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DESIGN AND INDUSTRIAL TESTING OF INNOVATIVE NONEXPENDABLE PICKS FOR CUTTER-LOADERS

The tendency of increasing dimensions of cutter–loader picks results in many departures of the machine from face area during rock breaking in mines. This is governed by the current structure of the tangential rotary picks making their repair and second use impossible. The studies of the mechanisms and degree of the pick wear yield the proposal of the new design aimed at essential extension of life time of the rock-breaking tool. In the developed split pick design, up to 80% of the tool is usable many times. The working part subjected to abrasive wear and making 20% of the pick weight and length is replaceable after wear of the tungsten carbide nose.

The experimental pilot picks of the spit design were tested in cutting coal (with adjacent rocks with hardness f = 5–6) in a Kuzbass mine in December 2017. The tests proved availability and repairability of the proposed design. No detachment of the replaceable heads from their shank ends was observed. During the tests, the cutter–loader broke 7500 t of rocks. The picks underwent 4–5 replacements of the worn-out heads while preserving their shape and workability.

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Introduction

In the recent decades, the upward trend in the power, productivity and weight of heading and mining machines continues in the world [1–4]. Lightweight heading machines of 15–20 t are replaced by average weight and heavy shearers of 30–40 and 50–80 t, respectively. Super heavy machines have weight of 85–125 kg. Power of drum engines has increased from 44–110 to 270–350 kW. Heavy cutter–loaders are capable to produce 200–250 kg of hard rocks per day. The upper strength limit of cut rocks reaches 90–130 MPa. Modern mining machines can cut seams to 5.5 m thick, and have the total rated power of drives more than 2100 kW and coal productivity up to 10000–15000 t/day.

The rock-breaking tools follow the trend. Ten years ago, in the leading coal mining region in Russia—Kuzbass, cutter–loaders were equipped with picks 120–140 m long with a weight of 0.7–0.8 kg. Hard-alloy inserts with a diameter of 12–16 mm were in use. The lately picks have the lengths of 200–320 mm and weight of 2–3 kg (**Fig. 1**). In this case, the tungsten carbide–cobalt inserts have diameter of 19–24 mm and more.

The number of picks on the drums of Russian heading machines can vary from 28 to 56. On Sandvik MB 600 boom-type roadheaders, the number of picks can be 160 or 210 depending on the drum width. The cutter–loader drums are equipped with 108–130 picks [5, 6]. All earlier and current picks have a comparatively short operating life. This fact is governed by the rod-like structure of the picks. Such structure is named as a tangential–rotary pick (TRP) and represents a round extended shank end and a cone head reinforced with a tungsten carbide nose-piece. Owing to the rode-type shape, TRP rotates in the toolholder, which ensures uniform wear of the reinforcement, provides longer life of the picks (as compared with radial tools) and contributes to their popularity.

At the same time, after the tungsten carbide insert is worn-out, a pick is no more usable, is removed and

Fig. 1. Change in dimensions of picks for cutter–loaders.

replaced with a new tool. The best portion of the tool gets in waste nearly fresh, which means inefficient use of high-quality metals. The process of rock cutting in mines continuously tends to much metal waste, cannot be assumed as a resource-efficient operation and calls for improvement.

It is possible to extend operating life of TRP by means of: selection of the highest-quality materials for manufacturing of picks and inserts; improvement of thermal treatment processes; betterment of rock cutting conditions; perfection of pick nose shapes; optimization of pick patterns on drums; development of design and parameters of picks, etc.

Higher resistance to the abrasive wear is achieved by using steels with higher content of alloying elements [7]. The quality thermal treatment ensures uniform distribution of hardness length-wise the body of the picks. Professor V. I. Bolobov and his colleagues revealed that Russian picks RS32 had nonunifom hardness distribution length-wise the head: the hardness differed in the core and on the surface [8]. The highest hardness and wear resistance are found in the widest part of the head (round 55 HRC), while the minimal hardness (32–42 HRC) is determined in the middle and nose zones which are the most subject to wear during rock breaking. The authors of this article propose improving the thermal treatment flow chart by removal of cooling-down of pick noses, by maintenance of even temperature along the pick heads and by avoidance of structural nonuniformities.

The increase in the diameter of the tungsten carbide inserts extends the pick life [9]. Hard rocks are expedient to be cut using inserts with diameter not 18 but 22 and 25 mm. The decelerated wear of picks is observed when water jet under pressure to 20 MPa is fed on rock face in front of the pick. K. Kotwica arrived to a conclusion that water jets were to be generated using nozzles 0.5 mm in diameter installed on the drum in front of each pick. The positive effect of water on penetrability and longer life of picks is also revealed in the experimental investigations of Chinese scientists [10].

Substitution of the cylindrical and mushroom-shaped indenters for ellipsoids of rotation enables removal of stress raisers from the insert surface and extending the life of the picks [11]. It is proposed to make inserts of super-hard composites (cubic boron nitride and synthetic diamond) for longer life of picks for breaking higher hardness rocks. Application of such picks to cutting potassium salt with hardness f = 2–4 on Protodyakonov's scale revealed different causes of pick breakdown. At the present time, the authors continue laboratory testing aimed to assess energy consumption of rock cutting by composite picks [12].

Reinforcement of pick heads by longitudinal inserts and stalinite surfacing of pick bodies prevents the pick wear [13, 14]. Reduction of the contact area between the steal head and rocks as well as the increase of the higher strength surface area of the body decelerates the pick wear rate.

Installation of a special carbide ring on the nose of the pick head prevents metal from wear and extends the operating life of the reinforcement element and the whole pick. This design is manufactured by the leading TRP manufacturers—Sandvik and Kennametal [15, 16].

To prevent damage of long picks used in coal cutting and to expand their resource, the split design is proposed for drum picks [17]. The pick is composed of a rod reinforced with a tungsten carbide insert and a replaceable bushing put on the rod from below and acting as a mat structure at the contact with toolholder. After the rod wear, the bushing can be used several times. However there is no information on the tests of this design or its working efficiency in the scientific literature.

The rate of pick wear is affected by the pick–rock friction dependent on the operating angles of the picks. The theoretical model of finding such angles is described in [18]. The experimental studies show that for the reduction in coal–pick friction, the cutting angle should be 45–50° while the pick incline to the cutting surface is to be round 20°, which provides free cutting conditions [19, 20]. The lowest cutting force and destruction energy of rocks is achieved at the level of 0.84–0.88 kWh/m^3 [21].

The analyses show that the proposed and partly developed engineering solutions and process designs ensure longer life of cutter–loader picks. All earlier and currently operated picks have short operating life. This is conditioned by the structure as it makes the picks unrepairable after they are worn-out. As a consequence, the picks are expendable, and the waste of rock cutting continuously grows in connection with tendency toward the increasing dimension of picks. The aim of this study is to find design solutions targeted at the elongation of operating life of picks and practical testing of new designs in mines.

Objects and methods

The R&D objects were picks of the Russian and foreign manufacture used in the mines in the major coal basin of Russia—Kuzbass, Kemerovo Region. The operation of picks was inspected in heading and actual mining in more than 15 mines for five years. The picks were examined in their initial condition and after operation. The methods of inspection were measurement, weighing, comparison and assessment. The standard certified measurement tools and weighing machines were employed.

During the research, the scientific and patent literature was reviewed and the methodology of the invention solution theory was used. The parameters of the head shank end were substantiated based on the design of pick model RGP 33-87-70/16M. The actual dimensions of picks were used for their geometrical modeling and strength calculation using the finite element method in the SolidWorks Simulations environment.

The developed structure of the split pick was tested in mines of the Northern Kuzbass Mining Company, Russia. The tests involved operation of picks on both heading machines KSP-35 and EBZ 230, and on cutter–loaders KSW 460 and Joy. The test picks were manufactured by such companies as Mining Tool Plant, BETEK and Kennametal. Structurally, the picks were represented by steel holders to 1800 m long with diameter to 60 mm, equipped with tungsten carbide–cobalt noses with diameter of 19–24 mm. The shank ends were made as two-step structures with diameters of 38 and 30 mm, and had a length of 75–85 mm.

The new split design was tested in the Berezovskaya Mine on cutter–loader KSW-460 in longwall No. 21 in seam

Fig. 2. Low-worn rejected picks in coal mine

XXVI. The mining depth was 200–309 m. The seam had a dip of 18–29° and a thickness of 1.05 m. The structural design of the longwall system allows the extractable thickness of 1.3 m. The adjacent roof rocks are represented by siltstone with hardness f = 5–6 on Protodyakonov's scale. REM picks were used simultaneously with BETEK picks. Three new picks were installed in a row in all three loops of the front-running drum.

Results and discussion

In the tests, we examined the mechanisms and degree of wear of both new and worn-out picks. It is found that the majority of picks feature low wear uniformly distributed around the tip of the cone head. This part of the pick holds the strong nose breaking coal and rocks. As a consequence, front bevel part of the pick is mostly subjected to wear, while the rest of the structure keeps nearly initial shape. However, without the tungsten carbide insert, the further operation of the picks is prohibited due to the increased cutting force [22], intensive friction-caused sparking [20] and higher load on the cutter–loader transmission [23].

The analysis of the size and shape of the picks shows that up to 70–80% of the pick body keep almost inalterable. The used and removed picks often have wear not more than 10–15% (**Fig. 2**).

The rejects include up to 85–90% of the initial item made of high-strength and expensive steel. A new pick of average-size cutter–loader KP-21 has weight of 1050 g, and up to 840 g of the weight goes to waste after the pick removal. On the heavier cutter–loader, with picks with weight of 2000–2500 g, the rejects include 1600–2000 g of metal from each item. Almost flawless parts of the picks fall to waste.

In the Berezovskaya Mine, Kemerovo Region, Russia, in cutting coal seam by machine KSW-460, in case of pyrite inclusion, all picks on two drums had to be replaced in a single pass 0.6 m wide and 200 m long, i.e., 180–200 picks were replaced per shift. Such regime of picks governs high metal loss and high financial charges connected with purchase of many new picks, as well as disagrees with modern standards of economic production.

The analysis of the advanced designs of the newest R&D and invention picks used in mines, as well as the formulation and solution of the invention task made it possible to design

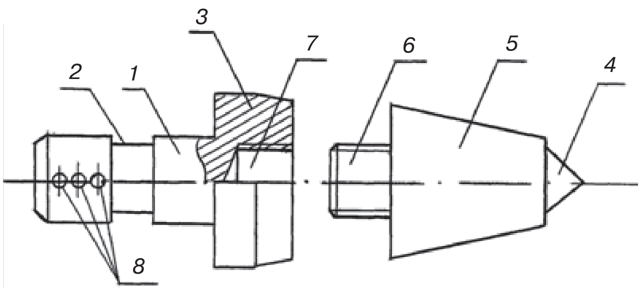

Fig. 3. Split pick design:
1 — shank end; *2* — grove in shank end; *3* — holding head; *4* — tungsten carbide nose; *5* — working head; *6* — shank end of working head; *7* — nest; *8* — holes for split pins

a split pick for rock cutting (**Fig. 3**). It is found that the structure of a pick head composed of holding and working parts with reliable joint allows replacement of the worn working part while the pick is used many times. Structurally, such pick includes a shank end with a holding head with a nest to hold the shank end of the working head with a reinforced nose. The joint of the holding and working heads is ensured by a screw threaded from the holding head to the shank end of the working head. The screw prevents from axial offset of the working head while allowing its free rotation.

As a result, the structure has two assemblies of the nose rotation (pick in the pick holder and the working head in the holding head), which reduces probability of the tool jam and too fast single-side wear of the pick nose. It is possible to unscrew the working head and replace it by a new part directly in the face area.

Such structure allows replacement of a small-size working head after removal of a pick. Up to 80% of the pick body becomes reusable. In the structure proposed earlier in [17], after wear of a pick, the whole rod with the nose is replaced. The renewed part makes 80% of the whole pick weight. The new-proposed engineering solution features high resource efficiency.

The finite element method was used to model stresses in the body of the split pick during rock cutting. The obtained dependences provided the optimized parameters (length and diameter) for the working head shank (WHS) by the criterion of maximal strength. The study shows that the lowest stresses are observed in the pick body when

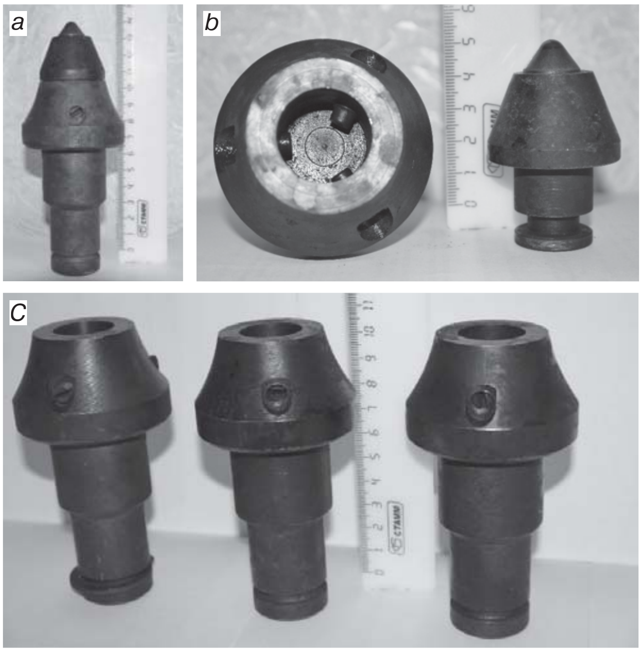

Fig. 4. Picks REM 38/30-74–70/16 before mine tests: a — assembled split pick; *b* — nest with screws and working head; *c* — pick holders

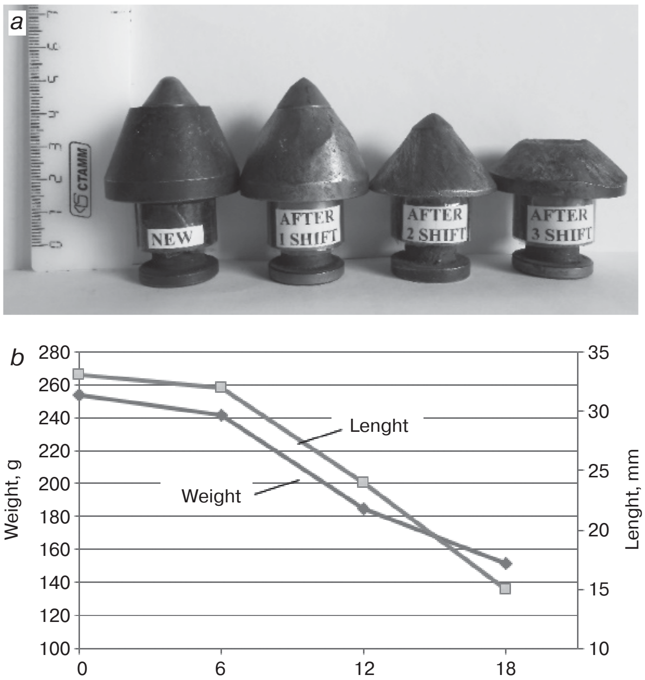

Fig. 5. Change in condition (*a*) and length of the cone and weight (*b*) of replaceable heads

WHS has the length of 23 mm and diameter of 28 mm. The obtained values were used to manufacture pilot test picks.

The pilot split picks included the two-stage cylindrical shank with diameters of 38 and 30 mm of the stages. The holding head diameter was 60 mm. The replaceable head was fixed in the holding head on three sides, which ensured reliable joint and axial rotation in the nest. For this purpose, three threaded holes were made in the holding head at 120º along the circumference. For drilling in the inclined surface of the head, three pockets were cut. The general view of the new-design picks is shown in **Fig. 4**.

The hew-design split pick REM was tested on the cutter–loader model KSW-460 in the Berezovskaya Mine. Three picks were arranged on the front-running drum on December 12, 2017. The rest 43 picks were manufactured by BETEK.

In each pass 0.6 m wide and 200 m long, the cutter–loader produced 250 t of coal. The shift plan was two passes, or production of 50 t of coal. After each pass, the drums were examined and the worn picks were replaced, including REM picks. After total wear of the working head, operator cleaned the screw pocket from coal dust, released the screw and replaced the head with a new part. The life of the working head lasted for 2–4 shifts. The wear of the replaceable heads is characterized in **Fig. 5**.

The analysis revealed two stages of deformation of working heads. At the first stage (first shift or 6 h long operation), the cone experienced diameter reduction and thinning at the preserved length. At the second stage (during the next 12 h), the length and weight of the cone extensively decreased up to the loss of the nose. During operation, the length of the head cone decreased from the initial 33 mm to 15 mm (45% of the initial loss). The weight of the worn head made 60% of its initial weight.

Fig. 6. REM picks after cutting tests

The life of BETEK picks during the tests was 5–6 days. The REM picks served for 5 days. During this time, 4–5 heads were replaced on each pick. Unfortunately, on the sixth day, during the night shift, KSW-460 stopped: the reduction unit of the rear-running drum lift broke. The cutter–loader was dismantled and substituted for Czech machine MB-12. It was impossible to install the two-stage picks on the drums of that cutter–loader.

The picks removed from the drum are shown in **Fig. 6**. The head on one pick was absent and the nest was filled with coal. After coal removal, the support disk of WHS was discovered on the bottom of the nest. Probably, under high loading, the disk separated from the shank and the head fell out. Installation of a new head would allow further operation of the pick. Two other picks had their working heads moderately worn and were further usable.

Operation of the pilot picks for 5 days proved their efficiency in cutting coal adjoined with 30% of rocks. During the tests, 7500 t of rock was broken. The design proved its repairability in the face area. The REM picks had the same life length as the conventional expandable picks. In case of the further use, the pilot picks could offer the economic effect. Satisfied with availability of the multiple-use split picks, the mine ordered a pilot batch of the picks for operation with a new cutter–loader.

Conclusion

The investigation and the test result allow arriving at a few conclusions as follows:

1. The trend of increase in the size and weight of cutter–loader picks leads to higher metal consumption of rock breaking and necessitates finding new engineering solutions toward the extension of life of the rock cutting tool.

2. The developed split design of the picks ensures repairability in the face area without removal from cutter–loaders, by replacement of working head. The values of length and diameter of the working head shank calculated by the reliability criterion are proved by the absent detachment of the working head. Detachment of the support disk of one head was observed.

3. The tests of the pilot split picks proved their efficiency in coal faces with adjacent rocks up to 30%. The picks are suitable for multiple use in case of the prompt replacement of the worn-out working heads.

4. The further research is conditioned by the need to simplify the replacement procedure of the working heads by the cutter–loader operators in the face area. It is required to analyze detachment of the support disk from the working head shank. Furthermore, the option of the reduction in the length of the working heads and, thus, in metal consumption can be studied. Particular scientific and economic interest lies in assessment of ultimate life of toolholders given the multiple replacement of the working heads, which is going to be the subject of the future tests.

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References

1. Sidorenko A. A., Sishchuk J. M., Gerasimova I. G. Underground mining of multiple coal seams: Problems and solutions. *Eurasian Mining.* 2016. No. 2. pp. 11–15. DOI: 10.17580/em.2016.02.03
2. Prokopenko S. A. From underground coal mining—to the coal-power complexes. *Gornyi Zhurnal.* 2005. No. 11. pp. 8–10.
3. Yutyaev E. P. Current challenges and development prospects for underground mining of flat gas-bearing coal seams. *Ugol.* 2017. No. 5. pp. 30–36.
4. Plakitkin Yu. A., Plakitkina L. S. The Industry 4.0 global innovation project's potential for the coal industry of Russia. 1. The Industry 4.0 program—new approaches and solutions. *Ugol.* 2017. No. 10. pp. 44–50.
5. Cheluzska P. Computer–aided design of robotised technology for manufacturing working units of mining machines. *International Journal of Mining, Reclamation and Environment.* 2015. Vol. 29(1). pp. 62–81.
6. Prokopenko S. A., Kurzina I. A., Lesin Yu. V. Prospects for improvement of mining machines' cutting picks. *IOP Conference Series: Materials Science and Engineering.* 2016. Vol. 124(1). pp. 1–5. DOI:10.1088/1757-899X/124/1/012134
7. Klishin V. I., Gerike B. L., Nikitenko S. M., Krestovozdvizhensky P. D. Types and causes of failure of tangential-rotary cutter bits. *Gornyi Zhurnal*. 2016. № 7. pp. 92–95. DOI: 10.17580/gzh.2016.07.20
8. Bolobov V. I., Bobrov V. L., Talerov M. P., Bochkov V. S. Cause rapid wear tangential cutters. *Proceedings of the Mining Institute*. St. Petersburg, 2012. Vol. 195. pp. 238–240.
9. Kotwica K. Results of laboratory investigations into operating conditions of cutting tool. *Journal of Mining Science.* 2003. Vol. 39(2). pp. 168–173.
10. Liu X., Liu S., Li L., Cui X. Experiment on conical pick cutting rock material assisted with front and rear water jet. *Advances in Materials Science and Engineering.* 2015. Vol. 2015. ID 506579. DOI: 10.1155/2015/506579
11. Krestovozdvizhensky P. D., Klishin V. I., Nikitenko S. M., Gerike P. B. Selecting shape of reinforcement insertions for tangential swivel cutters of mining machines. *Journal of Mining Science*. 2015. Vol. 51(2). pp. 323–329.
12. Dvornikov L. T., Korneyev V. A., Korneyev P. A., Krestovozdvizhensky P. D., Nikitenko S. M. Main development trends and some technical decisions on mining tools equipped with super-hard composite materials inserts. *IOP Conference Series: Earth and Environmental Science*. 2017. 012031. DOI: 10.1088/1755-1315/53/1/012031
13. Prokopenko S. A., Ludzish V. S., Kurzina I. A. Design of new-class picks for cutter–loaders. *Gornyi Zhurnal.* 2017. No. 2, pp. 75–78. DOI: 10.17580/gzh.2017.02.14
14. Chinakhov D. A Study of thermal cycle and cooling rate of steel 30HGSA single-pass weld joints. *Applied Mechanics and Materials*. 2011. No. 52–54. pp. 442–447.
15. Surface miner cutting tools. Available at: http://mining.sandvik.com/en/products/tools/surface-miner/surface-miner-cutting-tools (accessed: 30.11.2017).
16. Kennametal value business system. Kennametal catalog 2006. 38 p.
17. Moshkin N. V., Kalinin V. V. Tool contributing to higher productivity. *Ugol.* 2006. No. 8. pp. 46–47.
18. Gao K. D., Du C. L., Jiang H. X. et al. A theoretical model for predicting the peak cutting force of conical picks. *Fratt Integr Strutt.* 2014. No. 8. pp. 43–52.
19. Kim E., Rostami J., Swope C., et al. Study of conical bit rotation using full-scale rotary cutting experiments. *Journal of Mining Science.* 2012. No. 48. pp. 717–731.
20. Kim E. Effect of skew angle on main precursor of frictional ignition in bench-scale simulation of excavation processes. *International Journal of Rock Mechanics & Mining Sciences*. 2015. No. 80. pp. 101–106.
21. Fu L., Du C. L., Li J., Zheng K. Influence of pick working angle on cutting performance of auger miner's aiguille. *Advances in Mechanical Engineering.* 2015. Vol. 7(5). pp. 1–10. DOI: 10.1177/1687814015585427.
22. Shabaev O. E., Semenchenko A. K., Khitsenko N. V., Stadnik N. I. Experimental studies into the operating modes of cutter–loader drum. *Gornoe oborudovanie i elektromekhanika*. 2010. No. 10. pp. 49–56.
23. Mamet'ev L. E., Khoreshok A. A., Tsekhin A. M., Borisov A. Y. Stress distribution in attachments of disc cutters in heading drivage. *Journal of Mining Science.* 2015. Vol. 51, No. 6. pp. 1150–1156. EM