UDC 622.232.72

S. A. PROKOPENKO[1], Leading Researcher, Professor, Doctor of Engineering Sciences, sibgp@mail.ru
V. S. LUDZISH[1], Scientific Consultant, Professor, Doctor of Engineering Sciences,
V. V. SEMENTSOV[1], Head of Laboratory, Candidate of Engineering Sciences
N. N. RAVOCHKIN[2, 3], Associate Professor, Doctor of Philosophical Sciences

[1]VostNII Science Center, Kemerovo, Russia
[2]Kuzbass State Technical University, Kemerovo, Russia
[3] Kuzbass State Agricultural Academy, Kemerovo, Russia

TANGENTIAL ROTARY PICKS: WEAR MODELING AND REUSABILITY EVALUATION

The evaluation of reusability of conventional one-piece picks in manufacturing recyclable modular tools necessitated modeling the pick head wear. This article proposes a space–time model of the pick wear dynamics, representing the pick head in the initial condition and at the key stages of deformation depending on geological conditions of the tool operation. The model images the wear dynamics of the nose bit and steel body of picks. It allows predicting a wear stage (half-wear, pre-wear, normal wear and over-wear) of the pick heads, and determining the time of this stage. It becomes possible to find the limits of the tool wear by the criterion of reusability of the pick residues.

The implemented wear analysis of picks of JOY 4LS-20 Longwall Shearer in operation in a Kuzbass mine shows that in coal cutting, the half-wear stage comes on the 6th–7th day of operation, at the residual length of the head of 76 mm, and the pre-wear stages comes on the 11th–12th day of operation, at the residual length of 67 mm. After operation for 15 days, the nose bit 28 mm long becomes totally worn, and the head length decreases from 90 to 62 mm, but the pick preserves a high potential for being reused in rock breaking. The wear limits are evaluated for the picks by the criterion of their reusability. The range and limits of wear on conventional picks by the criterion of strength of a modular structure are justified and tested. The results open prospects for multiple recycling of rock breaking tools of mining machines.

Keywords: *pick, wear, wear stage, model, pick head, nose bit, split-type structure, residue, module, second-hand material, recycling*
DOI: *10.17580/em.2023.02.19*

Introduction

As a subject of scientific research and further improvement, tangential rotary picks of cutting and shearing machines interest researchers in many countries [1–8]. The recent studies focus on the development and justification of a composite design of the tool and its modifications. This area of research seems to be promising as it offers opportunities to reduce metal consumption in rock cutting, and to save money and labor input in underground mining operations. Scientists propose different designs of such picks, substantiate their parameters and carry out laboratory and full-scale testing of their operational capability.

The scientific men from the Saint-Petersburg Mining University present a tangential rotary pick with a replaceable head [9]. The head is held on the shank by the locking members made as radial lips on the side surface of the holder front. The lips are fixated in the circular groove of the cylindrical hollow of the replaceable head. A tetrahedron-shaped replaceable head held on a round shank is described in [10]. Each vortex of the tetrahedron has a reinforcing tungsten-carbide insert. The head attacks a material to be broken by a sharp edge of the tungsten-carbide insert. As soon as the edge gets blunted, the head is turned, and the other sharp edge of the head comes into play. All edges worn, the head is re-attached so that an unworn insert is on the cutting line.

Polish scientists propose a composite design of a conical pick with a replaceable member represented by a tungsten-carbide nose bit. The nose bit is held in the center of the holder by a spring ring [11, 12]. The nose bit may be made of sintered carbide or diamond-coated sintered carbide. For better rotation, the tungsten-carbide nose bit has a slide bearing set between it and the holder body.

Scientists from Novokuznetsk put forward a detachable rotary pick design [13]. This tool contains a rod bit and a detachable head. The rod is inserted in the head and is connected to it via a self-braking congruent cone tapered connection along the whole contact length.

A modular tangential rotary pick with a replaceable business end of the head is designed by the scientists from Kemerovo [14]. They propose to make the front part of the head to be replaceable and to be connected to the carrying module via a quick disconnect coupling. The wearable cutting module has a minimized length of the order of 15–20% of the total length of the head. The preservable carrying module makes up to 80% of the whole pick length in this case, and can serve repeatedly. This engineering solution enhances efficiency of the cutting tool.

The modular design allows using the worn picks of the conventional one-piece structure as the carrying modules [15]. Abundance of the worn picks increases the relevance of the studies aimed at recycling metal tools and at their reuse in rock breaking. It is necessary to analyze and modeling the pick head wear in time to predict the pick endurance and further reuse capacity.

Pick head wear model

Applicability evaluation of the standard one-piece picks as a secondary feedstock for the tool recycling needed modeling the pick wear and checking the model efficiency. The staged wear of pick heads was studied using the actual worn tools in the mines in Kuzbass and in other coal regions. The operating life of the cutting tools was examined by the authors using the industrial testing data and other research materials [16–20]. The accumulated and generalized information enabled constructing a space–time model of pick wear, which images the pick head in the initial condition and at the key stages of deformation, and presents the pick wear dynamics in the length–life time coordinates (**Fig. 1**).

The life time of a pick is estimated in terms of its operating time, or volume of broken rock up to the tool failure. Numerals *1–7* in the model mark the head outlines at different stages of wear. The key measure of the head wear is the length of the brazed-in nose bit *K*. Shortening of the nose bit passes the typical stages of half-wear and pre-wear. Total attrition defines the normal head wear which is reflective of the exhausted operating life of the pick.

Picks have a long life time P_3 in coal and in soft rocks, a shorter life time P_2 in medium-strength and medium-abrasivity rocks and a very short life time P_1 in strong rocks.

The steel body of the head (dash-outlined in fig. 1) wears concurrently with the nose bit deformation, which shows up as the reduction of the body length L_b. In case of the normal wear, the intact part *N* of the head makes 50–60% of its initial length L_h. Such pick can be re-used as a rough workpiece for manufacturing the carrying module of a compound pick. The mating socket in the worn head body is spaced from the shank at the distance H_1, which guards against weakening zones in metal. Such zones form around

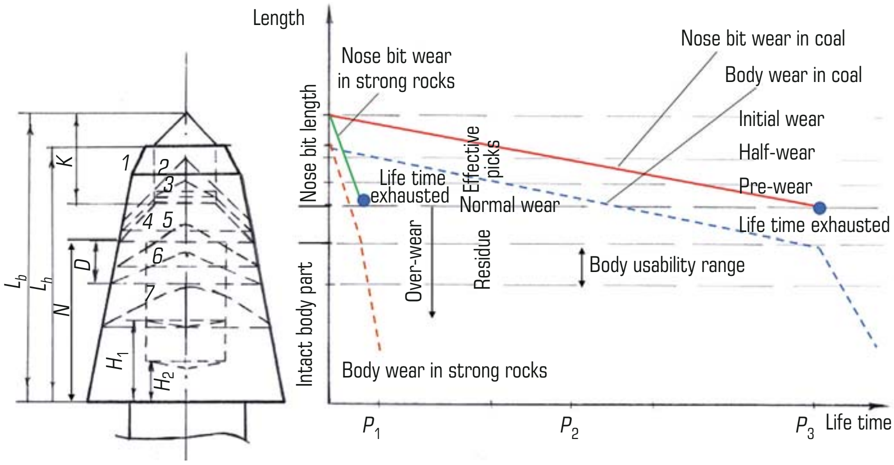

Fig. 1. Wear model of pick head and its reusability evaluation

the socket in the line of the shank when H is shortened down to the limit distance H_{lim}.

Due to late removal of a pick from the cutting drum, the pick head can experience over-wear (states *5* and *6* in fig. 1). The head keeps being reusable when it has the length N and a diameter decreased in the range D. The mating sockets can yet be made in such picks at the fulfilled strength criterion expressed in terms of the distance from the shank, $H_2 \geq H_{lim}$. The range D defines the secondary life time of standard pick residue when reused. The picks with the heads having the intact part length N and the diameter in the range D belong in the category of second-hand material.

If the pick remains unremoved from the cutting drum, the head passes to state *7* (see fig. 1) when $H < H_{lim}$. Such tool goes to the category of unreusable and unrecycable residue only suitable for remelting.

The developed model visualizes the states of the picks and the transition of the pick head from the serviceable to disabled condition. The model demonstrates the connection of the pick head length and primary life time in different geological conditions. It becomes possible to define pick residue as a second-hand material for manufacturing split-design tools.

Model application

The model is checked as a case-study of a cutting machine pick model RSH 35-95L90/19. The initial parameters of the pick head are given in **Fig. 2*a***.

The values of wear characteristics for the modeling were found using specific samples of worn picks removed from JOY 4LS-20 Longwall Shearer in the Kemerovo Region in May 2020 (**Fig. 2*b***). The measurements were taken using a calibrated tool on a laboratory scale. The measures were inserted in the pick head map and on a coordinate grid. The pick head with the measures at different stages of wear is demonstrated in **Fig. 3.**

The shearer was run in mining of coal seam 2.0 m thick. The hardness factor of coal was 0.9–1.0 on Protodyakonov's scale. From observations, the life time of the picks was 15 days. During this time, the nose bit 28 mm long gets worn totally, and the length of the head decreases from 90 to 62 mm. The half-wear stage comes when the head length is 76 mm, and the stage of pre-wear comes when the head length is 67 mm.

Replacement of picks is implemented in the first operating shift, and the operating conditions of picks in different flights of a cutting head are different. For this reason, the wear degree of the picks is different, including over-wear. The nose bit being lost, the unprotected body experiences accelerated wear. This is imaged by the change in the angle of the dashed lines in fig. 3.

The modeling shows that when normal wear comes, the intact part of the body has a length of 50 mm approximately. In such picks, it is possible to make the mating socket for the replaceable head at the sustained distance of 25 mm from the shank.

According to Dosco manufacturer of continuous miners, the amount of picks in operation in coal and sandstone having $\sigma_{com} = 100$ MPa reaches 300 m^3/pick in coal and 3 m^3/pick in sandstone [21]. Based on these data, it is predicted that the life time of the test pick model RSG in strong sandstone makes 1–2 operating shifts. The pick wear dynamics in difficult operating environment is depicted by the steep straight line in fig. 3. The coal mining practice in Kuzbass shows that when a continuous miner reaches a strong sandstone interbed or a pyrite pocket, up to 200–300 picks may be replaced per day in a package of 84 picks.

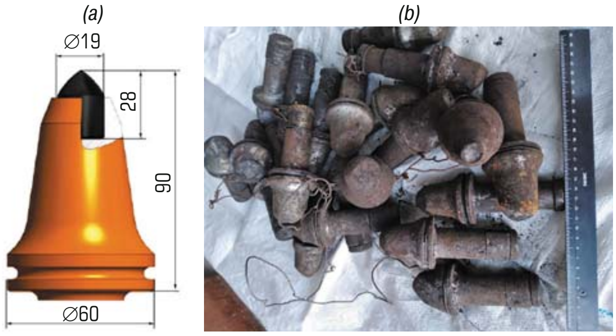

Fig. 2. Pick RSH 35-95L90/19: (*a*) new and (*b*) worn

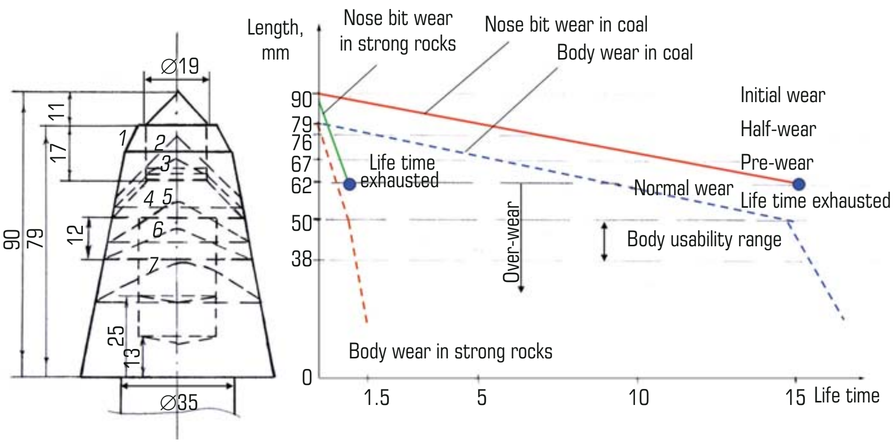

Fig. 3. Wear plot of head of pick RSH 35-95L90/19

The developed model finds out that for the specific model of the picks, the half-wear stage comes on the 6th–7th day of operation, and the pre-wear stage comes on the 11th–12 day. The limit length of the head at depletion of the life time is 62 mm. The intact part of the body is 50 mm approximately.

Reusability evaluation of pick residue

The new design of the two-module picks allows recycling of the residue of the conventional picks [22]. The shank and the intact part of the picks can be reused in the structure of the carrying module of the compound picks. The usability of the pick residue in recycling is defined, first of all, by the length N of the intact part of the head. The parameter N is connected with the residual length of the head, and, for this reason, the studies aimed at determining the relationship $N = f(L_b)$ were carried out. The wear of the heads of picks RSH 35-95L90/19 was measured and plotted (**Fig. 4**).

The analysis shows that the residual length of the heads of 43 test picks ranged as 58–70 mm, and the intact parts of the heads was 30 to 60 mm long. Two picks exhibited a strong one-sided wear, and the intact parts of the heads were 5 and 10 mm long, respectively.

The pattern of L_k and N is approximated by the exponential function:

$$N = 94.495\ln(L_b) - 349.52, \quad (1)$$

where L_b is the residual length of the head, mm; N is the intact part of the head, mm.

In the test sampling of 43 picks, 19% of the tools had the intact part smaller than the limit N_{lim} by the recycling criterion. The rest 81% of residue fall in the category of reusable feedstock for manufacturing carrying modules.

The length ratio of holders and adaptors of cutting modules defines the strength of the split-type design. **Figure 5*a*** shows two disassembled modular-structure picks for different shearers. The pick on the left has an overhang of 90 mm, and the pick on the right has an overhang of 70 mm. Both picks have the mating sockets with a length of 25 mm and a diameter of 25 mm. The diameter of the cutting modules is 40 mm.

The left-hand and right-hand picks have the mating sockets spaced from the shank at 25 and 13 mm, respectively. Both tools were tested in coal and rock breaking. After 30 days of operation, the picks lost only 50% of their service life. The compound pick with $H_{lim} = 13$ mm operated longer than a month on longwall shearer KP-21 in top coal cutting with overcutting of 10% of roof rocks having the hardness factor $f = 5–6$ on Protodyakonov's scale without the strength loss in the head. The pick after the month-long operations is shown in **Fig. 5*b***.

Given the recent level of knowledge, the value of 13 mm can be assumed as an allowable value by the strength factor of the modular structure. Than the usability range D of the intact part of the head is 1 mm (see fig. 3). The heads of residue picks RSH 35-95L90/19 having the length of 38 to 50 mm can be set as the second-hand material for manufacturing modules for further recycling.

The presented results are obtained in actual testing of picks in Kuzbass mines. The same results of pick wear are also observed on shear picks in Vorkutaugol's mines. Because of improper replacement, the picks pass two extra stages of wear (**Fig. 6**). In fig. 6, on the right, there are the over-worn picks (the fifth stage), but the length of the residue heads allows using them for recycling. The picks fall in the category of second-hand material. The carrying modules made of such picks has a service life 10 times longer than the service life of the one-piece structure picks [14]. The left-hand picks have passed the fifth stage of wear and are no more reusable. These are the picks on the sixth stage of above-standard wear—unreusable waste.

Conclusions

Targeting at reusing worn shearer picks in modular structures needed modeling the process of transformation of picks to waste. The proposed space–time model of the pick head transformation visualizes the process of pick wear during operation. It becomes possible to predict condition of a pick at different times and in different operating environment, and to evaluate reusability of rejects. As a case-study of a pick of JOY 4LS-20 Longwall Shearer in operation in a Kuzbass mine, the proposed model determined the stages of the pick head wear and their times, and evaluated their characteristics. The parameters of rejects, such that the residue picks can be reused in modular structures capable to operate much longer, are determined. The range of the allowable wear-and-tear of a pick head after it lost its reinforcing nose bit is 12 mm. It is proved that by the condition of recycling, the worn picks with the intact part of the head 38 to 50 mm long are reusable. In this case, the pick reconstruction is possible without the strength loss and failure in the further operation in the mode of recycling.

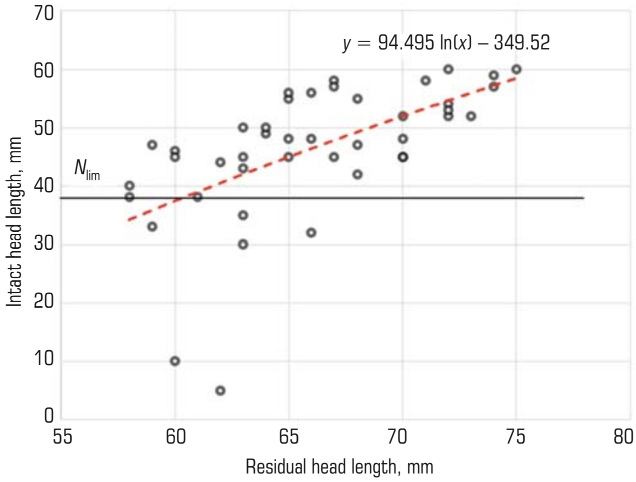

Fig 4. Reusable length *N* of worn pick versus residual length L_b of pick head

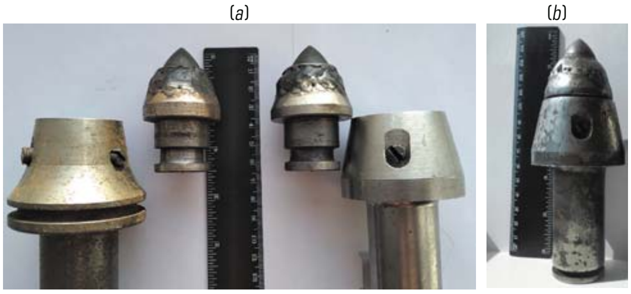

Fig. 5. Holders and cutting modules (*a*) and modular-stricture pick REM of KP-21 longwall shearer after operation for 30 days (*b*)

Fig. 6. Above-standard wear of picks RSH 33-85/17.5 after failure of reinforcing nose bit [21]

References

1. Talerov M. P., Bolobov V. I. Life and failures of tangential-rotary picks. *Gornyi Zhurnal*. 2018. No. 4. pp. 77–81.
2. Bolobov V. I., Chupin S. A., Akhmerov E. V., Plaschinskiy V. A. Comparative wear resistance of existing and prospective materials of fast-wearing elements of mining equipment. *Materials Science Forum*. 2021. Iss. 1040. pp. 117–123.
3. Gabov V. V., Zadkov D. A., Nguyen Van Xuan, Hamitov M. S., Molchanov V. V. To the problem of improving the working tools of mining excavation machines. *GIAB*. 2022. No. 6-2. pp. 205–222.
4. Yasar S., Yilmaz A.O. Drag pick cutting tests: A comparison between experimental and theoretical results. *Journal of Rock Mechanics and Geotechnical Engineering*. 2018. Vol. 10. pp. 893–906.

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