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Conical selections of mining equipment with enhanced utility characteristics: specific technological and construction elements

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Abstract

mineral deposits, especially hard coal, and for drilling roadways in underground mines, tunnels and other underground buildings in civil engineering. As the primary working process of this type of machines, mechanical mining of rocks is carried out by cutting. These machines' working units are equipped for this purpose with picks, usually conical (point-attack). They have the form of an axially symmetrical body consisting of a steel shaft and a tip usually made of tungsten carbide, connected by a hard brass solder. Due to the possibility of spontaneous rotation in the pick holders and even wear and tear of their tip around the entire perimeter, conical picks have a much longer service life compared to radial picks. Their life, especially when cutting hard and sharp abrasive rocks, is, however, still unsatisfactory. Rapid wear of the picks leads to a decrease in mining efficiency, an increase in this process's energy consumption, and an increase in dynamic surplus to which the cutting machine is subject. Among many forms of wear and tear of the conical picks, attention was paid to the problem of asymmetrical abrasive wear of the tips, pulling out the connection of the soldered pick tip and fatigue breaking of the pick shafts in the transition zone of the shank into the shoulder. The article presents original propositions of modification of the construction of the roadheaders/shearers conical pick shafts and the method of fixing the tip in the pick shaft in order to increase their operational durability significantly. The technologies and devices necessary to manufacture conical picks of the proposed structure were described. The developed modifications significantly contribute to the improvement of functional properties, including the reliability of conical picks, used in particular for hard rock mining.

Keywords

conical picks of mining machines, wear and tear, modification of the construction, manufacturing technology, improvement of durability

Introduction

Conical (point-attack) picks with tips typically made of tungsten carbides are a common feature of modern longwall shearers used to mine coal and other minerals in longwall systems, as well as roadheaders used to drill roads in underground mines, tunnels, and other underground buildings (Fig. 1a & b). Depending on the application, they take the shape of axially symmetrical rotary parts inserted in pick holders that are welded to the side surface of cutting drums or heads of various sizes and forms. Between the pick holders and the conical picks, there are frequently unique, interchangeable alloy steel sleeves that have been heat-treated to strengthen resistance to contact pressure and erosive and abrasive wear (Fig. 1c).

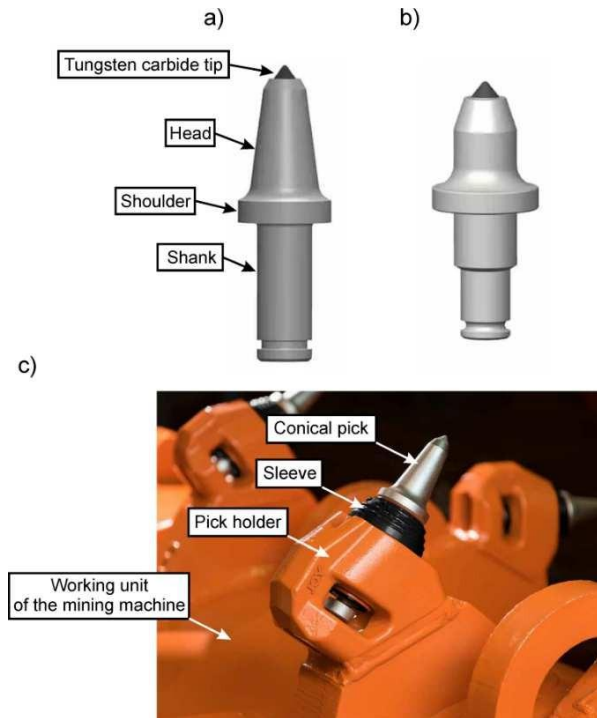


Fig. 1. Conical (point-attack) pick: a) U85/U85HD with a single shank (<https://www.jyfmachinery.com/product/u85-u85hd-style-cutting-picks-fitting-underground-mining-and-surface-mining>, 2020), b) TS30C with a stepped shank (<https://www.jyfmachinery.com/product/ts30c-cutting-picks-fitting-underground-mining-and-surface-mining>, 2020), c) mounted in a pick holder equipped with a sleeve (Komatsu, 2020)

Conical picks are known for their high efficiency because, when cutting, they naturally rotate in relation to their axes, ensuring that their heads, particularly the tips, wear down on a regular basis. The picks have a sort of "self-sharpening" as a result. As a result, the picks' service life can be extended and mining energy consumption can be decreased (Jonak, 1998; Liu et al., 2015; Dewangan and Chattopadhyaya, 2016).

The pick rotation process is frequently disrupted in mining shearers and roadheaders due to a variety of causes. When dust, particularly stone dust, is mixed with water used to spray the mining zone, the mixture frequently solidifies due to water evaporation, which is greatly increased by heating picks during working. It becomes challenging and eventually stops the picks from rotating due to deposits of hardened dust that cover the spaces between the pick shanks and the slots in the pick holders. Because the corrosion products have a greater volume than the corroded material, corrosion processes also prevent the picks from rotating. Longer gaps in the mining machines' work are favoring these negative events.

Conical picks are destroyed when they are unable to spin quickly. Pick deterioration is accelerated when wear takes on an unfavorable asymmetrical form. Then, more frequently, the cemented carbide tip chips or even completely separates from the pick shaft head (Dewangan et al., 2015; Liu et al., 2015; Dewangan and Chattopadhyaya, 2016). The energy consumption of mining then rises, vibrations become more intense, and there are significant dynamic surpluses that hasten the breakdown of the drives and bodies of mining machines. Additionally, the picks' temperature rises quickly, hastening their demise. The strong solder used to implant the picks in the pick shafts is even melted by it (Fig. 2). The picks on mining machines' heads and drums wear differently. The location of the specified pick on the side surface of the mining machine's working unit determines this (Tiryaki, 2004). This is caused by the uneven cutting conditions that each pick performs and the path that they come into

contact with the rock that has been mined. In addition to abrasive wear, the impact of picks on the mined rock causes numerous other types of wear.

such as adhesive wear, oxidation, micro fracturing, fatigue, thermal cracking, impact damage or chemical erosion (Singh et al., 2013; Sarwary and Hagan, 2015; Underground Mining, 2020).

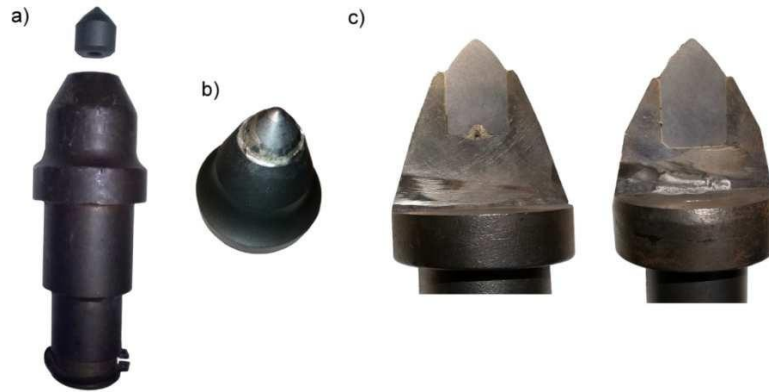


Fig. 2. The conventional method of fixing a tip in a conical pick shaft by brazing: a) components, b) view of a fixed cemented carbide tip, c) cross-section through a solder connection

Solutions that support the rotation of the picks in the pick holders and enable more robust clamping of the tips in the conical pick shafts should be sought in the scenario described (Kotwica, 2010; Prokopenko et al., 2016; Choi et al., 2017; Bołoz, 2019).

Fatigue fracture of the pick shanks is another kind of operating damage to the conical picks of the mining equipment (Luo et al., 2010; Lu et al., 2018) (Fig. 3). This kind of damage is less common than symmetrical and asymmetrical wear of the picks' heads and tip breakage (in 70–80% of cases, only the tips and the picks' heads are worn; Prokopenko et al., 2018). These damages, nevertheless, are more serious. The accumulation of strains in the shoulder's contact area with the pick holder due to digging pressures and the presence of a geometric notch in the shank's transition zone into the pick's shoulder is what causes the fatigue fracture effect. In this case, the direction of the resulting force from mining to the pick's longitudinal axis is crucial (Park et al., 2018). Large gaps in the pick seat within the pick holder exacerbate the pick's vulnerability to fatigue fracture. They could be the consequence of severe wear on the pick holder's seat surface or improperly chosen tolerances for the diameter of the pick shank and the socket in the pick holder. The picks instantly lose their capacity to cut rocks following a fatigue fracture of the shank, which happens abruptly and without any prior signs. The pick holders sustain significant damage very rapidly. The cutting drum or head must be removed and transported, typically to a repair shop, in order to fix any damage to the pick holders. This leads to substantial mining losses, expensive expenses, and a prolonged suspension of the shearer/roadheader.



Fig. 3. Examples of the point-attack pick with low tip wear and fatigue broken shafts in the transition area between the shank and the shoulder

To extend the fatigue life of conical pick shafts in the given scenario, every material and technological option should be employed. Using surface crush in the form of static or dynamic burnishing is one method to significantly extend the fatigue life of pick shafts (Cheluszka et al., 2019). The picks' resistance to varying loads is greatly increased as a result of the compressive stress created in the surface layer by the burnishing treatment, which delays and inhibits the development of fatigue cracks. Because the number of picks installed on the cutting heads/drums of mining machines typically ranges from 40 to 60, and in the case of roadheaders with transverse cutting heads, it can reach 90, the issue of ensuring high durability of cutting tools used in these machines is fundamental (Gehring K H and Reumüller, 2002). As a result, this roadheader has 180 picks. Additionally well-known are mining equipment with a special design that is intended to extract hard, extremely abrasive rocks in a longwall system (with a compressive strength of up to 120 MPa). Certain deposits of gold, copper, and platinum are mined using them. Compared to those previously described, they have a significantly greater quantity of conical picks (<https://www.engineerlive.com/content/mining-hard-rock-longwall-efficiency>, 2020). They can have two arms with two cutting heads each that are positioned in a plane perpendicular to the wall's face. These heads are capable of carrying between 126 and 168 picks. Consequently, 672 picks may be added to the shearer (Rock Straight System, 2020). Cutting tools are therefore expensive, particularly when wear and tear is increased.

In light of the aforementioned, research and development efforts have been conducted for many years to extend the mining machine picks' service life. Cemented carbides with a suitably chosen structure (like S-Grade, Sandvik), tips with a multilayer structure (like Sandvik XT-Grade), thermostable diamond composites, or ceramic materials are examples of increasingly superior, more wear-resistant materials for tips (Restner et al., 2007; Jonak, 2011; Li et al., 2011; Prokopenko et al., 2016; Vogt, 2016; García et al., 2019). In order to lessen the abrasive wear of the pick shaft head near the tip, further technological steps are also included. Examples include installing cemented carbide rings, applying synthetic diamonds (PCD) to the surface, using flat or round cemented carbide inserts, or hardening the pick shaft head's surface using methods like carburizing, laser, electric arc, HVOF, or nanoHVOF (Bołoz, 2019; Choi et al., 2017; Krauze et al., 2016; Luo et al., 2010; Mu and Min, 2009). The goal of these treatments is to lessen the pick's severe wear, which typically causes the tip to quickly peel and pull out of the mounting. The wear of the pick shaft's head need not be directly caused by the rock mining process; for instance, the pick's friction with the highly abrasive spoil and the spoil's recirculation might cause this wear (Underground Mining, 2020).

In order to increase the operational endurance of conical (point-attack) picks used specifically for hard rock mining, the article discusses a few technical and constructional aspects of their production.

Innovative ideas for altering the conical picks' structure were put forth, along with technological solutions and tools that would allow for their widespread industrial application. The advantage of the produced alterations is their minimal implementation costs, in addition to guaranteeing the potential of accomplishing the aforementioned goal. This is crucial to their industrial use's financial viability.

Modification of the construction of the conical picks for mining machines

Conical pick shafts typically have a cylindrical shank that is either graduated in diameter as it increases in the transition zone into the pick's shoulder (Fig. 1b) or has a constant diameter along the whole length of the shank (Fig. 1a). The larger the radius of the shanks and the average radius of the contact surface of the picks, the greater the moment of resistance opposing the rotation of the picks around their axis (conditioning even wear of the tip around its whole circle).

pick shoulder with the pick holder's front surface (Kotwica, 2012). To guarantee pick rotation, it would be advantageous to choose the shortest shank diameter and the smallest shoulder outer diameter. In turn, a wide surface area and a large external diameter of the shoulder are desirable to provide adequate resistance to contact pressure and resistance to abrasive wear. The pick shanks' big diameter is necessary because of their strong static and fatigue fracture strength. To reduce the negative impact of the geometric notch in this pick zone, it is also preferable to use the biggest transition radius between the shank and the shoulder (Fig. 4). The selection of the most beneficial dimensions in the sensitive zone of mining machine picks is challenging due to the stated opposing requirements.

The transition radius of currently produced conical picks used in mining machinery ranges from 1.5 to around 5 mm, with lower values predominating. In the meantime, using the same guidelines as for grading shaft diameters, the set-off's transition radii should be at least (Dębrowski, 2013):

$$R \geq 0.25 \cdot (D_{SL} - d_{SH}); [mm] \tag{1}$$

where:

- R – transition radius between the shoulder and the shank of the pick shaft [mm],
- D_{SL} – shoulder diameter [mm],
- d_{SH} – diameter of the shank of the pick shaft [mm].



Fig. 4. View of the transition area between the shank and the shoulder of a typical conical pick

For instance, the transition radius R should be more than $5\frac{1}{2}$ mm for picks with a shank diameter of $d_{SH} = 38$ mm and a shoulder diameter D_{SL} between 52 and 65 mm. Conversely, the transition radius $R > 6.9$ mm for picks with a shank diameter $d_{SH} = 30$ mm and a shoulder diameter D_{SL} from the previously stated range.

Using adapter rings between the pick holder or sleeve and the bottom surface of the pick shaft shoulder could be one way to help fulfill the aforementioned requirements. When the picks are placed in

hardened sleeves, such rings—made, for example, of alloy steel that has undergone heat or thermochemical treatment to obtain high hardness—allow for the efficient reconciliation of the aforementioned opposing needs. Fig. 5 shows an example of the adapter rings' form. The adapter rings reduce the pick shank's outer diameter and allow for a greater radius of transition into its shoulder. A fixed transition radius, as shown in Fig. 5a, is an option. Using a half-toroidal form (Fig. 5c) or shaping this pick zone with a variable radius R (Fig. 5b) with the maximum radius in the zone of transition into the pick shaft shank is a far more advantageous approach. This arrangement makes it possible to reduce the notch as effectively as possible, which increases the pick shafts' fatigue life.

Regardless of the kind of construction, surface deformation combined with shank burnishing can further improve the pick shafts' transition radius. Here, it is practical to shield this area from corrosive elements, such as by applying a heat-resistant varnish. In addition to increasing abrasive and erosive wear, the use of a modest angle β the slope of the abutment surface makes it more difficult for the spray water with dust suspension to enter the pick seat and pick holders (Fig. 5b).

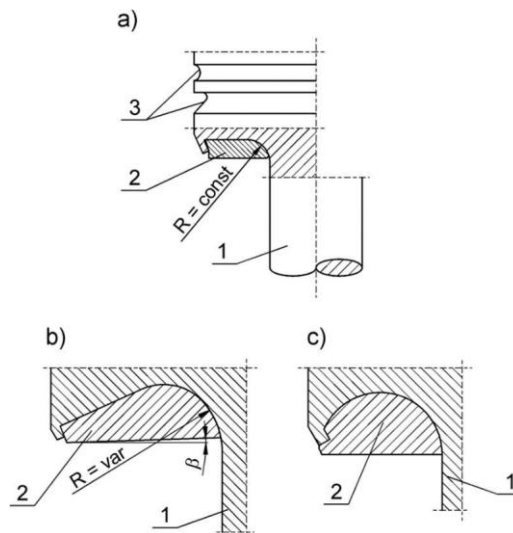


Fig. 5. Modification of the construction of the shaft of mining machines conical picks with adapter rings fixed by rolling the device from Fig. 6: a) adapter ring with constant radius $R=const$, b) adapter ring with variable radius $R=var$ increasing towards the shank and with a bevel at an angle β that facilitates the removal of dust and wear products from the friction area of the shoulder against the sleeve or pick holder, c) the half-toroidal adapter ring: 1 – shank of the pick, 2 – adapter ring, 3 – relief notches reducing stress concentration in the transition zone of the head of the pick into the shoulder

The adapter rings should be permanently seated in the pick shafts; this can be accomplished, for example, by rolling with the tool shown in Fig. 6. The adapter ring (2) is put into the opening (1a) of the shoulder (1b) from the shank (1c) of the pick shaft after the pick (1) is placed in the socket (9) with the high-friction insert (6) and fastened in the base (3). Then, as seen in Fig. 6c, the head (4) with the rollers (5) is lowered while rotating it about an axis (10) and applying longitudinal pressure until the pick's edge section (7) is finally created. The state prior to rolling the adapter ring is seen in Fig. 6b. A cover (8) is used to secure the rollers (5) in the head (4). A pillar drill, table drill, or vertical milling machine can be used to revolve and press the head (4). By permanently joining the adapter ring to the pick shaft, this process also safeguards the shaft's crucial zone, which is where pick shank fatigue fractures most frequently occur.

The conical picks with the suggested modification can be used in the cutting heads and drums of mining machines that are currently in use since they maintain the same external dimensions as conventional picks.

To lessen drag while the picks rotate, various sintered materials with friction coefficient additives, including graphite or molybdenum disulphide (MoS₂), can be utilized for the adapter rings. The adapter rings can be heated locally, for example, by high-frequency currents, or they can be rolled cold. Regardless of the technique used, the thermal cramp following the process further reinforces the achieved connection of the adapter rings with the pick shafts.

Positive-fit fastening of cutting tips in conical pick shafts

sometimes used brazing (Fig. 2) to secure cemented carbide tips in pick shanks sometimes fails to satisfy operating requirements, particularly in hard rock mining. Extreme weather might cause tips to deteriorate more quickly.

tip chipping and even complete extraction (Cheluszka et al., 2019). Hard, often brass solder softens and occasionally melts due to large temperature gradients that occur when cutting hard, extremely abrasive rocks. This is a result of improperly chosen cutting parameters and inadequate or inaccurate sprinkling of the cutting zone.

Figure 7 shows the method of fixing tips in conical picks shafts through a form-fit connection and a device for the practical implementation of the rolling process of tips (Cheluszka and Mikuła, 2019). This method consists of permanently setting the tip by hot rolling the material of the head of the pick shaft. The appropriate shape of the tip and its seating will ensure high operational durability of the connection with the simultaneous strengthening of the material of the head of the conical pick.

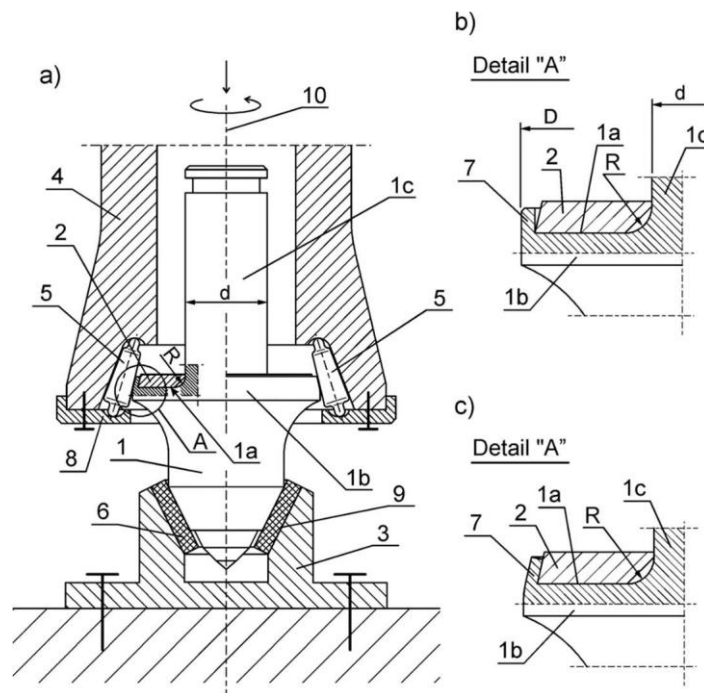


Fig. 6. Device for mounting adapter rings in the shafts of mining machines conical picks: a) the device when connecting the adapter ring (2) in the pick (1) by rolling the shoulder material, b) detail "A" before the rolling operation, c) detail "A" after permanent rolling of the shoulder material (7) on the adapter ring (2) (description of the operation and indications of the device elements in the text)

The pick (1) under processing has a cemented carbide tip (4) and a cylindrical seat (1b) in the shaft's head (1a). The cross-section of the tip should increase as it gets closer to the base. They may resemble a cone with a minor angle of sidewall convergence when the points are axially symmetrical. Once the material in the connection zone has been heated to a softening temperature, the tip is permanently attached to the pick shaft head by rolling with rollers (6). Heating can be done via a gas burner system or inductively. Using a bench or column drill, for example, the head (5) set in rotary motion presses the rollers (6) to the pick. The A separator (13) keeps the rollers (6) evenly separated in the head, and

a cover (12) protects them. A cooling system made up of a copper cooler (11) filled with cooling liquid (20) cools the rollers and head that are heated during rolling. The coolant temperature differential causes the cooling liquid to gravitationally circulate around partition (19). An air stream produced by a fan (9) attached to the head (5) gathers the heat from the cooler (11). Because the air entrance is on a smaller rotating radius than the exit, the airflow through the fan with spiral blades (10) occurs automatically while the head is spinning. In Figure 7, arrows indicate the coolant and air flow directions.

The complete cycle of the device illustrated in Fig. 7 is as follows. With the head (5) raised, the pick (1) is inserted into the tubular guide (2), in which it rests on the spring under pressure (3). After heating the pick shaft head to the material's softening temperature, the tip (4) is placed inside the seat (1b). When the pick is pressed through the rollers (6) by the lowered head (5), the springs (3) and (22) bend and the jaws (7), which are shielded by the cover (16), clamp down on the pick. Teeth (7a) cut on the inside of the jaws (7) securely imprison the pick. The loose connection with cylindrical inlets (15) prevents the jaws from rotating while permitting them to move along the hull's cone (14) (attached to the base (17) with pins (18)). By rolling the softened material of the pick shaft's head (1a), the rotation of the head (5) under increasing longitudinal pressure results in a permanent seating of the tip.

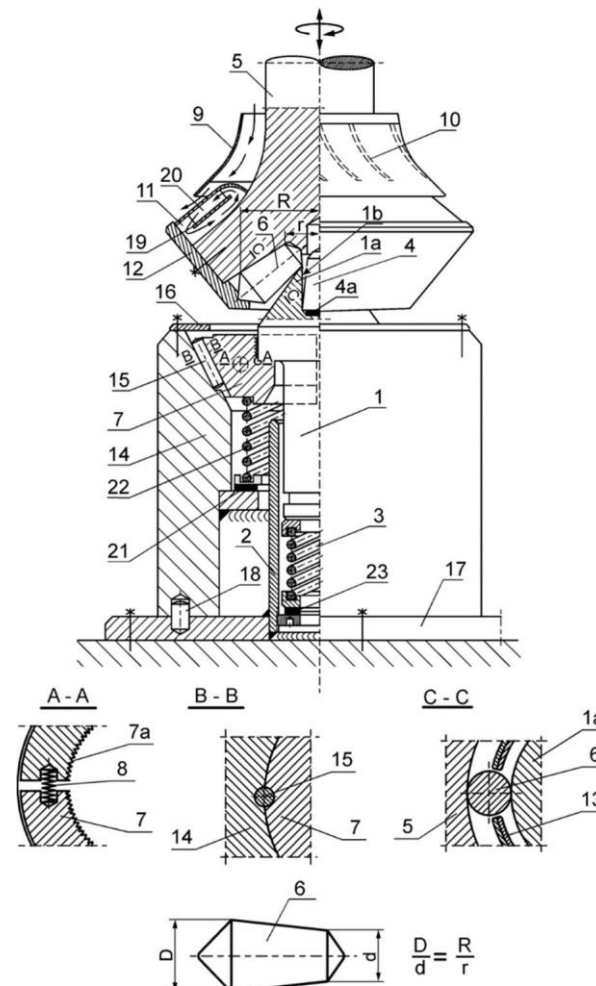


Fig. 7. Device for fixing tips of point-attack picks by rolling (description in the text)

In order to cool both the rollers and the head, the head (5) with the rollers (6) is raised while continuing to rotate after the tip has been rolled. The jaws (7) then open as a result of the spring (22) releasing their pressure (8). The pick is carried up by the tensioned spring (3) and is easily removed. A new pick

is then inserted, and the previously mentioned procedure is repeated. Spring tension (3) and (22) are adjusted via washers (21) and (23).

The pick shaft's head material shrinks on the tip when it cools down after rolling, strengthening the bond even more. Cooling the tip before placing it in the pick shaft seat can improve thermal shrinkage efficiency. To ease the distribution of tip contact pressure on the bottom of the seat, an alternative is to insert a thin metal disk (4a), such as brass, into the bottom of the seat before inserting the tip.

When cutting extremely hard rocks, this lessens the possibility of brittle cracks in the tip from pressures brought on by the impact pick's high impact loads.

The strengthening process by thermo-mechanical treatment can also be carried out using the pick shaft's head's plastic deformation. Steel's strength, hardness, and resistance to abrasive wear are all improved by heat-mechanical treatment (Dobrzański, 2007). Selecting the proper heating level, rolling time and speed, and chilling procedure after rolling the tips are all essential to maximizing the benefits of heat-mechanical treatment. Additional cooling of the picks' rolling zone, such as using an adjustable air stream, would therefore be beneficial. To achieve the optimal thermal-mechanical treatment effect, these parameters should be chosen during practical testing. This offers more chances to enhance the performance of conical picks, which are not achievable with the present tip brazing method.

It is possible to achieve significant improvements in pick durability and reliability at cheap costs, low energy consumption, and solder savings by using the disclosed method of mounting the tips and the device for its implementation. Having the apparatus described, any machine tool having a vertical spindle can be modified to carry out the process. Significant financial outlays are not necessary for this.

Conclusions

Blocking the picks' ability to rotate around their axis while cutting is one of the causes of increased operating damage to mining equipment' conical picks. The consequent uneven wear of the picks raises the energy consumption of the cut and the possibility of pick shaft fatigue fractures. The structural changes outlined in this research can improve the picks' rotational conditions and increase the pick shafts' resistance to fatigue cracking. It is feasible to provide the necessary high resistance to contact pressure and lower the resistance of movement of the pick relative to the associated pick holder during the pick rotation by utilizing an adapter ring with appropriately designed mechanical characteristics (which is an integrated part of the pick). These rings can be manufactured of sintered materials with additions that lower the friction coefficient or alloy steel that has undergone the proper heat and thermochemical treatment. As a result, these rings' physicochemical characteristics can be shaped independently of the pick shafts. The potential to greatly increase the radius of the pick shaft's shank transition into the shoulder is a major benefit of using adapter rings. The radius of the transition might be either constant or, better yet, variable. Because the impact of the geometric notch is lessened, the fatigue life of the pick shafts in this sensitive zone is significantly improved. This will lessen the pick shaft fatigue fracture issue, which is by no means an isolated occurrence.

It is sturdy and dependable to secure the adapter ring by rolling the shoulder's edge on it. By appropriately structuring this ring's contact surface with the pick holder's face or sleeve, water with a dust suspension cannot penetrate the pick seat in the pick holder, preventing the pick from becoming blocked and preventing its rotation.

There are numerous practical benefits to the hot rolling technique for attaching tips to conical picks that is suggested in this article. It does not require the solder to join pick shanks to tips. The soldered connection of

these elements does not satisfy the durability criteria, as observed under working conditions. This is especially true for picks meant for cutting hard rock that are subjected to high temperatures, which could cause the solder to soften or even melt due to the severe abrasive impact of the rock being mined and damaged. Even in the case of severe abrasive wear on the shaft head, the developed connection of the pick tips with their shafts remains inseparable for the duration of the picks' lives. It fits the use in a nice way. of the effect of thermal shrinkage. The device described in this work cooperating with typical machine tools with a vertical spindle can be used to perform the rolling operation of the picks.

This work presents modifications to the technology and design of conical (point-attack) picks that significantly reduce their wear and tear intensity, particularly in hard rock mining. The technology that has been developed to produce picks with a modified design does not significantly raise the expenses and financial outlays associated with making picks for mining machines.

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