy working conditions.

"Metso Outotec" Corporation (Finland) is a global leader in sustainable technologies, integrated solutions and services for the mineral processing and aggregates industries [4]. The "Lokolink™" steep incline conveyor is versatile. It is mobile, allowing efficient transport of rock mass between processing stages in the open pit and mining industries. The "Lokolink™" conveyors can be assembled into a conveyor system.

The range of products manufactured by "ContiTech Transportbandsysteme GmbH" (Germany) [5] includes conveyor belts for steep and vertical transport of load. In particular, tubular belts with a special coating made of XLL rubber compound are produced. This compound has a low coefficient of friction. This helps to reduce energy consumption caused by the resistance of the belt to the rollers (up to 35%). The maximum inclination angle of the conveyor can be precisely set for the selected bulk material using a special test bench. The "Flying Belt" system is also available, which combines the advantages of a belt conveyor and a rope conveying system. The "Flying Belt" steep inclin overhead conveyor can be used in conjunction with mining equipment. The conveyor consists of four load-bearing ropes and a conveyor belt in the form of a deep semicircular trough. Productivity is up to 2000 tones/hour, belt width is from 600 mm to 1600 mm, span length is up to 500 m, maximum rock piece size is up to 300 mm. Advantages: wide possibilities for adaptation of the route; modular system for moving the line. Disadvantages: small maximum slope is up to 25 degrees; low productivity (up to 2000 tones/hour).

At the Muruntau open pit of the Central Ore Management Department of Navoiiskyi Mining and Metallurgical Combine the project of steep inclin conveyor SIC-270 [6] was realized, which had two closed belts (lower load-bearing 2000St-5400 and upper pressure 2000St-3500). The working branch of the pressure belt is pressed against the load by the rollers of the holding down devices, and at the edges is directly against the surface of the load-carrying belt. Special holding down devices are installed on the conveyor. The conveyor capacity is 3500 tones/hour, the ore lifting height is 270 m, the belt width is 2 m, and the belt inclination angle is 37 degrees.

Table 1.1 shows the technical characteristics of SIC in open pit around the world.

Table 1.1 – Technical characteristics of SIC in open pit around the world [6]

Place of exploitation	Year	Transported material	Density, tones/m^3	Productivity, tones/hour	Inclination angle, degrees	lifting height, m	Length, m	Belt speed, m/s	Belt width, m
Beth Energy Mines (USA)	1991	hard coal	0.8	726	90	76.2	90.2	2.8	1372
Island Greek (USA)	1992	waste coal	1.28	454	up to 41	174.8	454.2	2.3	914
Cementos Veracruz (Mexico)	1992	hot clinker	1.36	715	35	41.3	198.9	1.7	1219
Montague SYS (USA)	1993	hard coal	0.88	1950	57	59.4	90.8	3.7	1829
TurrisCoalCo (USA)	1993	Hard coal	0.88	1361	90	103	113	4.6	1524
Perini (USA)	1993	Stripping	1.1–1.3	1266	90	70.1	83.8	3.6	1372
Colver PWR Plant (USA)	1994	Hard coal	1.12	260	up to 60	48.5	75	2.3	762
Qualitech still (USA)	1998	Iron ore	2.2	180	68	67.6	91	1.2	914
Tera Nova (Mexico)	2000	Copper ore	3.7–4.1	2500	35	34	79	2.66	1524
Muruntau (Uzbekistan)	2011	Gold-bearing ore	2.6	3500	37	270	960	3.15	2000

2. Methods

Currently, steep incline tubular belt conveyors are increasingly being used in various industries, including mining, chemical and light industries and agriculture, both abroad and in Ukraine. In particular, as the depth of open pits grows and the overall angle of inclination of the sides increases, the mining and technological situation becomes more complicated. Transport support for stripping and mining operations is of particular importance due to the problems of using road transport. However, there are no universal methods for selecting and calculating conveyors for transporting rock from deep open pits at a high angle of inclination. In this regard, the use of SICs in these conditions is a very relevant issue. Therefore, in order to effectively solve the problem of delivering cargo in open pits at a high angle, it is important to choose the right type and parameters of the SIC, taking into account the nature of the route elevation, mining and geological conditions, cargo properties and other factors.

The aim of the work is to study the influence of pit depth on the choice of the type of conveyor transport at open-pit mining.

Research objectives. Selection of the SIC type and its maximum inclination angles in deep open pits**.**

3. Theoretical part

When selecting the type of SIC, it is necessary to proceed from the conditions of its operation in a deep open pit, taking into account the influence of climatic factors (temperature, atmospheric precipitation), the nature of its maintenance, and the seismic impact of blasting operations [7]. Therefore, the conveyor must have a shelter that prevents precipitation from falling on it; must be equipped with transport devices for transporting materials during conveyor repair. In addition, it is necessary that the conveyor consists of structural elements whose reliability has been tested by long-term operation in the given mining and geological conditions.

Then, at a preliminary stage, the application of possible SIC types for given pit conditions is analyzed. If during the detailed study of initial data (height of lifting, angles of lifting sections across the board, lumpiness of rock mass), the sections with the angle of lifting more than 25 degrees (up to 30 degrees) are identified in the technological scheme, it is advisable to use hold-down conveyors or tubular conveyors.

The analysis shows that the great experience of SIC application in the open pit is achieved for hold-down conveyors. However, application of hold-down conveyor for large lump rocks of the Kryvyi Rih basin has definite difficulties [8, 9]:

1. When transporting pieces of cargo with a diameter from 0 mm to 400 mm on the hold-down conveyor, there is a loose fit between the belt and the load, which leads to the load spilling onto the idler branch of the conveyor.
2. Due to the difference in the speeds of the main and pressure belt, the belt slips during conveyor operation, and since the rocks are abrasive, this leads to rapid wear of the pressure belt.
3. Insufficiently studied modes in the design at the transition of the conveyor to the steep incline part, there is no adhesion of the belt to the load, which results in its spillage.
4. Complex and bulky metal structure for servicing and operating the pressure belt.
5. When using the SIC for ore extraction during the open pit refinement, the service life of the mining benches is short and the capital expenditures for the construction of the SIC do not have time to pay off.

Recently in Ukraine and in the world more and more tubular conveyors are used, which have a wider range of parameters and exclude the pressure belt. Therefore, if there are sections with an angle of elevation of more than 25 degrees (up to 30 degrees) and impossibility to create a reloading unit in the middle of the route, it is decided to apply a tubular conveyor, which has no limitation on the length. This allows to avoid an additional transshipment unit on the side of the open pit.

The main parameters of tubular conveyors that are currently in use are within the limits of:

- conveyor length is from 200 m to 19100 m;
- inclination angle is from 0 degrees to 30 degrees;
- belt speed is from 2 m/s to 7 m/s;
- capacity is from 300 tones/hour to 8650 tones/hour;
- belt width is from 1200 mm to 3000 mm;
- maximum piece size is from 0.1 m to 0.33 m;
- power is from 1000 kW to 3300 kW.

The advantages of tubular belt conveyors include:

- the ability to transport cargo along curvilinear sections of the route;
- inclination angle is up to 30 degrees, equal to the resulting angle of the open pit wall;
- no harmful impact on the environment;
- less number of transfer points and saving space;
- no spillage of cargo on the idle branch of the conveyor.

The disadvantages of tubular belt conveyors include:

- increased loads on the rollers;
- increased resistance to belt movement;
- torsion of the belt;
- considerable length of loading and unloading areas of cargo;
- more complex installation and operation compared to a belt conveyor.

The main factors affecting the operation of tubular conveyors: geometry of the route (inclination angle of the conveyor, radii of curvilinear sections); belt capacity and diameter; design and distance between roller supports; belt tension and speed; elastic and viscous properties of the belt; physical and mechanical properties of the load.

Studies [9] shown that the limiting angle of inclination for tubular belt conveyors transporting bulk load depends on the coefficient of internal friction of the load f, the coefficient of friction of the load on the belt f_1 and the degree of belt filling (angle of unfilled belt θ).

It was found that the maximum angle of inclination of the tubular conveyor α_n varies within the following limits:

$$\operatorname{arctg} f_1 < \alpha_n < \operatorname{arctg} f \text{ at } f_1 \le f;$$

$$\alpha_n = \operatorname{arctg} f \text{ at } f_1 > f.$$

Assuming that $f = 0.7$, at $f_1 = 0.6$, we obtain

$$31 \text{ degrees} < \alpha_n < 35 \text{ degrees}.$$

For belt hold-down conveyors, the maximum inclination angle of the conveyor varies between

$$\mathrm{arctg}\, f_1 < \alpha_n < \mathrm{arctg}\, [f_1(1+2q_{c2}/q_v)], \qquad (1)$$

were q_v is linear weight of the load, N/m; q_{c2} is working weight of the pressure belt, N/m.

Substituting the values of q_v = 3300 N and q_{c2} = 740 N into formula (1), we obtain the following at f_1 = 0.6:

$$31 \text{ degrees} < \alpha_n < 41 \text{ degrees}.$$

4. Results and discussion

A comparative analysis of the maximum inclination angles of a tubular conveyor and a hold-down conveyor showed that, with the same basic conveyor parameters, the maximum inclination angle of a conveyor with a clamping belt is only 5–10 degrees higher than the maximum inclination angle of a tubular conveyor. At the same time, the cost and design complexity of a hold-down conveyor is higher than that of a tubular conveyor.

Thus, based on the analysis, it can be recommended to use tubular conveyors on sections of the route with an inclination angle of up to 30 degrees.

5. Conclusions

The conducted analysis allows us to formulate the following conclusions:

1. It is found that with the increase in the depth of open pits, there is a need to use hold-down conveyors of various types and designs.

2. For conveyor inclination angles of up to 25 degrees conveyors with deep trough belts are used. For inclination angles from 20 degrees to 30 degrees tubular belt conveyors are used. For conveyor inclination angles above 30–41 degrees, hold-down conveyors are used. Belt conveyors with partitions are used for inclination angles above 50–68 degrees.

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ВПЛИВ ГЛИБИНИ КАР'ЄРІВ НА ВИБІР ТИПУ КОНВЕЄРНОГО ТРАНСПОРТУ

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Анотація. При відкритій розробці родовищ корисних копалин відбувається збільшення глибини кар'єрів. В результаті виникає необхідність у виборі конвеєрного транспорту, що дозволяє транспортувати гірську масу на велику висоту при високих кутах підйому. Для транспортування гірської маси по криволінійним та вертикальним трасам використовуються конвеєри зі стрічками глибокої жолобчастості, а також трубчасті та крутопохили стрічкові конвеєри. Використання конвеєрів, які адаптовані до умов глибоких кар'єрів, дозволяє зменшити довжину траси, знизити капітальні витрати, а також енерговитрати на транспортування гірської маси. Основна відмінність існуючих видів крутопохилих конвеєрів полягає у способі утримання вантажу на стрічці від мимовільного руху вниз. В роботі розглянуто основні види крутопохилих конвеєрів, їх переваги і недоліки. Зазначено, що в глибоких кар'єрах для досягнення максимальної ефективності транспортуванні великих шматків дробленої гірської маси доцільно використовувати двоконтурні стрічкові конвеєри типу "сендвіч", а також перегородки на вантажній стрічці. Розглянуто крутопохили конвеєри та стрічки які розробляються компаніями "Flexowell" (США), "Savatech" (Украина), «Metso Outotec» (Фінляндія), "ContiTech Transportbandsysteme GmbH" (Німеччина), а також крутопохилий конвеєр КПК-270 з двоконтурною стрічкою (Узбекистан). Наведено рекомендації щодо вибору типу крутопохилого конвеєра. Розглянуто основні технічні та технологічні параметри трубчастих конвеєрів, які експлуатуються в даний час. Зазначено, що граничний кут нахилу трубчастих стрічкових конвеєрів, які транспортують насипні вантажі, залежить від коефіцієнта внутрішнього тертя вантажу, коефіцієнта тертя вантажу об стрічку і ступеня заповнення стрічки. Встановлено діапазони зміни граничних кутів нахилу трубчастих конвеєрів. На базі аналізу технічних та технологічних параметрів граничних кутів нахилу трубчастого конвеєра та конвеєра з притискною стрічкою встановлено, що граничний кут нахилу конвеєра з притискною стрічкою на 5–10° перевищує граничний кут нахилу трубчастого конвеєра. При цьому вартість та конструктивна складність конвеєра з притискною стрічкою вище ніж у трубчастого конвеєра. Рекомендовано використовувати трубчасті конвеєри на ділянках траси с кутом нахилу до 30°.

Ключові слова: кар'єр, крутопохилий конвеєр, стрічка, кут нахилу, вантаж**.**