ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

№1
2026

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

1 (475)

JANUARY – FEBRUARY 2026

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2026

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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Communications of the Republic of Kazakhstan № KZ50VPY00121155, issued on 05.06.2025
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).

Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген № KZ50VPY00121155 мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*

Мерзімділігі: жылына 6 рет.

http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Собственник: ТОО «Центрально-Азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и коммуникаций и Республики Казахстан № KZ50VPY00121155, выданное 05.06.2025 г.
Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*
Периодичность: 6 раз в год.
http://www.geolog-technical.kz/index.php/en/

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NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 1.
Number 475 (2026), 55–73

https://doi.org/10.32014/2026.2518-170X.590

IRSTI 52.13.17
UDC [622.2/.8.002.5:539.3]:005.2

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JUSTIFICATION OF PARAMETERS OF A STEEPLY INCLINED TUBULAR CONVEYOR OF CYCLIC-FLOW TECHNOLOGY AT A DEEP OPEN PIT IN KRYVBAS

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Abstract. In the mining industry, transporting rock overburden and ores from deep and medium-depth open pit horizons to the surface is a critical challenge. The most efficient solution is the use of cyclic flow technology (CFT) with steeply inclined conveyors (SIC). This paper justifies the application of a steeply inclined tubular conveyor at the Gleivatsky open pit of PJSC 'Central Mining and Processing Plant', Ukraine, detailing the design and calculation of key structural parameters across all conveyor sections. Key technical dependencies—such as belt speed, belt width, roller support pitch, and space filling—are related to mining and geological characteristics of the rock mass (including maximum piece size and strength) and conveying parameters (angle, height of ascent, and route length). The belt tension at critical points of the conveyor contour is calculated, along with drive and tensioning station parameters. For a specified conveyor route with defined lengths and inclined angles, a tubular conveyor design with a 3000tonnes/hour capacity is proposed. The conveyor's total lifting height is 370meters. The drive system is a two-drum tandem with a belt girth angle of 430°, and power of 6300kW. The belt used is a 2200mm wide rubber rope conveyor belt. The conveyor bed section design includes 8 roller supports, each with 6 rollers; the section measures 12,000mm in length, 1300mm in width, and 2200mm in height. The practical significance lies in the validated application of steeply inclined tubular conveyors alongside quarry faces in cyclic-flow technology, enabling efficient transport between deep mining horizons and the surface.

Keywords: deep open pit, conveyor parameters, roller supports, conveyor belt, drive

For citations: *Babii K., Kiriia R., Smirnov A., Kuttybayev A., Mishchenko T. Justification of Parameters of a Steeply Inclined Tubular Conveyor of Cyclic-Flow Technology at a Deep Open Pit in Kryvbas. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. 2026. No.1. Pp. 55–73. DOI:https://doi.org/10.32014/2026.2518-170X.590*

©Бабий К.[1], Кирия Р.[1], Смирнов А.[1*], Құттыбаев А.[2], Мищенко Т.[1], 2026.

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КРИВБАССТЫҢ ТЕРЕҢ КАРЬЕРІНДЕГІ ЦИКЛДІК АҒЫНДЫ ТЕХНОЛОГИЯНЫҢ КҮРТ ҚҰЛАМА ТІК БҰРЫШТЫ ҚҰБЫРЛЫ КОНВЕЙЕРІНІҢ ПАРАМЕТРЛЕРІН НЕГІЗДЕУ

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Аннотация. Тау-кен өнеркәсібінде терең және орташа тереңдіктегі карьерлерде тау жыныстары мен руданы жер бетіне тасымалдау мәселесі ерекше өзекті болып табылады. Бұл мәселені шешудің ең тиімді жолдарының бірі – циклдік-ағымдық технологияны (ЦАТ) қатты еңісті конвейерлермен (ҚЕК) үйлестіре қолдану. Осыған байланысты жұмыста Украинадағы «ЦГОК» АҚ-ның Глееватский карьері жағдайында қатты еңісті түтіктік конвейерді қолданудың техникалық-экономикалық негіздемесі жасалды. Конвейердің барлық тасымалдау учаскелері үшін конструкциялық шешімдер таңдалып, негізгі конструктивтік параметрлері есептелді. Тау-кен-геологиялық параметрлерге (кесек жыныстың максималды өлшемі, жыныстың беріктік қасиеттері) және тасымалдаудың технологиялық параметрлеріне (көтеру бұрышы мен биіктігі, трасса ұзындығы) байланысты конвейердің негізгі техникалық сипаттамалары арасындағы тәуелділіктер анықталды. Атап айтқанда, лента жылдамдығы, лента ені, ролик тіректерінің арақашықтығы және жүктің толу коэффициенті есептелді. Түтіктік конвейер контурының негізгі нүктелерінде лентаның тартылу кернеулері анықталып, жетек және тарту станцияларының параметрлері негізделді. Белгілі бір ұзындық пен еңістікке ие конвейер трассасы үшін сағатына 3000 тонна өнім тасымалдауға арналған түтіктік конвейердің конструкциясы ұсынылды. Конвейердің жалпы көтерілу биіктігі 370 м құрайды. Жетек екі барабанды (тандем-жетек) болып табылады, ал лентаның жалпақ оралу бұрышы 430°-қа тең. Жетек қуаты 6300 кВт. Қолданылатын лента түрі – резина-арқанды конвейерлік лента, ені 2200 мм. Бастапқы технологиялық талаптарға сәйкес конвейерлік тірек секциясының конструкциясы қабылданды: ол 8 ролик тірегінен тұрады, әрбір тірек 6 роликпен жабдықталған. Секцияның ұзындығы 12 000 мм, ені 1300 мм, биіктігі 2200 мм. Жұмыстың практикалық маңызы циклдік-ағымдық технология шеңберінде карьердің шеткі аймағында ашық орналастырылатын қатты еңісті түтіктік конвейерлерді қолдануды негіздеуде жатыр. Бұл тәсіл терең карьерлердегі өндіру горизонттарын жер бетімен тиімді әрі үздіксіз жүк тасымалдау жүйесімен қамтамасыз етуге мүмкіндік береді.

Түйінді сөздер: терең карьер, конвейер параметрлері, ролик тіректері, конвейерлік лента, жетек

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ОБОСНОВАНИЕ ПАРАМЕТРОВ КРУТОНАКЛОННОГО ТРУБЧАТОГО КОНВЕЙЕРА ЦИКЛИЧНО-ПОТОЧНОЙ ТЕХНОЛОГИИ НА ГЛУБОКОМ КАРЬЕРЕ КРИВБАССА

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Аннотация. Для горной промышленности особенно актуальна проблема транспортирования скальных вскрышных пород и руд из глубоких и средних по глубине горизонтов карьеров на поверхность. Наиболее рациональным решением является применение циклично-поточной технологии (ЦПТ) с крутонаклонными конвейерами (КНК). В связи с этим в работе выполнено обоснование применения крутонаклонного трубчатого конвейера для условий Глееватского карьера ЧАО «ЦГОК» (Украина), проведён выбор конструкции и выполнен расчёт основных конструктивных параметров конвейера на всех участках транспортирования. Установлены зависимости технических параметров (скорости ленты, ширины ленты, шага роликоопор, степени заполнения транспортируемым материалом) от горно-геологических характеристик горной массы (крупности максимального куска, крепости пород) и технологических параметров транспортирования (угла и высоты подъёма, длины трассы). Определены натяжения ленты в основных точках контура трубчатого конвейера, а также рассчитаны параметры приводной и натяжной станций. Для конвейерной трассы с заданными длинами и углами наклонных участков предложена конструкция трубчатого конвейера производительностью 3000 т/ч. Общая высота подъёма составляет 370 м. Привод - двухбарабанный (тандем-привод) с суммарным углом обхвата лентой 430°. Мощность привода - 6300 кВт. Тип ленты: резинотросовая конвейерная лента шириной 2200 мм. По исходным технологическим условиям принята конструкция секции конвейерного става, включающая 8 роликоопор, каждая из которых состоит из 6 роликов. Длина секции става составляет 12 000 мм, ширина - 1300 мм, высота - 2200 мм. Практическое значение работы заключается в обосновании применения крутонаклонных трубчатых конвейеров с открытым расположением по борту карьера в циклично-поточной технологии, что обеспечивает эффективную грузотранспортную связь добычных горизонтов с поверхностью в глубоких карьерах

Ключевые слова: глубокий карьер, параметры конвейера, роликоопоры, конвейерная лента, привод

Introduction. One of the main tasks of open-pit mining of ores in the Kryvbas, which determines its prospects and economic efficiency, is the development of efficient technologies of excavation, transport and dumping of crystalline rocks. In the world practice cyclic, flow and cyclic-flow technologies are widely used (Isakov et al., 2021). However, there are a number of problems in the application of each of them. Cyclic technology is based on the transportation of rock mass by railway and road transport, which have very high operating costs (Annakulov et al., 2023). Flow technology is used for shallow open pits with insignificant productivity, while for deep horizons of open pits requires a high degree of automation of technological processes and application of, at least, artificial intelligence. This is the technology of the future. Cyclic-flow technology in its classical version has an angle of inclination of the conveyor route no more than 16 degrees, which blocks the non-working side of the pit and the movement of the working side of the pit (Rakishev et al., 2014). Thus, the issue of improving technological solutions for transporting rock mass from deep horizons of the open pit remains relevant, as it significantly affects the efficiency of ore extraction from deep horizons (Babii et al., 2022; Zhang et al., 2010).

Literary review. The modern direction of solution of the set problem is application of steeply inclined conveyors in the technological scheme of mining and transporting of rock mass, therefore the most rational solution is application of cyclic flow technology (CFT) in complex with steeply inclined conveyors (SIC) (Babii, 2022), as it gives an opportunity to transport overburden rocks and ores from deep and middle depths of the open pit horizons to the ground surface.

In IGTM named after N.S. Polyakov of the National Academy of Sciences of Ukraine the scientific and technical justification of the application of steeply inclined tubular conveyor for the conditions of Gleivatsky open pit of PJSC ‘Central Mining and Processing Plant’ was performed and design study of its parameters was carried out (Kiriia et al., 2024).

As the depth of the open pit increases and the overall angle of inclination increases, the mining and technological situation of mining operations becomes more complicated (Bubnova, 2024; Zhumagulov et al., 2022). Transport support of stripping and mining operations becomes especially important due to problems with the use of road transport. In this connection the substantiation of application of steeply inclined tubular conveyor for conditions of Gleevatsky open pit of PJSC ‘Central Mining and Processing Plant’ provides: analysis and comparison of designs of steeply inclined conveyors with a pressure belt and tubular conveyor; selection of design and calculation of basic design parameters of steeply inclined tubular conveyor on all sections of conveying; calculation of loads of loaded conveyor framework on the support bridge, created for passing of motor transport, and determination of its parameters.

The design of the steeply inclined conveyor depends on the angle of lift of ore and rock overburden by the conveyor, which can be up to 30-35 degrees. Operability of inclined and steeply inclined conveyors is also determined by the particle size distribution of the rock mass, which should be such that at a given design of the steeply inclined conveyor the stable condition of the belt and load is preserved (Gao et al., 2024), there is no rolling of pieces and slippage of the belt, tight clamping of pieces by the belt.

In works (Annakulov et al., 2023; Kiriia et al., 2024) the steeply inclined belt conveyors used in the world practice were analysed. The closest analogues in terms of mineral density and lifting height to the conditions of Kryvbas deposits development are the conditions of copper ore mining, for example, the application of a steeply inclined conveyor at the Majdanpek deposit (Serbia) (Pysmennyi et al., 2022) and at the Muruntau open pit (Uzbekistan) (Xayitov et al., 2022).

In (Galkin, 2008) a comparative characteristic of technical and technological features of conveyors with a pressure belt and tubular conveyor is given. The comparative analysis of the limiting angles of inclination of the tubular conveyor and the conveyor with a pressure belt showed that at the same basic parameters of the conveyor the limiting angle of inclination of the conveyor with a pressure belt is only 5-10 degrees higher than the limiting angle of inclination of the tubular conveyor, but at the same time the cost and design complexity of the conveyor with a pressure belt is higher than that of the tubular conveyor.

Application of SIC with a pressure belt for large lump rocks of the Krivoy Rog basin has certain difficulties (Babii et al., 2022; Kiriia et al., 2024):

1) when transporting lumps of 0-400 mm in diameter on the conveyor with a pressure belt there is loose adherence of the belt to the load, which leads to spillage of the load on the idle branch of the conveyor;

2) due to the difference in speeds of the main and pressure belt during the operation of the conveyor there is slippage of the belt, and since the rocks are abrasive, it leads to rapid wear of the pressure belt;

3) insufficiently investigated modes in the design at the transition of the conveyor to the steeply inclined part, there is no adherence of the belt to the rock, resulting in their spillage;

4) complex and voluminous metal construction for maintenance and operation of the pressure belt;

5) when using SIC for ore extraction during pit reclamation, the service life of mining ledges is short-term and capital expenditures on SIC construction do not have time to pay off.

Therefore, the next stage of research and design work in Ukraine and in the world is timed to tubular conveyors, which have a wider range of parameters and exclude the pressure belt.

Thus, the purpose of this work is to substantiate the main technical parameters of the steeply inclined tubular conveyor in the conditions of application of CFT in ore mining at deep open pits on the example of Gleevatsky open pit of PJSC ‘Central Mining and Processing Plant’.

The main parameters of currently operated tubular conveyors are in the range:

– conveyor length - from 200 m to 19100 m;
– inclination angle - from 0 to 30º;
– belt speed - from 2 m/s to 7 m/s;
– productivity - from 300 t/h to 8650 t/h;
– belt width - from 1200 mm to 3000 mm;
– maximum lump size - from 0.1 m to 0.33 m;
– power - from 1000 kW to 3300 kW.

The advantages of tubular belt conveyors include;
– possibility to transport cargo along curvilinear sections of the route;
– angle of inclination up to 30° equal to the resulting angle of the quarry face;
– absence of harmful impact on the environment;
– reduction in the number of transshipment points and space saving;
– no spillage of cargo on the idle branch of the conveyor (Zhang et al., 2024).

However, it should be borne in mind that tubular belt conveyors are characterized by:
– increased roller loads;
– increased resistance to belt movement;
– belt torsion;
– considerable length of loading and unloading sections;
– more complicated installation and operation compared to belt conveyors.

The main factors affecting the performance of tubular conveyors include:
– track geometry (conveyor slope angle, radii of curved sections);
– belt capacity and diameter;
– roller support design and spacing;
– belt tension and speed;
– elastic and viscous properties of the belt;
– physical and mechanical properties of the load.

All the above-mentioned allowed the authors to consider the tubular conveyor as the main type of belt conveyor (Masaki et al., 2017), possible for application in the CFT scheme for delivery of rock mass to the surface in the conditions of Gleevatsky open pit of the Central Mining and Processing Plant.

Object of research. According to the terms of reference, the depth of the Gleevatsky open pit has reached 400 metres, with an annual ore output of 5.2 million tonnes. The transport and conveyor scheme should ensure annual output from the open pit of 10 million tonnes of rock mass (5.2 million tonnes of ore and 4.8 million tonnes of rock overburden). The operation mode of the complexes is year-round with 355 working days and a continuous working week with two 12-hour shifts.

Materials and methods. Studies (Babii et al., 2022) have 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 filling of the belt (the angle of non-filling of the belt θ), and can be up to 30°, which corresponds to the parameters of our route.

The layout scheme of the crushing and conveyor complex with the use of a steeply inclined conveyor is presented in (Kiriia et al., 2024), in which also calculated the technical characteristics of the conveyor route at the angle of rise of rock mass 18–30 degrees on the side of the quarry and the maximum piece of 250 mm, which depends on the belt speed (Ma et al., 2024), belt width, as well as the design features of the belt conveyor and loading and unloading points.

A critical condition for the application of the steeply inclined conveyor is the granulometric composition of the rock mass, which should be 150–200 (maximum 250) mm. This granulometric composition can be provided by coarse crushers such as KKD-1200/150, KKD-900/140, but the quality of blasting should be improved and the oversize should be not more than 1000 (900) mm, respectively (Kratkovskyi et al., 2020; Bubnova et al., 2024).

At detailed study of initial data (height of lifting, angles of lifting of sections on the whole side, lumpiness of rock mass) taking into account preliminary researches, the conclusion about the greatest expediency of application of tubular conveyor in this case was made. Therefore, in further studies the calculations of the tubular conveyor design were carried out.

In this work we used the Methodology of calculation of the main parameters of the tubular conveyor developed at the Institute of Geotechnical Mechanics named after N.S. Polyakov of NAS of Ukraine. N.S. Polyakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine Methodology of calculation of the main parameters of the tubular conveyor, in which the main dependences of technical parameters (belt speed, belt width, space filling) on the mining and geological parameters of the rock mass (Zeitinova et al., 2024) (size of the maximum piece, rock strength) and technological parameters of transportation (angle and height of ascent, length of the route) are established.

Below is a preliminary calculation of the main parameters of the tubular conveyor for the Gleevatsky open pit of the Central Mining and Processing Plant of Krivoy Rog according to the Methodology. Based on the initial data, the project provides a six-roller design of the tubular conveyor support (Fig. 1). The calculation scheme of the tubular conveyor with the route profile is shown in Fig. 2.

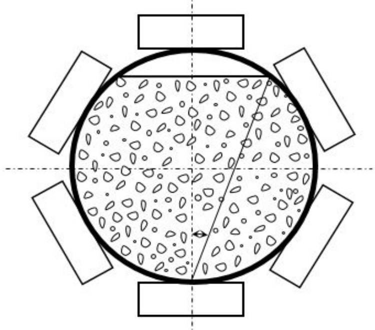

Figure 1 - Normal cross-section of a tubular conveyor with six-roller roller supports

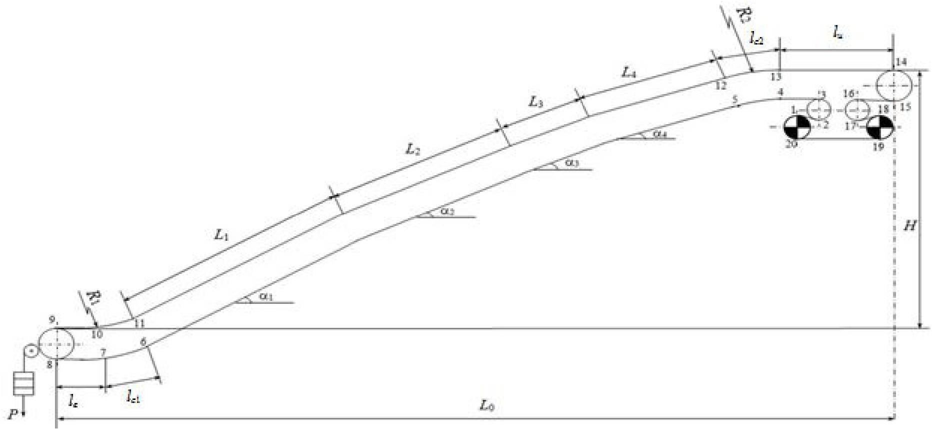

Figure 2 - Calculation diagram of the tubular conveyor

A two-drive tubular conveyor with straight and curved sections of the framework is considered. For calculation we have the following initial data:

1. Parameters of the conveyor:

– annual mass productivity of the conveyor, t/y	Q =10000000
– number of working days in a year	$M = 320$
– duration of a shift, h	$t_{sh} = 8$
– irregularity coefficient	$k_{ir} = 1.15$
– coefficient of machine time	$k_m = 0.75$
– total length of the conveyor, m	$L = 1006$
– distance between the axes of the head and tail drums, m	$L_0 = 900$
– height of cargo lifting, m	$H = 370$
– lengths of inclined sections of the conveyor, m:	$L_1 = 300$
	$L_2 = 230$
	$L_3 = 113$
	$L_4 = 176$
– length of the loading part of the conveyor, m	$l_l = 50$
– length of the unloading part of the conveyor, m	$l_u = 53$
– length of the first curvilinear section, m	$l_{c1} = 52$
– height of lifting the load on the first curvilinear section, m	$h_{c1} = 6$
– length of the second curvilinear section, m	$l_{c2} = 52$
– height of lifting the load on the second curvilinear section, m	$h_{c2} = 15$
– radii of curvilinear sections, m:	$R_1 = 180$
	$R_2 = 360$
– angles of inclination of inclined sections of conveyor, deg:	$\alpha_1 = 30$

	$\alpha_2 = 25$
	$\alpha_3 = 23$
	$\alpha_4 = 18$
– belt speed, m/s	$v_b = 2$
– angle of belt unfilled, deg	$\theta = 33$
2. Parameters of roller supports:	
a) six-roller supports:	
– distance between roller supports of the load branch, m	$l_r = 1.5$
– distance between roller supports of the idle branch, m	$l'_r = 1.5$
– mass of rotating parts of rollers of the working branch, kg	$m_r = 106$
– mass of rotating parts of rollers of the idle branch, kg	$m'_r = 64$
– distance between roller supports of the 1st curvilinear section, m	$l_{r1} = 1$
– distance between roller supports of the 2nd curvilinear section, m	$l_{r2} = 0.5$
b) three-roller supports:	
– distance between roller supports, m	$l_1 = 1$
– angle of inclination of side rollers, deg	$\beta = 20$
– mass of rotating parts of rollers, kg	$m_{r1} = 106$
3. Properties of transported cargo:	
– bulk density of the transported cargo, t/m^3	$\rho = 2.5$
– coefficient of internal friction of bulk cargo	$f = 0.7$
– angle of natural slope of bulk cargo at its movement with the belt on the conveyor rollers, deg	$\varphi_m = 20$
– average linear size of the largest large pieces of cargo, m	$a_{\max} = 0.25$
4. Additional constants	
– coefficient of resistance when moving the belt with the load on the roller supports of the conveyor	$\omega = 0.3$
– coefficient that takes into account additional resistance when moving the belt and the load	$k_1 = 1.1$
– coefficient of adhesion of the belt with the drive drum	$\mu = 0.3$
– reserve of adhesion of the belt with the drive drum	$K_{ad} = 1.3$
– reserve of drive power	$K_d = 1.2$
– coefficient of safety margin of the belt	$n_s = 8.3$
– conveyor drive efficiency	$\eta = 0.85$

First, we determine the design capacity of the tube conveyor

$$Q_d = \frac{Q_{tfh} k_{ir}}{2 t_{sh} k_m} = \frac{31250 \cdot 1.15}{2 \cdot 8 \cdot 0.75} \approx 3000 \text{ t/h}.$$

According to the Methodology we determine the parameters of the tubular conveyor belt:

– belt diameter

$D_b = 2R \approx 0.54$ m.

In this case the condition must be fulfilled

$$2.5a_{\max} \le D_b \,.$$

We take $D_b = 0.6$ m or $R = D_b/2 = 0.3$ m on condition of passage of large pieces (Adamaev et al., 2015:1)

$$2.5a_{\max} = 2.5 \cdot 0.25 = 0.626 \text{ m} \approx D_b = 0.6 \text{ m.}$$

In this case, according to, for the given characteristics of the load, the degree of filling of the belt by the load $\psi = 0.6$ (60 %).

Determine the minimum value of belt width

$$B_1 = 2\pi R + \Delta = 2 \cdot 3.14 \cdot 0.3 + 0.5 \cdot 0.6 \approx 2.18,$$

where $\Delta = 0.5D_b$ m is the width of the overlapping belt section,

$$B_1 = 2 \cdot 3.14 \cdot 0.3 + 0.5 \cdot 0.6 \approx 2.18 \text{ m.}$$

At the transition section the belt width is determined according to:

$$B_2 = 1.1\left(\sqrt{\frac{Q_d}{3600\, v_b \rho K_n'}} + 0.05\right) =$$

$$= 1.1\left(\sqrt{\frac{3000}{3600 \cdot 2 \cdot 2.5 \cdot 0.158}} + 0.05\right) \approx 1.18 \text{ m,}$$

where K_n' is the belt capacity coefficient at the transition section, for this case, according to the calculation method, equal to 0.158.

Since $B_1 \ge B_2$, the belt width is taken equal to $B = B_1 = 2.2$ m = 2200 mm.

Maximum linear load on the belt

$$q_l = \frac{Q_d g}{3{,}6 v_b} = \frac{3000 \cdot 9.81}{3.6 \cdot 2} = 4088 \text{ N/m.}$$

Maximum linear load per framework

$$q = q_l + q_b = 4088 + 1078 = 5166 \text{ N/m.}$$

Let's assume linear weight of the cable belt q_b = 1078 N/m and thickness of the belt h_b = 0.03 m.

Maximum distance between roller supports

$$l_{\max} = \frac{4S_x}{\pi R^2 \gamma} f_{\max} = \frac{4 \cdot 100000 \cdot 0.025}{3.14 \cdot 0.3^2 \cdot 25000} = 1.42 \text{ m},$$

where γ is specific weight of transported cargo, $\gamma = 1000\rho g$, N/m³.

We take the minimum tension of the belt on the tail drum S_x = 100000 N and the maximum allowable deflection of the belt $f_{\max} = 0.025$ m.

As a result, the distance between the roller supports is chosen equal to l_r = 1.5 m, from which we can determine the distributed loads on the conveyor framework from the rotating parts of the rollers of the six-roller supports.

To determine the power of the conveyor drive we find the belt tension at characteristic points of the conveyor route (Khomenko et al., 2024), bypassing the belt from right to left (Fig. 2).

The values of tension are given in Table 1, where

S_{ab1} is the tension of the advancing branch on the first drive drum, N;

S_{ab2} is the tension of the advancing branch on the second drive drum, N;

S_{rb1} is the tension of the conveyor belt at the point of run-off from the first drive drum, N;

S_{rb2} is the tension of the conveyor belt at the point of run-off from the second drive drum, N.

Table 1. Belt tensions at characteristic points of the tubular conveyor

Tension, N	Established motion (ω = 0.04)
S_1=S_{rb2}	405886
S_2	405886
S_3	430239
S_4	432524
S_5	422708
S_6	98980
S_7	91330
S_8	94340
S_9	100000
S_{10}	122452
S_{11}	186328
S_{12}	2163538
S_{13}	2263228
S_{14}	2275678
S_{15}	2412220

S_{16}	2412220
S_{17}	2556952
$S_{18}=S_{ab1}$	2556952
$S_{19}= S_{rb1}$	1122908
$S_{20}= S_{ab2}$	1122908

Then we determine the girth angles of the drive drums

$$\alpha = 395° \approx 400° \cdot$$

Let's take the girth angles of the first and second drive drums equal to α_{01} = 200° and α_{02} = 200°.

Traction force of the conveyor drive

$$W_0 = S_{ab1} - S_{rb2} = 2556952 \; - 405886 \; = 2151066 \text{ N}.$$

Belt strength utilisation factor

$$\Phi = \frac{e^{\mu(\alpha_{01}+\alpha_{02})} - 1}{e^{\mu(\alpha_{01}+\alpha_{02})}} = \frac{e^{0.3(3.49+3.49)} - 1}{e^{0.3(3.49+3.49)}} = 0.88.$$

We choose from the table according to the value of the belt strength utilisation factor Φ = 0.88 the coefficient of load distribution between the drive drums K_Φ = 2.

Circumferential forces on each drive

$$W_1 = W_0 \frac{K_\Phi}{K_\Phi + 1} = 2151066 \frac{2}{2+1} = 1434044 \text{ N};$$

$$W_2 = W_0 \frac{1}{K_\Phi + 1} = 2151066 \frac{1}{2+1} = 717022 \text{ N};$$

Tension of the surging branch on the second drum

$$S_{ab2} = S_{rb1} = S_{ab1} - W_1 = 2556952 \; - 1434044 \; = 1122908 \text{ N}.$$

To check the clutch reserve on the first drum, we determine the ultimate tractive force on the first drive drum

$$W_{k1} = \frac{1}{K_{ad}} S_{rb1}\left(e^{\mu\alpha_{01}} - 1\right) = \frac{1}{1.3} 1122908\left(e^{0.3 \cdot 3.49} - 1\right) = 1597199 \text{ N}.$$

Since W_1 = 1434044 N < W_{k1} = 1597199 N, the girth angle α_{01} = 200° provides the design tractive force on the first drive drum.

Determination of the ultimate tractive force on the second drive drum

$$W_{k2} = \frac{1}{K_{ad}} S_{rb2}\left(e^{\mu\alpha 02} - 1\right) = \frac{1}{1.3} 405886\left(e^{0.3\cdot 3.49} - 1\right) = 577323 \text{ N}.$$

Since W_2 = 717022 N > W_{k2} = 577323 N, it is necessary either to increase the tension of the conveyor belt at the runaway point S_{rb2} or the angle of girth of the second drive drum α_{02}.

The minimum belt girth angle of the second drive drum is determined from the expression:

$$S_{rb2} = \frac{(S_{ab2} - S_{rb2})K_{ad}}{e^{\mu\cdot\alpha 02} - 1}$$

or

$$e^{\mu\cdot\alpha 02} - 1 = \frac{(S_{нб2} - S_{сб2})K_c}{S_{сб2}} = \frac{(1122908 - 405886)\cdot 1{,}3}{405886} \approx 2{,}3;$$

$$e^{\mu\cdot\alpha 02} = 3.3;$$

$$\alpha_{02} = \frac{\ln 3.3}{0.3} = 3.98 \text{ рад} = 228.2°.$$

Let's assume that the angle of the second drive drum is α_{02} = 230° (4,01 rad).

Then

$$W_{k2} = \frac{1}{K_{ad}} S_{rb2}\left(e^{\mu\alpha 02} - 1\right) = \frac{1}{1.3} 405886\left(e^{0.3\cdot 4.01} - 1\right) = 727501 \text{ N}.$$

Since W_2 = 717022 N < W_{k2} = 727501 N, the girth angle α_{02} = 230° provides the design traction force on the second drive drum.

Finally, the total girth angle of the drive drums of the conveyor is as follows

$$\alpha = \alpha_{01} + \alpha_{02} = 200° + 230° = 430°.$$

Conveyor drive power

$$N = \frac{W_0 v_b K_d}{1000\,\eta} = \frac{2151066 \cdot 2 \cdot 1.2}{1000 \cdot 0.85} = 6073.6 \approx 6074 \text{ kW}.$$

Drive powers on the drive drums

– on the first drive drum

$$N_1 = N\frac{K_\Phi}{K_\Phi + 1} = 6074\frac{2}{2+1} = 4049 \text{ kW;}$$

– on the second drive drum

$$N_2 = N\frac{1}{K_\Phi + 1} = 6074\frac{1}{2+1} = 2025 \text{ kW.}$$

We choose the power of the first and second drives equal to

$$N_1 = 4200 \text{ kW} = 2\times2100 \text{ kW; } N_2 = 2100 \text{ kW.}$$

Total power of motors

$$N = N_1 + N_2 = 4200+2100 = 6300 \text{ kW.}$$

Loads on rollers of the six-roller support of the linear section of the tubular conveyor framework are determined according to the method, which makes it possible to determine the reliability parameters of the support elements of the conveyor line for the selected type of bearings: the intensity of the failure flow of roller supports, the average service life. Having such data for the conveyor it is possible to determine the intensity of its maintenance, i.e. to predict the mode of repairs (replacements) of supporting elements, providing a given level of reliability of the whole conveyor framework.

At the last stage we determine the parameters of the tensioning device:

– type of tensioning device – hoist;

– forces acting on the tensioning drum at stationary mode

$$S_b = S_8 + S_9 = 94340 + 100000 = 194340 \text{ N;}$$

– forces acting on the tension drum during start-up

$$S_s = 2.7S_8 = 2.7\cdot94340 = 254718 \text{ N.}$$

Calculation of the full stroke of the tensioning drum

$$L_{full} = L_{elon} + L_{dock} = 0.025L + 0.015L = 40 \text{ м,}$$

where L_{elon} is the length of the working stroke of the tensioning drum caused by belt elongation, m; L_{dock} is the length of the tensioning drum stroke required for belt docking, m.

Results and discussion. So, for a conveyor route with certain lengths and angles of inclined sections (Fig. 2), the design of a tubular conveyor with a capacity of 3000 t/h is proposed. The total lifting height of the tubular conveyor is 370 metres. The drive is two-drum (tandem-drive) with the belt girth angle 430°. Drive power 6300 kW. Belt type: rubber cable conveyor belt made by Conti Tech (Continental). Belt width 2200 mm. Breaking strength 10000 N/mm.

The basic data for designing of tubular conveyor with increased angle of inclination are determined: parameters of conveyor, roller supports, belt, drive and mechanical characteristics of transported cargo (Rupam et al., 2024). According to the initial technological conditions the design of the section of the conveyor framework is accepted (Fig. 3). The section of the framework consists of 8 roller supports, each of which includes 6 rollers. The length of the mill section is 12000 mm, width 1300 mm, height 2200 mm. The roller support of the tubular conveyor is shown in Fig. 4.

The total length of the loading section of the conveyor is 50 m, where after the tensioning drum on the section l_1 = 2 m three-roller supports with variable angles of side rollers from 0 to 20° are installed. At the loading point in the section l_2 = 3 m, roller supports with side roller angles from 20 to 25° are installed. In the section l_3 = 30 m the belt is formed into a tube by lower side rollers with side roller angles from 20 to 60°. The distance between roller supports is 1 m with a sequential increase of the angle of inclination of the side rollers by 1°20′. In the section l_4 = 10 m, the belt is formed into a tube using the upper side rollers with an inclination angle of the side rollers from 80 to 120°. The distance between roller supports is 1 m with a consecutive increase of the angle of inclination of the side rollers by 4°. In the section l_5 = 5 m the belt edges are formed by the upper rollers. The distance between roller supports is 1 m.

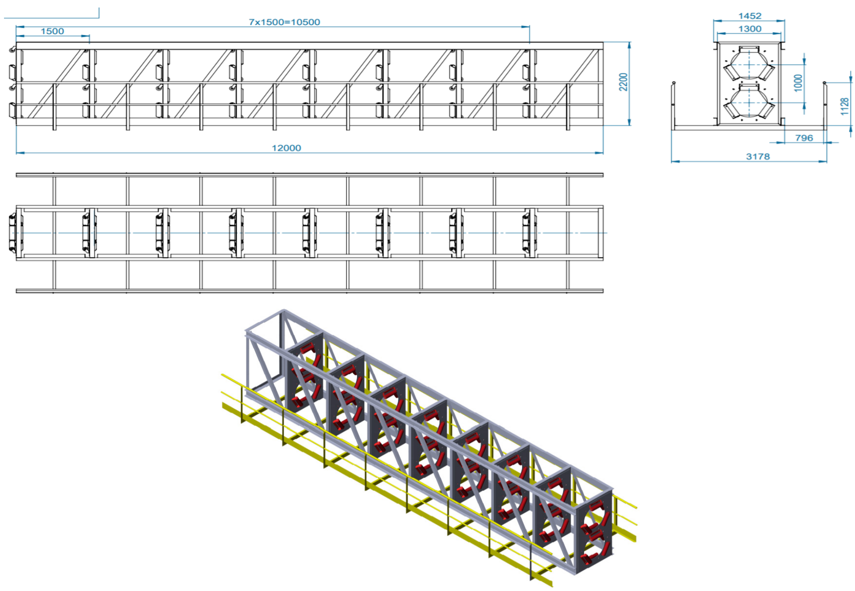

Figure 3 - Layout diagram of the conveyor framework section layout

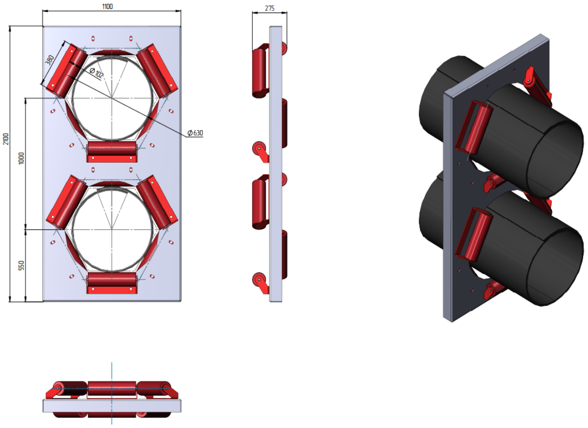

Figure 4 - Roller support of the tube conveyor

Unloading is performed in reverse order with side rollers in vertical position and subsequent belt flattening. The total length of the belt unloading forming section is 45 m.

According to the calculation, the total power of the tubular conveyor drive has been determined, which is 6300 kW. It is provided to apply 3 electric motors MV-HV 560X-04 with technical characteristics: phase rotor; 2500 kW; 6000V; 50 Hz; 1500 rpm; S1; DOL; IP55; IC 611; IM B3 (1001). Electric motor manufactured by FOCOQUET (Belgium).

The set of actuator station includes 3 gearboxes model GSM RXP3/834MS/A/63/ECE/N/M1/LF (Italy).

Conclusions. Based on the results of the work performed, the following can be noted.

1. The experience of development in the world mining industry in the direction of ore mining at deeper horizons of open pits shows the greatest efficiency of the use of cyclic-flow technology with the use of steeply inclined conveyors.

2. The article considers the justification of application of steeply inclined tubular conveyors with open location on the side of the open pit in the cyclic-flow technology, which provides an effective cargo transport connection of mining horizons with the surface. Crushing and conveyor complex with application of steeply inclined tubular conveyor is envisaged to be carried out on the southern side of the open pit at its partial location on bedrock between horizons minus 299 to minus 150 m, and on bulk rocks of the inner deposit between horizons minus 150 m to plus 58 m.

3. Justification and calculation of the main design parameters of steeply inclined tubular conveyor for conditions of Gleevatsky open pit of PJSC ‘Central Mining and Processing Plant’. The design of the section of the conveyor framework, which consists of six roller supports, consisting of 6 rollers each. The length of the section of the mill is 12000 mm, width is 1100 mm, height is 2100 mm. Parameters and design of transition sections are also proposed.

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ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Ответственный редактор *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Т. Апендиев*
Верстка на компьютере: *Г.Д. Жадырановой*

Подписано в печать 06.02.2026.
Формат 70x90$^{1}/_{16}$. 20,5 п.л.
Заказ 1.

«Central Asian Academic Research Center» LLP
Алматы, Шевченко к-сі, 28