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OPTIMIZATION OF PULLING PART OF THE MAGISTRAL CONVEYER'S STRUCTURAL SCHEMES

Abstract. In this article,the work was carried out to find the optimal conveyor schemes which are necessary to successfully solve the pipelining problem when transporting rock cargo to the deep quarry. Analysis of ways to increase the conveyor length by varying independent variables has shown that the construction of the pipeline scheme is characterized only by those ways of increasing the length of the conveyors that determine the mechanical structure of their traction body and, consequently, the behavior of the latter under static and dynamic loads. The optimal algorithm was established for constructing the structural diagrams of the traction organ of the main conveyors. Theoretical grounds are given for the creation of new means of continuous transport, which ensure the continuous conveyance of technological chains for the extraction of minerals, the issuance and laying of overburden in the dump. Analysis and synthesis of structural schemes of "uninterrupted" conveyors was held. Synthesis of the structural schemes of these conveyors is carried out by a mathematical operation – the operation of adding the strength indicators of the traction organs used. Two classes of pipelines, fundamentally different from each other, were considered: a BC with parallel autonomous circuits and a BMC. The introduction of vertical and steeply sloped conveyors as a trench transport is a promising direction in the field of conveyorization of the mining industry and a reduction in the cost of mining.

Key words: magistral conveyer, optimization of structural schemes, conveyers' classification, autonomic pulling part, multigear conveyer.

Preconditions for the exploration and creation of fundamentally new, promising structures of traction bodies of conveyors. The technological designation of any conveyor, including conveyors with traction body (TB), – this is the movement of the cargo over a distance, so the main technological parameter of the conveyors is their length. At the same time, the maximum permissible length of the conveyor, limited by the strength of the TB, under the same operating conditions and the same TB depends on the perfection of the method of transporting the goods accepted on the given conveyor, i.e., on the value of the drag resistance coefficient ω'. For example, a downhole belt conveyor with a lower working line moving directly along the soil of the formation and drifting with a working branch moving along rollers of stationary roller bearings with belts of the same size, or scraper and belt-chain conveyors with traction chains of the same size for the same values of the linear load and the installation angle allow for different lengths with the same strength of the TB. n this regard, the maximum permissible length of the conveyor is still an indicator of the quality (perfection) of the conveyor's structural scheme, determined by the principle that "the larger the maximum permissible conveyor length, other things being equal, the better its scheme corresponds to the continuity and continuity of the cargo flow, and consequently, a reduction in the number of mechanisms in the transport line, i.e., the continuity of the transport scheme. Obviously, the introduction of a continuous transport scheme for moving the rock mass over long distances along complex curvilinear routes is one of the promising areas of work to improve the efficiency of production at mining enterprises.

To solve the set tasks, it is necessary to create new means of continuous transport, which ensure the continuous conveyance of technological chains for the extraction of minerals, the issuance and laying of overburden in the dump. The high economic efficiency of new means of transport should be determined by the reduction in the volume of mining and capital works when digging inclined transport workings (tranches), reducing the number of transport vehicles as a result of increasing their unit capacity, combining the delivery of basic and auxiliary cargo.

In this regard, for the successful solution of the problem of conveyorization of transportation of rocky cargoes at quarries, it is expedient to search for and develop the simplest schemes of conveyors, and first of all single-drive ones, which for each specific case of given operating conditions (for given values of productivity, transportation distance, curvilinearness of the route plan and profile, etc.) would be the most rational [1–18].

Obviously, such a problem can be solved if regularities in constructing the TB structure of the pipeline are established [5…18]. Then, using these patterns and developing them in the desired direction, it will be possible to create pipelines with pre-predicted properties.

To determine the rational schemes of special conveyors that transport rock and substantiate their basic parameters, all general and special purpose conveyors should be classified according to a single system. And the classification should be carried out according to the most common feature that reveals the main internal connections (mechanical structure) of the TB pipeline structural diagram [19]. This will allow us to find promising ways for the development of internal links, hence, the schemes of conveyors. At the same time, such connections can be found that will limit the sliding and rolling of cargo along TB, improve the cleaning conditions of the bearing surface from the adhered material, ensure maximum use of traction elements in strength, etc.

Having a technological task – increasing the range of uninterrupted transportation of rock cargo by conveyors, the main attribute of classification can be determined from the analysis of factors affecting the main technological parameter of conveyors – length.

The length of a straight conveyor, for example, is defined by

$$\frac{P_{РАЗ}}{n} - S_{сб} = Lq_C\left(\omega' \cos\beta \pm \sin\beta\right)g, \tag{1}$$

where $P_{РАЗ}$ – breaking force of the traction body, H; n – coefficient of safety factor of TB; $S_{сб}$ – force at the point of escape from the drive, H; q_C – total linear mass of moving parts of conveyor and cargo, kg/m; ω' – drag coefficient; β – angle of conveyor installation, grad. ; g – acceleration of gravity, m/s^2.

Решение равенства (1) относительно длины конвейера L дает

$$L = \frac{\dfrac{P_{РАЗ}}{n} - S_{сб}}{q_C\left(\omega' \cos\beta \pm \sin\beta\right)g} \, м.$$

Therefore, under certain operating conditions (given capacity and angle of inclination), the maximum permissible length of the conveyor from (1) is a function of three independent variables (rupture strength, safety factor, and drag coefficient). The force on the length of the conveyor L is not affected, since it is defined as the minimum permissible because of the reliable interaction of the TB with the conveyor drive. We assume that g_c=const (the weight of the load-bearing body of the TO is distributed evenly)

Analysis of ways to increase the length of the conveyor by the variation of these independent variables shows that the construction of the pipeline scheme is characterized only by those ways of increasing the length of the conveyors that determine the mechanical structure of their TB and, consequently, the behavior of the latter under static and dynamic loads. In this regard, in order to determine the optimal algorithm for constructing pipelining schemes, it is necessary to study the static and dynamic properties of TB, and then, having formulated the most common property of them as a mathematical problem, solve it for the optimum and establish the main feature of the classification of conveyors.

The optimal algorithm for constructing pipeline diagrams. Studies of domestic and foreign scientists [5] show that the static and dynamic properties of traction organs of all types of trunk pipelines are almost identical and allow us to draw the following conclusions:

– the magnitude of deformation of chain and cable TB, as well as conveyor belts on a fabric basis, in the absence of transverse loading on them, is directly proportional to the value of the applied tension;

– in the presence of transverse loads in chain TO and conveyor belts on a fabric basis, the dependence of the relative elongation on the tension value has a parabolic shape, and the conditional stiffness can be represented in a differential form;

– from the analysis of the characteristics of conveyor belts and chain traction organs and their comparison with the characteristics of cable TB, it can be assumed that the dependence of the relative elongation of the rope TB on the magnitude of its tension in the presence of a transverse load will also be determined by a curve of the second

Thus, TB long (main) conveyors are an elastic element, which under the action of the difference in forces at the ends is deformed. Absolute extension of TB within the length of the section under consideration:

$$\Delta L = \int_0^L \varepsilon dx,$$

where ε – relative extension (TB); x – distance from the drive to the considered section of the TB.

In most cases, TB of long conveyors, when in contact with or at the same time as a carrier, perceive the transverse load distributed along the length of the conveyor and sag between the running or fixed rollers. Such TBs do not obey Hooke's law, and their conditional rigidity as a coefficient of proportionality between the acting force S and the relative elongation (along the longitudinal axis) of TB is defined as E(S) = dS/dε.

Using the property of the invariance of differentials, these conditions can be written as a system of differential equations::

$$\left.\begin{aligned} &\frac{d\Delta L}{dt} = a\varepsilon; \\ &\frac{dS}{dt} = E(S)\frac{d\varepsilon}{dt}; \\ &dx = adt, \end{aligned}\right\} \tag{2}$$

where a = const - elastic wave propagation velocity, m/s; t - current time, s.

We solve the system of equations (2) to the optimum, using the Pontryagin "maximum principle".

Having assumed the rate of change of deformation for the control action and introducing the phase coordinates $x_1 = \Delta L; x_2 = \varepsilon; x_3 = S$ phase space X, we obtain a system of differential equations in phase coordinates:

$$\left.\begin{aligned} &\frac{dx_1}{dt} = ax_2; \\ &\frac{dx_2}{dt} = U; \\ &\frac{dx_3}{dt} = EU; \end{aligned}\right\}$$

Considering that TB can not be subjected to unlimited deformation, we introduce an effort constraint:

$$S \leq [S]. \tag{3}$$

Then the problem of optimal control can be mathematically formulated as follows: it is required to find the optimal control algorithm according to which the phase point will move from the position x_1, x_2, x_3 in the x_{11}, x_{21}, x_{31} for the minimum time.

For the case under consideration the Hamiltonian function:

$$H = \psi_1 x_2 a + \psi_2 U + \psi_3 E(S)U,$$

where ψ_1, ψ_2, ψ_3 – auxiliary variables, for the determination of which there is a system of equations:

$$\left.\begin{aligned} \frac{d\psi_1}{dt} &= -\frac{\partial H}{dx_1}; \\ \frac{d\psi_2}{dt} &= -\frac{\partial H}{dx_2}; \\ \frac{d\psi_3}{dt} &= -\frac{\partial H}{dx_3}. \end{aligned}\right\}$$

Differentiating, we obtain the following system of equations:

$$\left.\begin{aligned} \frac{d\psi_1}{dt} &= 0; \\ \frac{d\psi_2}{dt} &= -\psi_1 a; \\ \frac{d\psi_3}{dt} &= 0, \end{aligned}\right\}$$

which is satisfied by functions of the form

$$\left.\begin{aligned} \psi_1(t) &= C_1; \\ \psi_2(t) &= C_2 - C_1 at; \\ \psi_3(t) &= -C_3, \end{aligned}\right\}$$

where C_1, C_2, C_3 – constants of integration.

The function H will be maximal with respect to U provided

$$\frac{dH}{dU} = \psi_1 + \psi_3 E(\mathrm{S}) = 0. \tag{4}$$

Then, substituting the values $\psi_2(t)$ and $\psi_3(t)$ the equation (4), we find $C_3 E(S) = C_2 - C_1 at$, whence

$$E(S) = \frac{C_2 - C_1 at}{C_3}. \tag{5}$$

It can be concluded from equation (5) that the longitudinal stability E (S) of a linearly decreasing law on the length of the working body.

Having adopted the notation $\beta_1 = \frac{C_2}{C_3}; \beta_2 = \frac{C_1}{C_3}$ we have:

$$E(S) = \beta_1 - \beta_2 x. \tag{6}$$

Substituting the value of E (S) in condition (2), we determine from (6) that

$$U(t) = \frac{\frac{dS}{dt}}{\beta_1 - \beta_2 x}. \tag{7}$$

This is the optimal law of change in the rate of deformation in (TB) pipelines.

However, as follows from condition (2), in order to obtain the optimal control algorithm in each specific case it is necessary to know the law of the distribution of forces in the TB along its length. For example, for a straight section of the conveyor, when the stiffness and mass of the load-bearing organ are evenly distributed along the length, we can take the linear force distribution law:

$$S = \left[S^p_{\max}\right] + \frac{x}{L}\left(\left[S^p_{\max}\right] - \left[S^p_{\min}\right]\right),$$

where $\left[S_{\min}^{p}\right]$ и $\left[S_{\max}^{p}\right]$ – расчетные значения соответственно минимально и максимально допустимых статических усилий на ТВ, N. Then

$$U(t)=\frac{\left[S_{\max}^{p}\right]-\left[S_{\min}^{p}\right]}{t_{пр}(\beta_1-\beta_2 x)}$$

where $t_{пр}$ = L/a – the time of passage of the elastic wave along the section, s.

Maximum permissible static force on TB

$$\left[S_{\max}^{p}\right]=[S]=\frac{P_{раз}}{n},$$

where $P_{раз}$ – breaking force of TB, N; n – safety factor.

For the case under consideration, when cargo is transported over long distances along complex, curved lines, the total resistance to movement of the entire conveyor line

$$W_0 >> [S], \tag{8}$$

therefore, to overcome it, the required strength of the TO is created by summing up their permissible static forces, which is achieved by some complication of the structural scheme of the conveyors:

$$\sum_{i=1}^{m_j}[S]\geq W_0+m_j S_{сб}, \tag{9}$$

where m_j – the total number of terms (constituent units) when tying the required static strength of the TB [19].

The foregoing allows us to conclude that the desired conveyors have a complex constructive scheme, and the necessary static strength of their TB is created by synthesis (summation) of the permissible static forces of the used TB [20–22].

Synthesis methods and terminology of an uninterrupted conveyor. Suppose that the transportation of goods is carried out under specified operating conditions (productivity, transportation range, plan and profile of the route, etc.).

Indeed, condition (9) can be realized in the following ways: using in-line m_1 single-drive conveyors with single TB; one conveyor with autonomous parallel TB; One conveyor with a single TB and with m_3 drives sequentially arranged along the contour of the conveyor.

Here, single TBs mean not only those that consist of a single chain, one rope, a single synthetic or steel strip, that is, one element, but also consisting of a set of parallel elements having a direct mechanical connection (multi-packing and rubber-rubber tapes, multi-chain and multichannel TB with a mechanical link between the elements through common end sprockets and drums), but serviced by a single drive.

Stand-alone TBs have separate drives. Constituent units:

m_1 – conveyors, m_2 – TB, m_3 – actuators.

In connection with this, equality (9), which is the general formula of the desired conveyor, can be represented in the following form:

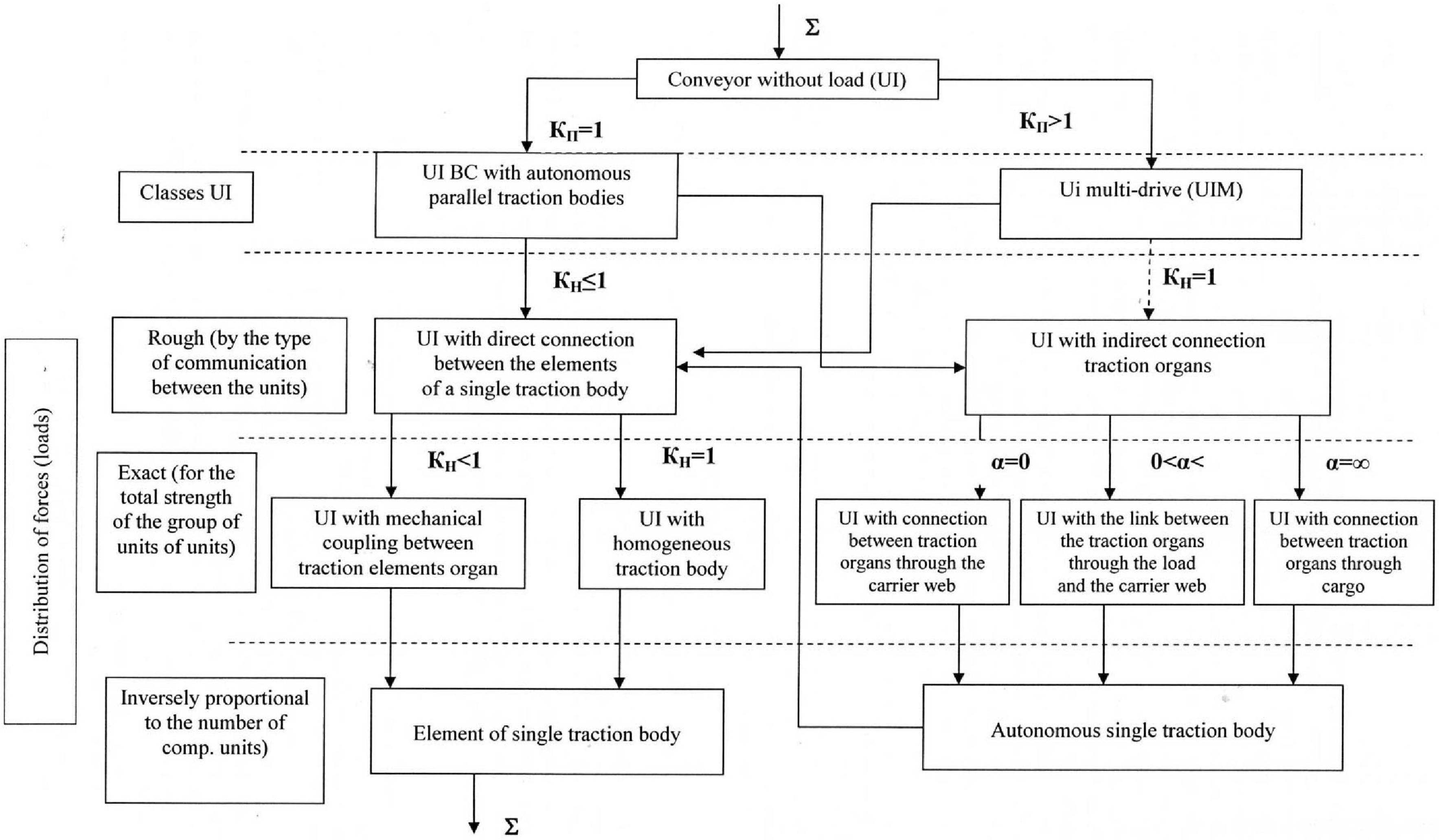
$$\sum_{i=1}^{m_j}[S]=\sum_{i=1}^{m_j}\left(\frac{W_0}{m_1}+S_{сб}\right)=\sum_{i=1}^{m_j}\left[\frac{W_0}{m_2}+S_{сб}\right)K_H=\sum_{i=1}^{m_j}\left(\frac{W_0 К_{пер}}{m_3}+S_{сб}\right)\frac{1}{К_п}$$

where $К_п$ – traction organ overload factor; $К_Н$ – coefficient of uneven load distribution between secondary elements.

Having transformed this equation, we have $m_1=m_2 K_H=\frac{m_3}{К_п}$ whence

$$m_3=К_п m_2 K_H.$$

Obviously, a single-drive single-unit conveyor (TB) is a special case (where m_2= 1) conveyor with autonomous parallel (TB), so the desired conveyors, according to the formulation of the problem



Analysis and synthesis of UI structural diagrams conditionally called "uninterrupted" (UI), synthesized as UI with autonomous parallel (TO) (1st class) and UI multi-drive (UIM, 2nd class).

Indeed, for a UI with autonomous parallel TBs, the total permissible static forces are determined, according to condition (9), as

$$\sum_{i=1}^{m_1}[S]=\sum_{i=1}^{m_2}[S]=m_2\frac{P_{раз}}{\mathrm{n}}, \qquad (10)$$

Whereas for UIM they should be reduced in connection with the redistribution of the total load of the conveyor between its drives, i.e.

$$\sum_{i=1}^{m_1}[S]=\sum_{i=1}^{m_3}[S]'=m_3\frac{P_{раз}}{\mathrm{nK_п}}, \qquad (11)$$

TB overload factor with partial or partial loading of the conveyor

$$\mathrm{K_п}=\frac{\mathrm{S_{max}}}{\mathrm{W_{гр}}+\mathrm{S_{сб}}}>1,$$

where $\mathrm{S_{max}}$ – The maximum force in TB, taking into account the transfer of load of the conveyor between its drives; $\mathrm{W_{гр}}$ – resistance to movement of a section with a nominal load; $\mathrm{S_{сб}}$ – the tension at the run-off point from the drive at rated load.

Coefficient $\mathrm{K_п}$ is determined for the most unfavorable case of loading the conveyor and depends on the number of its drives [20–22]. Consequently, under equal operating conditions, the use of the UI is associated with the need for equipping it with a large number of intermediate drives, rather than UIM with parallel autonomous circuits – the number of autonomous circuits, i.e.,$m_3 > m_2$, which is a definite advantage of the TB structural diagram of the latter.

Analysis and synthesis of UI structural diagrams (Figure) allows us to draw the following conclusions:

– synthesis of structural schemes UI is carried out by mathematical operation - operation of addition of strength indicators of traction organs used;

– there are two classes of UI, which are fundamentally different from each other: UI with parallel autonomous circuits and UIM;

– the difference in the distribution of forces in the traction organs of the main classes of conveyors is that for UI with parallel autonomous circuits the overload factor $\mathrm{K_п}= 1$, and for UIM $K_n > 1$;

– regularity of the distribution of forces in TB UI at the first level of classification - a rough gradation of the uneven distribution of forces in parallel branches: for a BC with a direct connection between the elements of a single traction body (I group) $K_н \leq 1$, and for UI with an indirect link between parallel traction bodies (II group) $K_H = 1$; at the second level of classification - the gradual gradation of the uneven distribution of effort: for UI of the I group – by the coefficient of unevenness K_H, and for UI of the П group – by the coefficient of distribution of the total load of the conveyor λ; at the third level of classification, an inverse proportion of the effort: for conveyors of group I – of the number of elements of a single TB z, and for conveyors of group II – from the number of autonomous individual TBs m_2, than the cycles are closed and return to the starting position: for group I – up to the static strength of the elements of a single TB, and for II – up to the static strength of autonomous unitary maintenance;

– the structural diagrams of UI represent a closed circle of circulation of forces: for pipelines of group I there is a small circle, and for II, a large circle, the latter including all the components of a small circle

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МАГИСТРАЛЬДЫ КОНВЕЙЕРЛЕРДІҢ ТАРТУШЫ ОРГАНЫНЫҢ ҚҰРЫЛЫМДЫҚ СЫЗБАСЫН ОҢТАЙЛАНДЫРУ

Аннотация. Осы мақалада тау жыныстарын терең карьерге тасымалдау кезінде конвейерлеу мәселесін табысты шешуге қажетті оңтайлы конвейерлік сызбаларды табу бойынша жұмыс жүргізілді. Конвейер ұзындығын тәуелсіз айнымалылардың көмегімен ұлғайту жолымен талдау көрсеткендей, құбыр схемасының құрылысы тек өздерінің тартқыш денесінің механикалық құрылымын анықтайтын конвейерлердің ұзақтығын ұлғайту жолымен және, тиісінше, статикалық және динамикалық жүктемелердің мінез-құлқымен сипатталады. Магистральды конвейерлердің тартқыш органының құрылымдық сызбаларын құру үшін оңтайлы алгоритм құрылды. Тау-кен жұмыстарының технологиялық тізбектерін үздіксіз конвейерлеуді, төгінділерді шығаруды және төгуді қамтамасыз ететін үздіксіз көліктің жаңа құралдарын құрудың теориялық негіздері келтірілген. «Үздіксіз» конвейерлердің құрылымдық сызбаларын талдау және синтездеу жүргізілді. Осы құбырлар құрылымдық схемаларын синтездеу математикалық операциямен жүзеге асырылады – қолданылатын тартқыш органдардың күш көрсеткіштерін қосу операциясы. Құбырлардың бір-бірінен түбегейлі ерекшеленетін құбырларының екі классы қарастырылған: параллель автономдық схемалары бар БК және ВМС. Траншеялық көлік ретінде тік және тегіс көлбеу транспортерлерді енгізу тау-кен өнеркәсібі құбырлары саласында перспективалық бағыт болып табылады және тау-кен жұмыстарының құнын төмендету болып табылады.

Түйін сөздер: магистралды конвейер, құрылымдық сызбаларды оңтайландыру, конвейерлерді жіктеу, автономды тартушы орган, көпжетекті конвейер.

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ОПТИМИЗАЦИЯ СТРУКТУРНЫХ СХЕМ ТЯГОВОГО ОРГАНА МАГИСТРАЛЬНЫХ КОНВЕЙЕРОВ

Аннотация. В статье проведена работа по поиску оптимальных схем конвейера, необходимых для успешного решения проблемы конвейеризации при транспортировании скальных грузов на борт глубокого карьера. Анализ способов увеличения длины конвейера вариацией независимых переменных величин показал, что построение схемы конвейеров характеризуется только теми способами увеличения длины конвейеров, которые определяют механическое строение их тягового органа и, следовательно, поведением последних при статических и динамических нагружениях. Установлен оптимальный алгоритм для построения структурных схем тягового органа магистральных конвейеров. Даны теоритические основания для создания новых средств непрерывного транспорта, обеспечивающих сплошную конвейеризацию технологических цепочек добычи полезных ископаемых, выдачи и укладки вскрышных пород в отвал. Проведен анализ и синтез структурных схем «бесперегрузочных» конвейеров. Синтез структурных схем данных конвейеров осуществляется математической операцией – операцией сложения прочностных показателей используемых тяговых органов. Рассматривались два класса конвейеров, принципиально отличающихся друг от друга: БК с параллельными автономными контурами и БМК. Внедрение в качестве траншейного транспорта вертикальных и крутонаклонных конвейеров является перспективным направлением в области конвейеризации горно-добывающей промышленности и снижение себестоимости добычи полезных ископаемых.

Ключевые слова: магистральный конвейер, оптимизация структурных схем, классификация конвейеров, автономный тяговый орган, многоприводный конвейер.