5. Shemyakin S. A., Shishkin E. A. Physical and mathematical model of rock destruction by a milling machine cutter. *Journal of Mining Institute*. 2021. Vol. 251. pp. 639–647.
6. Krauze K., Mucha K., Wydro T., Pieczora E. Functional and operational requirements to be fulfilled by conical picks regarding their wear rate and investment costs. *Energies*. 2021. Vol. 14, Iss. 12. ID. 3696.
7. Cheluszka P., Mikuła S., Mikuła J. Conical picks of mining machines with increased utility properties — selected construction and technological aspects. *Acta Montanistica Slovaca*. 2021. Vol. 26(2). pp. 195–204.
8. Jeong H., Jeon S. Characteristic of size distribution of rock chip produced by rock cutting with a pick cutter. *Geomechanics and Engineering*. 2018. Vol. 15, Iss. 3. pp. 811–822.
9. Bolobov V. I., Gabov V. V., Talerov M. P., Talerov K. P. Composite cutter for mining machines. Patent RF, No. 2448247. Applied: 30.11.2010. Published: 20.04.2012. Bulletin No. 11
10. Shishlyannikov D. I., Sukhanov A. E., Vasilev A. L., Borisov A. V., Gribov D. S. Composite cutter with mounting device on operating member of machine. Patent RF, No. 2755106. Applied: 14.12.2020. Published: 13.09.2021. Bulletin No. 26
11. Bołoz L. Directions for increasing conical picks' durability. *New Trends in Production Engineering*. 2019. Vol. 2(1). pp. 277–286.
12. Bołoz L., Kalukiewicz A., Galecki G., Romanyshyn L., Romanyshyn T. Conical pick production process. *New Trends in Production Engineering*. 2020. Vol. 3(1). pp. 231–240.
13. Prokushenko S. I., Kalinin V. V., Dvornikov L. T. Dismountable rotary pick for mining machines. Patent RF, No. 54093. Applied: 15.06.2005. Published: 10.06.2006. Bulletin No. 16
14. Prokopenko S. A., Ludzish V. S., Li A. A. Recycling possibilities for reducing waste from cutters on combined cutter-loaders and road builders. *Waste Management & Research*. 2017. Vol. 35, Iss. 12. pp. 1278–1284.
15. Prokopenko S. A., Vorobiev A. V., Andreeva L. I., Janočko J. Waste cutters utilization in underground coal mining. *Acta Montanistica Slovaca*. 2017. Vol. 22, No. 1. pp. 81–89.
16. Bolobov V. I., Chupin S. A., Bochkov V. S., Mishin I. I. Service life extension for rock cutters by increasing wear resistance of holders by thermomechanical treatment. *Gornyi Zhurnal*. 2019. No. 5. pp. 67–71.
17. Krestovozdvizhenskiy P. D. Some observations over operation of shearing machines in mines in Kuzbass. *GIAB*. 2009. No. 6. pp. 120–123.
18. Khoreshok A. A., Tsekhin A. M., Kuznetsov V. V., Borisov A. Yu., Krestovozdvizhenskiy P. D. Field Experience of the working tools on effectors of mining machines on mines of Kuzbass. *Mining Equipment and Electromechanics*. 2011. No. 4. pp. 8–11.
19. Bolobov V. I., Akhmerov E. V., Rakitin I. V. Influence of rock type on regularities of excavator bucket tooth crown wear. *GIAB*. 2022. No. 6-2. pp. 189–204.
20. Bolobov V. I., Chupin S. A., Bochkov V. S., Akhmerov E. V., Plaschinskiy V. A. The effect of finely divided martensite of austenitic high manganese steel on the wear resistance of the excavator buckets teeth. *Key Engineering Materials*. 2020. Vol. 854, Iss. 10. pp. 3–9.
21. Gabov V. V., Zadkov D. A., Lykov Yu. V., Gurimsky A. I., Shpil'ko S. I. Exploiting heading machines at Vorkutaugol JSC mines. *Mining Equipment and Electromechanics*. 2008. No. 12. pp. 2–6.
22. Prokopenko S. A., Ludzish V. S., Kurzina I. A. Improvement of cutting tools to increase the efficiency of destruction of rocks tunnel harvesters. *Journal of Mining Science*. 2016. Vol. 52, No. 1. pp. 153–159. EM

UDC 622.62

E. E. SHESHKO[1], *Professor, Candidate of Engineering Sciences, esheshko@mail.ru*
V. I. GALKIN[1], *Professor, Doctor of Engineering Sciences,*
I. A. BERDIYGIN[1], *Post-Graduate Student*
O. V. PESTRIKOV[1], *Post-Graduate Student*

[1]*National University of Science and Technology–NUST MISIS, Moscow, Russia*

ISSUES OF EXPANDING THE SCOPE OF APPLICATION OF SANDWICH BELT HIGH ANGLE CONVEYORS

The article considers the possibility of expanding the scope of application of sandwich belt high angle conveyors (HAC) by increasing the speed of the belts, productivity and the maximum size of the transported pieces. The data for the corresponding adjustment of the calculated parameters of HAC are given. It is shown that the introduction of HAC into the transport schemes of deep open pits will reduce the cost of production since the volume of waste rock, the number of transshipment points, and the fleet of loading equipment and railway transport are reduced at the same time. The discussed technology makes it possible to use natural resources more carefully.

Keywords: *sandwich belt high angle conveyor, productivity, belt speed, belt width, installation angle, maximum size of transported load, idlers*
DOI: *10.17580/em.2023.02.20*

Introduction

Despite appreciable benefits, including economic advantages of using high angle conveyors in deep open pit mining, and irrespective of successful operation of these high-productive facilities at Olenegorsky and Mikhailovsky GOKs in Russia and at surface mines abroad (Uzbekistan etc.), the mining industry shows not very much effort to utilize all merits of the technology [1].

An HAC consists of bottom bearing I and top clamping belts II equipped with independent motors III and IV, and with take-up units V and VI (**Fig. 1**). The top clamping belt has hold-down devices VII to create the required hold-down pressure to press and hold the load on the bottom bearing belt during the conveyor operation (see fig. 1).

The HAC conveyors have very well adaptable profiles which ensure space-saving installation at any wanted configuration, and enable standard modular and nonstandard lifting circuits.

Figure 2 depicts a few possible pathways of HAC, which allow load conveying between two points in an open pit mine without reloading, i.e. without extra work. The mining industry tends to use standard belt conveyors which are known for their limited spatial flexibility. Installation of such conveyors meant for high lifting of load requires setting a few standard flights, which involves investing in much stone development drivage. At the same time, the installation of a conveyor line composed of a few belts at overload chops availability of the equipment and increases its failure probability [2–5].

Main part

Selection and design of a possible configuration of an HAC often faces the task to find the rational installation angle. It is proved that high angles of lifting allow length reduction in HAC but require high-value hold-down pressure along the top clamping belt, while the decrease in the hoist angle leads to the increase in the conveyor installation length. The analyses show that the costs of HAC grow gradually with an increasing lift height while being slightly dependent on the conveyor angle [6].

When comparing HAC with the conventional belts, the priorities of the latter are the higher belt velocity, higher productivity, smaller belt width and the ability to transport load after preliminary (single-stage) crushing, i.e. when the maximum size of particles is ≤350 mm.

Discussing expandability of the HAC application field, it should be decided on the:

1. allowable velocities of the HAC belts;
2. HAC productivity;
3. grain-size composition of the load;
4. conveying belt width.

The two first questions may be answered from the analysis of real-life operating conveyors. For example, in Wyoming, USA, Triton Coal Co. operates two HACs in transportation of coal. One conveyor belt velocity is 5.33 m/s, and the other conveyor operated since 1993 has the belt velocity of 4.57 m/s. The maximum velocities recommended for the belts of the standard conveyors in open pit mining range as 5–7 m/s, i.e. agree or exceed insignificantly the belt velocities of the operating HACs.

The productivities achieved by HACs are also impressive. For instance, HAC installed at Majdanpek open pit mine in Serbia transported ore at the bulk density of 2.08 t/m^3 and had the capacity of 4000 t/h at the belt velocity of 2.87 m/s, and the HAC operated at Muruntau open pit mine in Uzbekistan since 2011 demonstrated the productivity of 3500 h/t at the belt velocity of 3.15 m/s in conveying gold ore at the bulk density of 2.6 t/m^3 and at the maximum size of 300 mm. Moreover, even larger fractions (to 35 mm) produced because of wear of operating crushers can enter the conveyor belts [7]. Mikhailovsky GOK's HAC conveyors transport ore having the bulk density of 2.2 t/m^3 at the capacity of 3000 t/h.

The issue related with the maximum size of a handled load particle for HAC is a more complex question. The literature sources offer no substantiation and updating for the maximum sizes of load to be transported; however, we know that before loading, the material passes two stages of crushing down to the size of 80 mm [8].

At the same time, there exist conveying facilities that successfully handle larger fractions. For example, in the USA, a vertical lift conveys the maximum sizes of 127 mm at the belt velocity of 2.79 m/s, and a bench reloader shows the capacity of 2500 t/h at the angle of 35^0 and at the belt velocity of 2.5 m/s in transportation of ore at the bulk density of 2.16 t/m^3 and at the maximum size of 203 mm [9].

For considering transportability of large sizes at justified width of HAC, we use the theory of belt conveyor as HAC is inherently the belt conveyor.

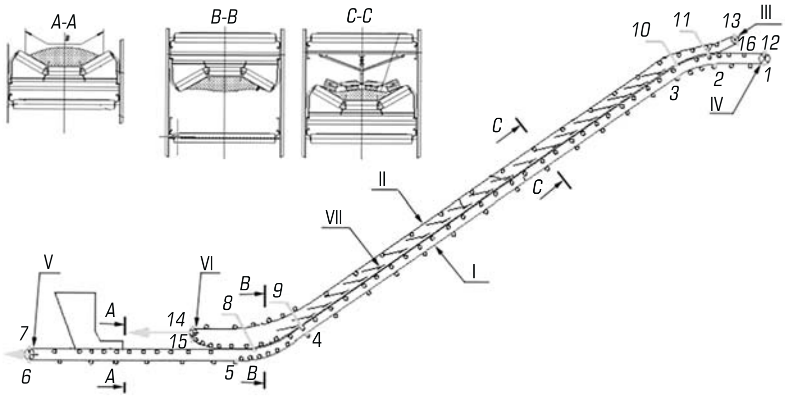

Fig. 1. Layout of sandwich belt high angle conveyor

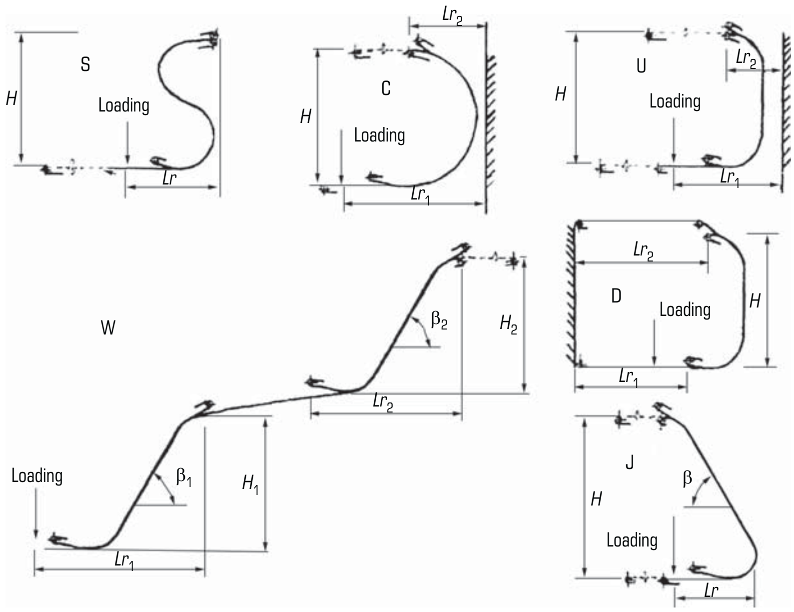

Fig. 2. Layouts of possible pathways of sandwich belt high angle conveyors

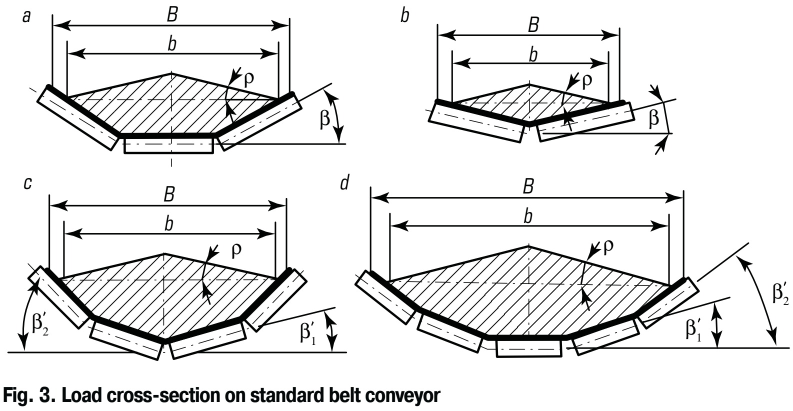

Fig. 3. Load cross-section on standard belt conveyor

The full belt width B of a belt conveyor can be found from the equation below:

$$B = 1.1\left(\sqrt{\frac{Q}{C_c v K \gamma_p}} + 0.05\right), \text{m} \qquad (1)$$

where 1.1 is the safety factor to take into account potential short-term increase in the freight traffic; 0.05 m is the size of the belt sides free from load to limit the load spill; Q is the conveyor capacity, t/h; γ_p is the bulk density of load, t/m^3; v is the belt velocity, m/s; K is the belt angle factor; C_c is the capacity factor.

In this manner, it is assumed that the load occupies only a part of the conveyor belt width evaluated from a radical expression, and the free sides of the belt total only 0.055 m (with regard to a potential increase in the flow by 10%). It is also assumed that the sitting of larger pieces of load is unlimited by the value b and can partly occupy the free sides (i.e. to occupy a larger part of the belt) as the latter only work to eliminate the load spill (**Fig. 3**).

For this reason, in calculations, the total width B of a belt conveyor is known to be checked with the coarseness of the transported load. For common loads, this value is given by:

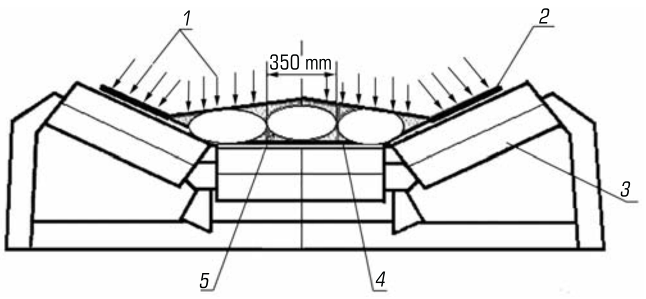

Fig. 4. Cross-section of HAC for coarse load:
1—hold-down force applied to belt; *2*—top clamping belt; *3*—idler; *4*—bottom bearing belt; *5*—load

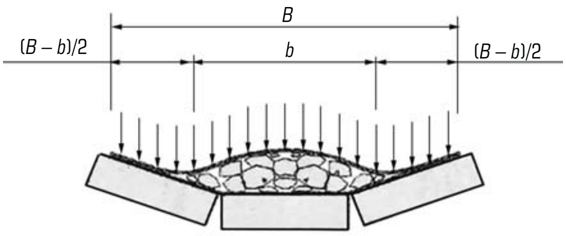

Fig. 5. Computational model of HAC belt width

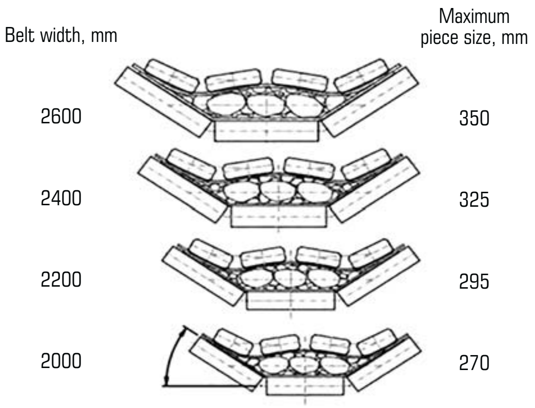

Fig. 6. Dos Santos International's recommendation on HAC belt width for coarse loads

$$B \geq (2.7\text{–}3.2)\, a_{max}, \tag{2}$$

where a_{max} is the maximum size of a transported piece, mm.

The HAC should have much larger sides, and their functions are broader as it is required to ensure the pressure seal of the load and to transfer the hold-down force to the load and to the belt sides. Introducing the calculations with the higher figure of 3.2 from Eq. (2), we define the most complex case when the width B can only accommodate 3 pieces of load (**Fig. 4)**.

So, when selecting a belt width for HAC, we should distinguish between a few strips of the belt. The total width B comes from the value b, which accommodates load, and is evaluated from the radical expression $\sqrt{\frac{Q}{C_c v K \gamma_p}}$ from (2), which should be checked in terms of its capacity to transport coarse pieces ($b \geq 3.2\, a_{max}$), and two sides having the values of $(B - b)/2$ (**Fig. 5**).

Certainly, the other cross-section layouts of the load on the HAC belt are possible, which lead to an increase in the belt width occupied by the load but add no substantial change to the general parameters of the system. For instance, the head of Dos Santos International proposes the other widths of the belts for coarse loads without regard to the belt capacity. Probably, the conveyor capacity is adjusted by varying the belt velocity (**Fig. 6**) [10].

The technical literature lacks recommendations on the size of the belt sides, except for the case when an HAC has an only bottom bearing belt which is equipped with a driven [5]. In this case, if the hold-down force is uniformly distributed across the width of the top clamping belt, the required size of the free sides can be found as follows:

$$b = \frac{B}{2\left(\frac{\mu_e}{\mu} + 1\right)}, \tag{3}$$

where μ is the coefficient of internal friction of load; μ_e is the coefficient of load–belt friction.

When these coefficients are equal or have close values, the required size of the free belt sides is 25% of the total width for each side. If a waste or a fine material gets between the free sides of the belts, μ_e can be much less than μ. When $\mu_e = \mu$, for instance, only 33% of the bottom bearing belt width is utilized to convey load.

It is advisable for the high-duty and high-capacity HACs in open pit mines to equip both the bearing and clamping belts with drives. In this regard, it was attempted to determine percentage of the belt sides relative to the belt width occupied with load from the review of the high-capacity HAC successfully operated in Russia and abroad. The analysis results are compiled in **Table**.

The analysis of the available and estimated data (Table 1) allows concluding that for the successfully operating HACs at different capacities, installation angles and physical and mechanical properties of load, the side size not always makes a 1/4 of the total belt width B but is frequently much smaller—from 9.5 to 2%.

Furthermore, this value is independent of the HAC angle and the freight traffic. These data imply that the side size ranges as 0.23–0.47% of the belt width b occupied by load (see fig. 4). Naturally, this is a material increase in the width of both belts, but considering the fact that the total length of the bottom bearing and top clamping belts drops with the increasing angle of an HAC, and at the installation angle of ≈ 38° becomes even shorter than the

Characteristics of high-capacity sandwich high angle belt conveyors in open pit mining across the world

Open pit mine, company, year of installation	Type of load and its bulk density γ, t/m³	Conveyor capacity Q, t/h	Conveyor angle, deg	Lift height H, m	Estimated width of loaded belt part, b	Total belt width B, mm	Belt velocity, v m/s	Side size (estimated value) *1/4 B*, mm	Portion of side (estimated) versus b, mm
Triton Coal Co, Wyoming, USA	Coal 0.95	2540	60	32.9	1050	1524	5.33	237 (381)	0.225
Majdanek, Serbia	Copper ore 2.08	4000	35.5	93.5	1260	2000	2.67	370 (500)	0.293
Turris Coal Co, Wyoming USA	Bituminous coal 0.88	1361	90	102	780	1524	4.57	372 (381)	0.469
Perini, Massachusetts, USA, 1993	Sandstone 1.1–1.3	1266	90	70.1	730	1372	3.56	321 (343)	0.440
Muruntau, Uzbekistan, 2011	Gold ore 1.75	3500	37	270	1070	2000	3.15	465 (500)	0.434
Olenegorsky, OLKONA, Russia, 2015	Iron ore 1.9–2.2	1200	36	124	610	1600	2.9	495 (400)	0.81
Mikhailovsky GOK, Russia, 2020	Iron ore 2.2	3000	37	215	No data	No data	No data	No data	No data

belt of a standard belt conveyor meant for load lifting to the same height, it is hardly that this problem can worsen efficiency of HACs [11].

At the same time, the standard-set width of the conveyor belts ranges as 300–3000 mm, which means no limitations imposed on the HAC capacity in case of coarse loads, especially considering the possibility to increase the HAC belt velocity.

The possibility of cutting down the secondary crushing costs is hard to be overestimated. For example, the total investment in HAC construction and installation in Olenegorsky OPM (re-crushed load size ≤ 80 mm) approached 900 millions of Russian rubles, including 770 M RUR spent for the crushing-and-conveying facility. Even under difficult local climate conditions, the conveying cost of 1 t of ore from the pit to the mine warehouse dropped by 2 times and equaled 17 Rub/t owing to the reduced length of the route [12].

Thus, the belt width of HAC should be evaluated from the modified formula below:

$$B = 1.3 - 1.5\left(\sqrt{\frac{Q}{C_c v K \gamma_p}}\right), \text{m} \qquad (4)$$

Regarding possible expansion of the application field and enhanced efficiency of HAC owing to the increased size of load pieces and to the reasoned selection of the bearing belt parameters, we should have respect to the choice of the idlers which, as the critical members of the belt conveyors and the high angle conveyors particularly, govern the conveyor efficiency.

The durability and unfailing performance of the idlers are influenced by the nature, value and characteristics of load, by the designs of the idlers and bearings, and by the operating conditions. The analysis of the operating conditions of the HAC idlers should take into account their dependence on the load generated by the weights of the load and the bearing belt, similarly to a standard belt conveyor, and the load generated by the clamping belt weight and by the hold-down forces produced by holding-down devices. Moreover, the latter can be commensurable with the load weight, which doubles the load applied to the idlers. In such a way, an HAC has the high-rate idlers equipped with the standard ball bearings which are not always capable to ensure the required resource, and this shows up in the currently operated HACs. For instance, one of the main operations included in the scheduled repair of Olenegorsky HAC is replacement of the idlers [13, 14]. In this case, there is an alternative to use the most common roller bearings that have a larger contact area than the ball bearings have. The rollers are arranged between the rings circle-wise a bearing in one or a few rows, and roll along the rings. Under loading, the line of the contact with the surface of the rings expands, and the contact area becomes much greater than the contact area of the ball bearings. In connection with this, the roller bearings possess a higher carrying capacity. The popular type of a roller bearing is the bearing with the cylindrical rollers meant for high radial loads. For another thing, they experience more powerful heating and have a lower rotation speed limit.

Finally, there are no insolvable problems in design and engineering of HAC and Russia's factories, for example, Akonit Machine-Building, which is highly skilled in production of belt conveyors, can manufacture sandwich high angle belt conveyors [15]. Equipment of the domestic open pit mines with high angle conveyors can improve transportation efficiency and, moreover, can save investment, which can be beneficial for the mineral transportation cost. For example, thanks to reduction of transportation chain, OLKON can save up to 210 million rubles yearly, and the complete pay-off of the technology will come in 4 years. Regarding Olenegorsky GOK, the ore production cost will be chopped by 2 times, which can promote the mine efficiency and can enable involving low-grade and earlier unprofitable ore in economic production [14].

Conclusions

1. The review of the operated high angle belt conveyors shows that their installation instead of a chain of standard belt conveyors and installation of the latter in inclined shafts and trenches allows drastic reduction in the length of transportation at the boosted reliability of the lifting systems.

2. The capacities and velocities of HAC operated in Russia and in the world are similar to these values provided by standard belt conveyors in open pit mines.

3. The parametric analysis of the operating high-capacity HAC shows that their width is 1.4–2 times as large as the width of standard belt conveyors having the same capacity and belt velocity, and the size of the belt sides totals 0.22–0.47% of the loaded width of the belt.

4. At the HAC angles greater than 33°, the purchase costs of the conveyors decrease as the total length of the belts becomes smaller than the length of a standard belt conveyor installed at the angle of 15°.

5. The main expenses connected with the installation of HAC facilities in open pit mines are spent for the construction and equipment of crushing and concentration horizons. Elimination of secondary crushing of load to be transported by HAC is tested on a number of effective HAC facilities and can be recommended for a wider application.

Reference

1. Istratova K. Cyclic-flow technology: what are the prospects. *Gornodobyvayuschaya promyshlennost*. No. 4. pp. 112–115.
2. Semenkin A. V., Zhuravlev A. G. Forecast and comparison of application areas of high-angle conveyors. *GIAB*. 2021. No. 5-2. pp. 322–337.
3. Sheshko E. E., Pestrikov O. V. Justification of the required hold-down dependence on the length and angle of high-angle pressure belt conveyor. *Gorniy Zhurnal*. 2021. No. 5. pp. 83–87.
4. Galkin V. I. Expanding range of application of pipe conveyor belts through innovative design concepts. *Gorniy Zhurnal*. 2020. No. 5. pp. 52–56.
5. Dmitriev V. G., Verzhanskiy A. P. Fundamentals of the theory of belt conveyors. Moscow : Gornaya kniga, 2021. 512 p.
6. Dos Santos J. A. The cost and value the high angle conveying—A comparison of economics for different conveying paths. *Bulk Solids Handling*. 2013. Vol. 33, No. 1.
7. Sanakulov K. S., Shemetov P. A. Development of conveyor ore transportation technology on the base of high-angle conveyors in deep quarries. *Gorniy Zhurnal*. 2011. No. 8. pp. 34–37
8. Available at: https://www.murmansk.kp.ru/daily/26438/3309607/ (accessed: 07.07.2023).
9. Sheshko E. E., Galkin V. I. Substantiation of parameters and efficiency of the use of sandwich belt high angle conveyors for deep open pit mines. *Eurasian Mining*. 2022. No. 1. pp. 64–68.
10. Dos Santos J. A. High angle conveying: The vital (missing) link to IPCC Systems-2017. *Bulk Solids Handling*. 2017. Vol. 37, No. 1. pp. 16–26.
11. Semenyuk A. A., Reshetnyak S. P., Baichurina N. I., Sultanova N. R. Innovation haulage technology with high-angle conveyor for Olenya Gora deposit. *GIAB*. 2015. Special Issue 56. Deep Open Pit Mines. pp. 413–420.
12. Kartavy A. N. High angle belt conveyors for the mining industry. *Gornoe oborudovanie i elektromekhanika*. 2006. No. 10. pp. 22–26.
13. Malakhov V. A., Tropakov A. V., Dyachenko V. P. Rolling resistance coefficient of belt conveyor rollers as function of operating conditions in mines. *Eurazian Mining*. 2022. No. 1. pp. 71–75.
14. Scheduled repair of Olenegorsky high angle conveyor. Available at: https://yandex.ru/video/preview/13975264164119369302. (accessed: 07.07.2023).
15. Available at: https://www.npoakonit.ru (accessed: 07.07.2023).