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Features of using equipment for in-pit crushing and conveying technology on the open pit walls with complex structure

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Abstract

Purpose is to substantiate the use of an in-pit crushing and conveying technology at the open pits with complex structure of the working zone, which technological complex includes inclined and steeply inclined conveyors for improved economic efficiency of mineral mining at deep levels.

Methods. The study applies a complex method including: technical-economical analysis of the practice of mining enterprises, experience of using conveying units at concentration plants and open pits; mining-geometrical analysis in terms of open pit sections – to identify the structure of the working zone of a deep open pit wall and its features along the depth; structural developments – to improve the design of a steeply-inclined conveyor; simulation modelling of the technological processes – to select optimal technical solutions.

Findings. Basing on the performed studies, it has been identified that transfer to a new trend of the in-pit crushing and conveying technology, considering the structural features of the working zone of a deep open pit, is rather prospective. In this context, it is expedient to use inclined conveyors or deep-trough conveyors on the sites of an open pit wall with the inclination angle of 10-18°; in case of sites with the inclination angle of 30-36°, it is recommended to use steeply inclined conveyors.

Originality. For the first time, a relation between the working zone of a deep open pit and formation of the structure of technological complexes has been identified. Dependences of the boundary inclination angle α_n of a pipe conveyor on the angle of non-filling θ of its belt with the cargo at different coefficients of cargo-belt friction have been defined.

Practical implications. The obtained results make it possible to widen the application sphere and increase the efficiency of mineral mining with the use of in-pit crushing and conveying technology.

Keywords: *open pit, ore, extraction, complex, in-pit crushing and conveying technology, conveyor*

1. Introduction

Open-pit mining of iron ore deposits depends on economic expediency of its extraction technology. An in-pit crushing and conveying technology in its classic form is limited by the angle of conveyor inclination of 16 degrees. Implementation of modern designs of steeply inclined conveyor plants is limited by the capacity of the working zone of an open pit. Consequently, design problems are studied and scientifically substantiated technical solutions are proposed in terms of open pit #1 of JSC CGZK (Central Mining and Processing Plant JSC).

One of the main trends to determine prospects and cost effectiveness of ore open-pit mining in Kryvbas is the development of effective ore mining technologies at deep open pit levels as well as extraction and transportation of crystalline overburden rocks from the levels located lower than the zone of railroad transport operation.

A problem of extraction and transportation of the overburden crystalline rock and ore from deep levels means that below the zone of railroad transport only motor transport can work in terms of overburden benches; and such motor transport is the most costly one as for its capital and operational costs. The parameters of the overburden working zone below the level of railway transport operation are rather considerable:

– height is from 150 to 300 m,

– angles of bench slopes at certain open pit areas are 30-36° as a result of the fact that the slopes are doubled, tripled and more;

– temporary non-mining flanks of an opencast are formed.

That is the fact for arising problems with railroad transport construction for deeper levels: there is the need in push-back, great capital costs for railing, and constructing the reloading stations for about the length of 0.6 km. Thus, the distance of automobile transportations of the overburden crystalline rock is constantly growing; that results in the increased prime cost of ore.

The second problem deals with the fact that some Kryvbas open pits apply insufficiently substantiated schemes of opencast development that do not consider a system of de-

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velopment and direction of mining operations. Application of the development schemes with the arrangement of accessways on the opencast working flanks has resulted in the open pit division into the sites while decreasing mining operations, restrained flank development, and formation of large pillars where considerable volumes of mineral are conserved. Due to untimely transfer of reloading stations of the in-pit crushing and conveying (IPCC) technology to the lower levels, we can observe restrained development of mining operations and conservation of ore reserves (Hannivskyi open pit of Northern GZK, a reloading station is closed down at open pit #1 of CGZK).

The third problem that influences significantly the efficiency of deep-level ore extraction is that the excavator reloading points are used at the open pits while applying combined transportation means, first of all the motor-railway ones. At some open pits, they include from two to six means. Due to their large parameters, the reloading points conserve great ore reserves. In terms of IPCC technology, the reloading stations also require certain conservation of ore reserves; however, the volumes are much lower.

The fourth problem is that considerable ore reserves are conserved under the operating transportation communications of the open pits. While cleaning-up the open pits, these reserves could be mined without additional extraction of overburden rock. However, transportation interconnection of deep levels with surfaces can be violated.

The research objective is the in-pit crushing and conveying technology for ore mass extraction and transportation from an open pit to the earth's surface. It is represented in the literature sources in such terms as "IPCC system" and "cyclic-and-continuous technology' or "cyclic-flow technology" (CFT). There is a worldwide practice of the system implementation. Analysis of the literature sources shows that it is used to mine and transport fuel, metallic and non-metallic minerals.

A problem of significance and widespread application of this technology is studied by Robert Ritter. In his thesis [1] of 2016 he did much statistic work. In particular, he questioned all leading plants manufacturing the corresponding equipment and identified that the equipment for 447 open pits worldwide were implemented and/or ordered. Robert Ritter considers that following enterprises are the main manufacturers of the IPCC equipment: Förderanlagen Magdeburg (FAM), FLSmidth, Hazemag, JoyGlobal, Metso, Mining Machinery Developments (MMD), Sandvik, Tenova TAKRAF, and ThyssenKrupp2. However, this list does not include the worldwide known Ukrainian plant Novokramatorsky Mashinostroitelny Zavod PJSC (NKMZ). Thus, appendix 1 of its paper [1] was analyzed; the analysis demonstrates that the list lacks many Ukrainian enterprises applying the IPCC technology (apart from the open pit of Poltava GZK). Consequently, it can be concluded that the number of 447 stated by Robert Ritter is not final at all.

Throughout the world, open-pit mining starts with a traditional cyclic technology based on motor transport. It has a lot of problems while being used (constantly increasing distance of transportation, limited optimal distance of transportation [2], high operating costs [3], continually growing cost of fuel and rubber etc.); nevertheless, there are also numerous advantages (mobility, logistic chain is not interrupted if one car is broken, shift-based extraction, wide limits of productivity changes, sequential partial replacement of a fleet unit etc. [4], [5]). Thus, a traditional technology is still rather popular.

Many scientists dealt with solving the problems concerning substantiation of the terms of IPCC introduction, its optimal productivity, technical parameters, terms and location of the reloading point transfer etc. In [6], the authors proposed a model based on different "year levels", i.e. the open pit deepening was taken into consideration. The model is used as the basis to develop a methodology for calculating optimal arrangement of the IPCC technology and the time for transfer. Paper [7] studied configuration of a mine field geometry and models discrete events in the IPCC system to evaluate the possibility of its application and identification of drawbacks. Study [8] compares cyclic and IPCC technologies of iron ore mining and transportation by analyzing the costs of previous feasibility study. The risks due to undetermined design parameters, affecting the cost analysis, are estimated by the Monte Carlo modelling. Their results show that the IPCC system is more efficient from the viewpoint of costs than the traditional one. To solve a problem of locating the IPCC complex, the authors of [9] represented a mixed-integral model of linear programming to select diverse equipment in an open pit with several locations in terms of certain schedule with several periods. The model helps substantiate the complex productivity.

Paper [10] is of practical significance. Chile's Chuquicamata copper mine is used as an example to represent a methodology of selecting the installation place for the third crusher. The rational variant is substantiated by means of minimal capital and operating costs while considering the probability of equipment failure. Two alternative configurations of location are evaluated involving stationary probabilities of the Markov chain model; the results are tested with the help of a simulation model with discrete events. However, despite all the prominent studies and developments, there is still no universal approach to the substantiation for implementing the IPCC technology. Each specific case requires analysis of certain mining conditions.

Last century, Ukrainian scientists and specialists of the Institute of Geotechnical Mechanics named by N. Poljakov of the NAS of Ukraine (IGTM NAS Ukraine) together with the specialists of Dnipro University of Technology of the MOS of Ukraine, design institutes (SID Kryvbassproekt SE, Yuzhgiproruda LLC, UkrNDIproekt SE), Novokramatorskiy Mashinostroitelnyy Zavod PJSC, Girnychi Mashyny SPC, and mining enterprises PivdGZK LLC, InGZK PJSC, PivnGZK PJSC, CGZK PJSC, AMKR PJSC developed and tested different technological schemes as the IPCC elements with the use of motor-conveyor transport at Kryvbas open pits [11]. At the first stage of development, the IPCC technology was developed for open-pit operations with the use of inclined belt conveyors that will make it possible to transport rock mass at the angle of 16°. That helped implement the advantages of a combined motor-conveyor transport and reduce sharply the distance of rock mass transportation from a face to the earth's surface [12].

Currently, new trends in the IPCC system development are in progress. It is proposed to complement a crushing-reloading point of the IPCC system after a coarse-crushing stage with a concentration complex with a coarse-size separation [13]. A technology of mineral extraction by steep layers with their wave-like displacement along the front has been implemented; the technology provides timely opening-up of the reserves and continuous rock mass supply on the IPCC reloading point [14]. Important results of industrial studies of a continuous technology at coal fields and the IPCC technology at the ore ones have been obtained [15], [16]. Technological schemes together with the movable or semi-stationary crushing complexes have been developed [17]. A large set of scientific and design works has been performed by Giprorud SC, Saint-Petersburg. Problems and prospects of the IPCC technologies while developing large ore and coal deposits are being studied.

The research results concerning conveyor transport analysis are of huge interest. Modern achievements in this sphere are associated to the development and manufacturing of new conveyor designs and belt types. Specialists of the Institute of Geotechnical Mechanics named after M.S. Poljakov of the NAS of Ukraine have represented theoretical and experimental improvements for the design of steeply inclined conveyors (SIC) for mining in deep iron-ore open pits for crystalline hard abrasive rocks. Methodologies for calculating main parameters of a steeply inclined pipe conveyor [18] and the deep-trough one [19] have been developed. Main dependences of technical parameters (belt velocity, belt width, space filling) on certain mining-geological of rock mass (size of a maximum rock piece, rock hardness) and technological parameters of rock mass (angle and height of elevation, path length) have been identified. Specified relations between the technical and technological parameters make it possible to outline the ways to improve the IPCC technology, substantiate new approaches to the opening-up schemes and systems of deposit mining, optimize conditions of conveyor plant operations, put pillars back into operation etc.

Selection of a rational scheme to open up deep levels is the most important element of the efficiency and application of the IPCC technology [11], [20]. While using open-pit mineral mining, one can use such techniques as trenching, underground mine workings or trenchless opening-up. Correct selection of the opening-up scheme is the guarantee that the operation of a technological complex will be long-lasting and efficient. Analysis of the formulated problems and current achievements in the conveyor transport shows that use of motor-conveyor cargo transportation is an optimal way here. Thus, the research purpose is to substantiate the use of IPCC technology at the open pits with a complex working-zone structure, which technological complex includes both inclined and steeply inclined conveyors for increasing the economic efficiency of mineral mining in terms of deep levels.

2. Research methodology

The first stage of the research object involved highlighting the research trend topicality and identifying the problems of its solution. Further, the purpose was set, and analysis of the practice of operating iron-ore enterprises along with the experience of using conveyor equipment at concentration plants and open pits was performed. That has helped make a decision concerning the application of a complex method that includes analytical calculations, modelling, substantiation of a technological complex, and design developments of a steeply inclined conveyor.

Studies concerning the selection of an optimal scheme for deep-level opening-up were performed in terms of open pit #1 of CGZK JSC. The open pit was commissioned in 1957. Before the Russian-Ukrainian war in 2022, its production output was 5.2 mln t of iron ore per year. The open pit depth reaches 400 m. According to a technical task of a feasibility study (FS), the in-pit crushing and conveying technology should ensure annual output of 16 mln t of rock mass (5.2 t of iron ore, 10.8 t of crystalline overburden rock). Its operating mode is year-round in terms of 355 working days and continuous working week with 2 shifts, 12 hours each.

Selection and substantiation of the scheme were complicated by certain mining and technological parameters, i.e.:

– a lying wall of the deposit, on which opening mine workings are usually planned, is undermined by underground mining operations;

– internal dump of the overburden rock is on the southern site of the open pit;

– western flank of the open pit is in constant motion, which allows production and open cut mining;

– the open pit wall, where opening mine workings can be arranged to install steeply inclined conveyors, have variable inclination angles and crossing with other transport communications.

That is why, the FS considered three opening-up variants:

1. By underground mine workings along with southern-western wall with the construction of IPCC system in a complex with classic flat conveyors.

2. Trench-digging opening-up of deep levels for motor transport to provide motor-railway transport complex (current use).

3. Trenchless opening-up of deep levels along the southern wall with the construction of IPCC system together with steeply inclined conveyors.

The paper pays special attention to the third variant that includes trenchless opening-up of deep levels, bench preparation and construction of the IPCC system, analysis of possible partial trench-digging opening-up of the medium and higher levels, substantiation of the necessity to use a reloading point, and a complex of steeply inclined and inclined conveyors.

The second stage involved mine surveying to study both southern open pit wall and renewed parameters of the internal dump. After that, we performed mining and geometrical analysis of a mine field in terms of cross-sections of the open pit. That helped identify the structure of a working zone of the wall of a deep open pit and its depth features.

A mining and geometrical analysis of a mine field in terms of cross sections is performed; the analysis has demonstrated that it is possible to locate the IPCC system on the southern open pit wall with its partial location along the internal dump body. However, detailed studies of the site have shown that the inclination angle of the open pit (in the cross-section along the path axis) has a variable value with the distinct angles: 30º (considering the laying out within the loading point), 25º, 23º, and 18º. A profile line of the conveyor path laying crosses the automobile communications within 5 sites (Fig. 1). In this context, in terms of three sites (+58, –90 and –218 m), it is necessary to plan a passage for motor transport; and in terms of the rest two sites, (±0 and +6 m) no construction works are allowed since the curvilinear turning sites of the automobile roads are crossed. The site of the southern wall of open pit #1 selected for the conveyor line construction is of complex mining and technical conditions: partial location on the bedrock crystalline rocks between the levels of –278 to –150 m and other location on the piled rock of the internal dump between the levels of –150 m and +58 m. According to the design, the path sites along the bedrock is of steeply inclined position at 36º with doubled benches between the levels of –255 to –150 m. There is no technical possibility to re-excavate the rock along the internal dump body; thus, it is impossible to dig trenches.

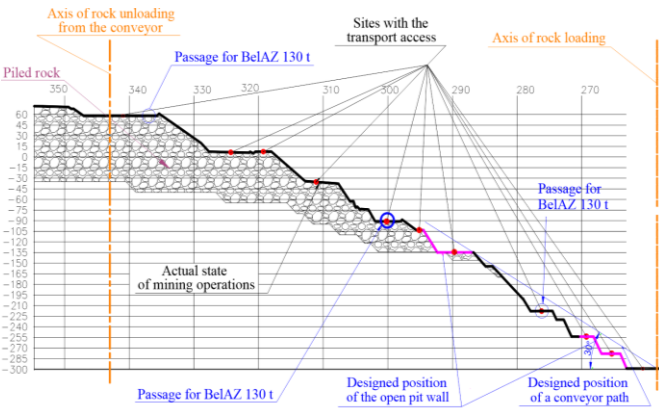

Figure 1. Section across the southern wall of open pit #1 (axial conveyor section)

As a result of the performed studies, a trenchless scheme of opening-up with the conveying plant located on the overhead road is the optimal variant for deep-level opening-up.

The third stage includes feasibility study of the variants of IPCC implementation and simulation modelling of technological processes in AutoCAD – to select optimal technical solutions. A grapho-analytical modelling was used to implement complex operation to analyze a structure of the open pit wall, technical parameters of the equipment, technological parameters to ensure and maintain all elements of a technological complex and their mutual arrangement. The performed calculations of possible production capacity of a technological complex made up of a crusher, a feeder, steeply inclined conveyor, a bin, an inclined conveyor, a conveyor overhead road (stacker) on the surface, a rock mass stockpile depending on the technical indices of a steeply inclined and inclined conveyor according to the methodologies developed at the IGTM [18], [19], and designed developments of a coarse crusher. Technical and technological parameters of the complex were analyzed. A set of calculations of the conveyor parameters as for belt width, degree of belt filling with loose cargo, parameters of roller supports, belt loading, belt type, parameters of a tension station, number of drums etc. were carried out. That was the basis to substantiate optimal technical and technological parameters of a technological complex. Design developments of a steeply inclined conveyor are performed.

3. Results and discussion

3.1. Structural features of the working zone of a deep open pit

A structure of the working zone of a deep open pit that influences the selection of the IPCC system depends on the mining and geological conditions, available transport communications and reloading points, applied technological equipment effecting the selection of the IPCC complex.

Railroad transport is used at the upper levels of a deep open pit. In case of this transportation type, there should be large-sized working sites and reloading points. Besides, there can be shear processes as soft and semi-crystalline rocks are developed here. That requires reduced inclination angle of the open pit wall to prevent from shear processes and ensure safe operation. In terms of medium and lower levels, motor transport is used either separately or in combination with the railway or conveyor ones. Consequently, the wall of a deep open pit has different inclination angles by height: at the upper levels – 10-18º but in the lower one – 30-36º (Fig. 2).

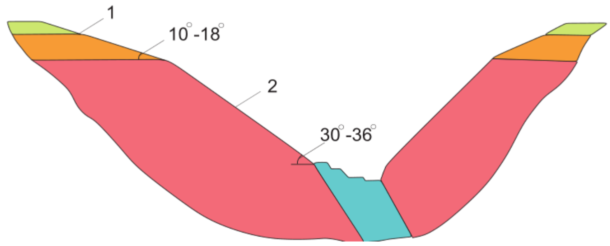

Figure 2. Structure of the deep open pit wall: 1 – open pit wall at the upper levels; 2 – open pit wall at the lower levels

Those structural features of the working zone of a deep open pit influence considerably the selection of a technological complex in case of in-pit crushing and conveying technology.

While using inclined conveyor with the elevation angle up to 18º, we need great number of conveyor lines together with conservation of the open pit wall for a long period and over the great area. Considerable capital costs are required while trenching for conveyor laying.

The performed studies make it possible to implement new trends in the sphere of IPCC improvement, which takes into consideration certain structural features of the working zone of a deep open pit and technical characteristics of new conveyors. In this context, it is recommended to use inclined conveyors or conveyors with a deep-trough belt on the sites on an open pit wall with the inclination angle of 10-18º; in case of sites with the inclination angle of 30-36º, it is recommended to use steeply inclined conveyors (Fig. 3).

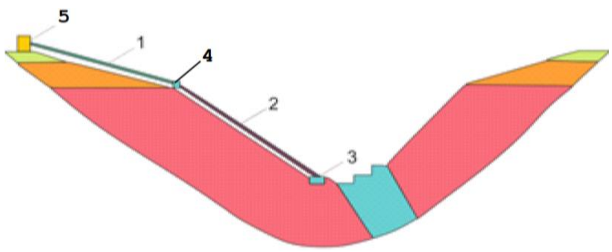

Figure 3. Schematic view of the IPCC use in a deep open pit with the use of inclined conveyor at the upper levels and steeply inclined conveyors at the lower ones: 1 – inclined conveyor; 2 – steeply inclined conveyor; 3 – crushing-reloading point in the open pit; 4 – reloading point from the steeply inclined conveyor onto the inclined one; 5 – reloading point on the surface

Complexity of the functioning of such complex is in the control of its productivity, i.e. one should substantiate corresponding conveyor parameters. Therefore, preliminary calculation of the main parameters of a steeply inclined belt conveyor was carried out. The calculated productivity of a pipe conveyor is 3000 t/year at belt velocity of 2 m/s. The overall length of the conveyor path is 1006 m; the conveyor elevation height is 370 m. The transported cargo is overburden rock with bulk density of 2.5 t/m^3 and maximum lump size of 250 mm. Calculations of the parameters of a complete conveyor without a reloading point have identified technical possibility of this design; however, great belt hardness (more than 10^5 N/mm) is the main disadvantage here. Thus, a project was proposed consisting of two conveyors with a reloading unit. In this case, belt strength is halved.

Studies [18] show that the boundary inclination angle for pipe belt conveyors, transporting loose cargo, depends on the coefficient of internal cargo friction f, coefficient of cargo-belt friction f_1, and degree of belt filling (Fig. 4) (angle of belt non-filling θ (Fig. 5)).

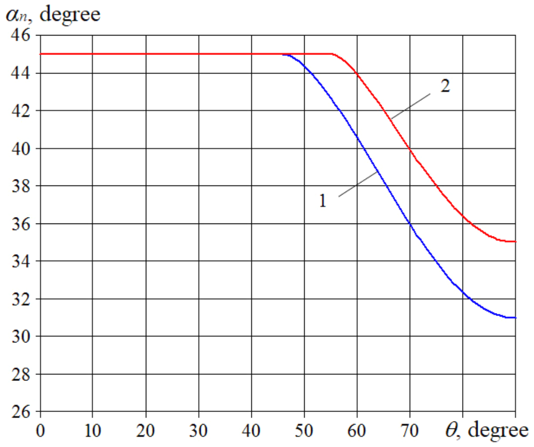

Figure 4. Graphs of dependence of the boundary inclination angle α_n of a pipe conveyor on the angle θ of non-filling of the conveyor belt with cargo at different values of the coefficient of cargo-belt friction f_1 in case of iron ore transportation: 1 – if f_1 = 0.6; 2 – if f_1 = 0.7

Figure 4 demonstrates graphs of dependence of the boundary inclination angle α_n of a pipe conveyor on the angle θ of its belt's non-filling with cargo at different coefficients of cargo-belt friction f_1. In this context, the angle of internal friction for iron ore is $f = 1$.

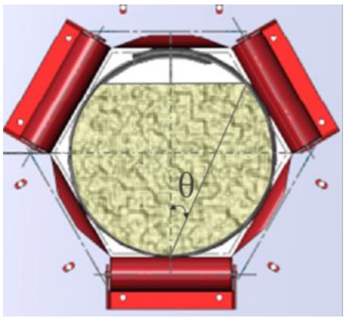

Figure 5. Scheme of determining angle θ, which indicates filling of the pipe belt conveyor space

Basing on the performed studies, it has been defined that the boundary angle of a pipe conveyor α_n varies within the ranges of:

if $f_1 \le f$, then

$$\text{arctg}\, f_1 < \alpha_n < \text{arctg}\, f \qquad (f_1 \le f);$$

if $f_1 > f$, then

$$\alpha_n = \text{arctg}\, f.$$

Considering that $f = 0.7$, we have:

if $f_1 = 0.6$ $\qquad 31° < \alpha_n < 35°$.

Thus, the boundary inclination angle α_n of a pipe conveyor is substantiated; it cannot be more than 35 degrees.

The conveyor path consists of four linear sites with the lengths of 300, 230, 113, and 176 m and with the inclination angles to the horizon of 30, 25, 25 and 18º, respectively. The conveyor path has two curvilinear sites with the radii of 180 and 360 m; it also consists of loading and unloading sites of 50 and 53 m, where belt is folded and unfolded. A line of linear sites consists of six roller supports with the distance of 1.5 m between them. The width and thickness of a conveyor belt is 2200 and 30 mm, respectively; the radius of a belt pipe is 0.3 m. Maximum tension on a drive drum is 255.7 t. Tensile strength of the belt is 9700 N/mm at the safety factor for strength being 8.3. A drive of the pipe conveyor with the general capacity of 6300 kW includes two drive drums with the capacities of 2×2100 kW and 2100 kW.

Since maximum rock lump, entering a steeply inclined conveyor, is 200-250 mm, the inclined conveyor may have lower velocity of a conveyor belt and lesser width.

3.2. Selecting a technological complex of the in-pit crushing and conveying technology

As a result of performed mining and geometrical analysis of a mine field, it is determined that the angles of the open pit wall inclination vary along its depth within a wide range: from 36° at the lower open pit levels to 18° at the upper ones. Taking into account the proposed rational scheme of the opening-up scheme for deep levels along with the technical capacities of IPCC system, the possibility of preparing the open pit wall is substantiated. It is provided that site I of the wall (Fig. 6) between the levels –135…–105 m with the angle of 36º is formed at the expense of rock mass re-excavation; that allows reducing the volume of rock mass extraction on site II (Fig. 6). In general, that will help reduce the conveyor path inclination to 30º.

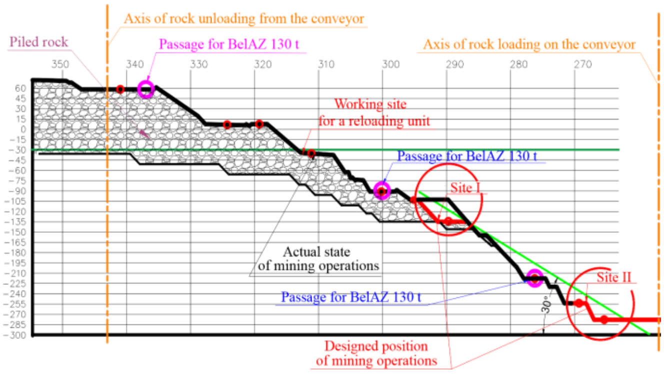

Figure 6. Sites of the open pit wall for preparing a conveyor path (axial conveyor section)

According to the early described new trend of improving the IPCC system and technical capabilities of a steeply inclined conveyors (SIC), it is proposed to divide the opening-up scheme at open pit #1 into two sites with a reloading point on the open pit wall involving different conveyor types on the overhead road (Fig. 6):

– on the lower site with the inclination angles of 30º and 25º with a steeply inclined pipe conveyor;

– on the upper site of the open pit wall with the inclination angles of 23º and 18º with a deep-trough conveyor.

This technological scheme cannot include a deep-trough conveyor in one line due to technological constraints: maximum inclination angle is 23º (critical angle is 25º); path length is not more than 500 m in terms of the required power.

3.3. Features of the formation of a crushing-reloading point while using a steeply inclined conveyor

It is planned that a crushing-conveying complex with a steeply inclined conveyor is to be constructed in the open form on the southern open pit wall. Grapho-analytical modelling was used to substantiate a rational technological scheme and a technological complex in general. The complex includes following objects (Fig. 7):

– a crushing-reloading point (CRP) at the level of –278 m is the stationary crushing-reloading equipment of primary rock mass crushing – crusher KKD-1500/180

(KKD-1500/180) of the NKMZ plant with the minimum size of a reloading slot or closed cycle for lumps more than 250 mm;

– a plate feeder at the level of –299 m that transports crushed rock mass from under the coarse crusher;

– a transferring conveyor at the level of –299 m that transfers rock mass to the place of its loading onto a steeply inclined conveyor;

– a steeply inclined pipe conveyor or the one with a pressure belt that transports crystalline rock from the CRP to a reloading unit #1 on the open pit wall;

– a reloading unit #1 (RU #1) where rock mass is reloaded from the steeply inclined pipe conveyor (or the one with a pressure belt) onto a deep-trough steeply inclined conveyor;

– a deep-trough steeply inclined conveyor that transports ore/overburden rock from RU #1 to a reloading unit #2 at the level of +58 m;

– reloading unit #2 at the level of +58 m where rock mass is reloaded from the main steeply inclined conveyor onto the mobile transferring conveyor on the overhead road. It is aimed for rock mass feeding and dividing into the ore and overburden stockpiles;

– a conveyor overhead road, on which a mobile transferring conveyor is installed for rock mass division into the ore and overburden stockpiles;

– an ore stockpile for storage and excavating loading into the railroad transport.

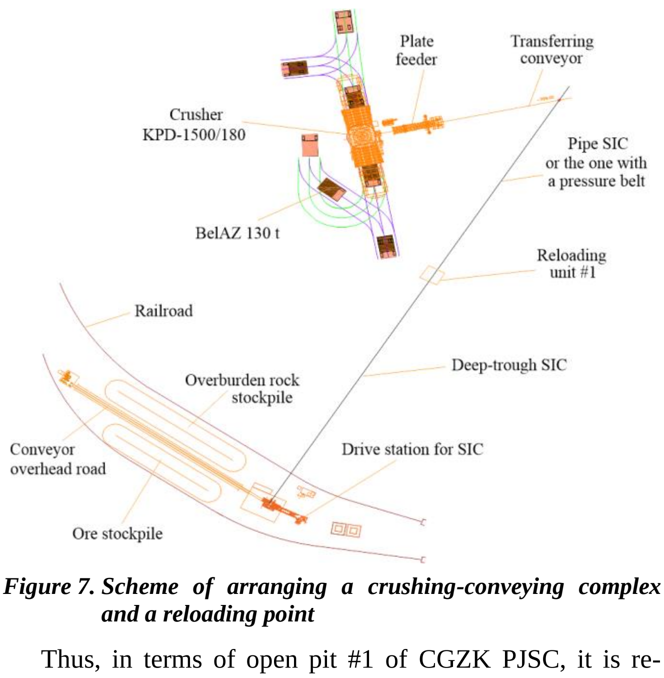

Figure 7. Scheme of arranging a crushing-conveying complex and a reloading point

Thus, in terms of open pit #1 of CGZK PJSC, it is recommended to use trenchless opening-up schemes with the conveying plant location on the overhead road. Schemes of deep level opening-up and technical capabilities of SIC have been substantiated. It is proposed to divide a conveyor line into two sites depending on the structure of the wall working zone: a steeply inclined pipe conveyor was used in bedrock within the lower site of the wall with the inclination angles of 30 and 25º; a deep-trough conveyor was applied along the internal dump body within the upper site with the elevation angles of 23 and 18º.

Despite the fact that the carried out work is of scientific and practical value, it is not over yet with the prospects for further development. Consequently, while analyzing specific conditions for using a technological complex of a cyclic-continuous technology within the range of a working wall of the complex-structure open pit, certain complications and drawbacks of a technological scheme were identified. Thus, there will be further scientific and experimental studies concerning the following:

– development of rational design of a reloading point from a steeply inclined to an inclined conveyor in terms of minimum height and metal-intensity of the structure;

– improvement of the surface of a conveyor belt of a steeply inclined conveyor for better adhesion with the rock mass and substantiation of a greater inclination angle of a conveyor;

– cooperation with a leading specialists of the machine-building plants as for the design of coarse mechanic crushers to obtain the regulated granulometric composition.

4. Conclusions

Improvement of the in-pit crushing and conveying technology for mining operations at Kryvbas open pits should be considered in terms of interconnected geological, technical, technological, and other factors. One of the main factors restraining the development of mining operations is the structure and parameters of the open pit working zones that requires implementation of innovative solutions as for rock mass transportation by the conveyors of new generation.

The technical and technological expediency of using inclined and steeply inclined conveyors for rock mass transportation has been substantiated. The efficiency of inclined and steeply inclined conveyors in one technological scheme has been proved; that allows considering structural features of the working zone of a deep open pit. In case of sites with minor wall inclination, it is recommended to use inclined conveyors or deep-trough conveyors; if wall inclination is up to 30º, steeply inclined conveyors should be selected. Currently, the world practice has no solutions like that.

The main trend in the mining industry is to reduce prime cost of the products by using cutting-edge mining technologies and innovative techniques. The in-pit crushing and conveying technology is still one of such trends; it helps increase ore output along with high rate of reduction of mining operations. Ore is going to be extracted at ever deepening open pit levels; therefore, widespread use of the IPCC technology with inclined and steeply inclined conveyors will make it possible to get end products with minimum costs.

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Особливості застосування обладнання циклічно-потокової технології видобутку руд на борту кар'єру складної будови

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Мета. Обгрунтувати застосування циклічно-потокової технології на кар'єрах зі складною будовою робочої зони, технологічний комплекс якої включає похилий та крутопохилий конвеєри для підвищення економічної ефективності видобутку корисних копалин на глибоких горизонтах.

Методика. В роботі використано комплексний метод, що містить техніко-економічний аналіз практики роботи гірничорудних підприємств, досвід використання обладнання конвеєрних установок на збагачувальних фабриках і в кар'єрах; гірничо-геометричний аналіз за поперечними розрізами кар'єру – для виявлення будови робочої зони борту глибокого кар'єру та його особливостей за глибиною; конструкторські проробки – для вдосконалення конструкції крутопохилого конвеєра; імітаційне моделювання технологічних процесів – для вибору оптимальних технічних рішень.

Результати. На основі проведених досліджень встановлено, що перспективним є перехід на новий напрямок циклічно-потокової технології, що враховує особливості будови робочої зони глибокого кар'єру. При цьому на борту кар'єру на ділянках з нахилом борту 10-18° доцільно застосовувати похилі конвеєри або глибоко жолобчастості, а на ділянках з нахилом борту 30-36° – крутопохилі.

Наукова новизна. Вперше встановлено взаємозв'язок між будовою робочої зони глибокого кар'єру та формуванням структури технологічних комплексів. Встановлені залежності граничного кута нахилу α_n трубчастого конвеєра від кута незаповнення θ його стрічки вантажем при різних коефіцієнтах тертя вантажу об стрічку.

Практична значимість. Отримані результати дозволяють розширити сферу застосування та підвищити ефективність видобутку корисних копалин із застосуванням циклічно-потокової технології.

Ключові слова: *кар'єр, руда, видобуток, комплекс, циклічно-потокова технологія, конвеєр*