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DIALECTICAL MECHANISM OF IMPROVEMENT OF ROCK BREAKING TOOL

The review and analysis of the process of the rock breaking tool improvement from the primeval age and to the present day enabled disclosing and substantiating dialectical opposites and identifying contradictions between them, which defined evolution of the tool through its history. The essence of the notion of a cutting pick is revealed as a material concentration of destructive energy. The determined hierarchy of dialectical opposites exposes the process of the cutting pick essence materialization in a certain thing. The presented sequence of dualities and their contradictory relations is a framework of the dialectical mechanism of the rock breaking tool improvement. The qualities of a rock breaking tool and the dialectical opposites, which govern these qualities, are identified. The logic of enduing the tool with qualities is revealed, starting from the effectiveness, i.e. actual feasibility of destruction of a matter by another matter, up to the implementation of this function better than other rival tools, i.e. competitive ability. In terms of the dual structure–design pair of a cutting pick, the process of resolution of contradictions between them, which transfers their interaction to a next engineering level, is discussed. Participation of the three laws of dialectic in the process of design improvement of cutting picks for mining shearers is described. The recent trends of change in the qualities of the rock breaking tool and the results of the tool operation display new inconsistencies and define directions for the further research.

Keywords: *mine shearer, rock breaking tool, cutting pick, dialectical opposites, contradiction, essence, thing, development, mechanism, improvement, duality*
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Introduction

Rock breaking tools belong to the ancient working tools created by human beings and possessing a special property owing to the spear point — it can generate high pressure at the contact with rock, which is sufficient to separate pieces of rock from rock mass [1]. As humans dug deeper underground, they needed a more prefect tool to break a stronger medium. During its historical development, the rock breaking tool passed a long way described in many scientific works [2–5].

Recent research aim at improvement of shearer cutter designs [6–8], development of methods and technologies of rock breaking tool manufacturing [9–11], analysis of the tool efficiency [12–14] and at setting its operational patterns [15, 16]. Furthermore, there are studies into the rock–tool interaction patterns [17], adaptability of the tool to different operating conditions [18], and into the possibility of enhancing the tool durability and reliability [19]. The strength and structural features of the tools are tested [20], and the ways of the tool strengthening and service life extension are developed [21, 22].

Both Russian and foreign researchers perform application investigations of the rock breaking tool properties and operating factors of shearer cutters [23–26], and develop theory of rock disintegration by cutting tools [27, 28].

The recently completed research works provide an insight into the history of the cutting tool improvement, analyze the tool evolution stages, determine the quality characteristics and examine the tool development laws. However, insufficient attention is yet paid to dialectic of improvement of mining shearer picks, their forces and force ratios and correlations with qualities of picks, which is the objective of this paper.

Methods

The methodological framework of the research was the earlier and recent studies on design and engineering of rock breaking tool, its operating conditions and results, as well as history of its improvement. The logic of driving forces and performance mechanism in history of improvement of shearer picks was disclosed using the dialectical method of cognition of contradictions between the opposites in the unity of a cutting tool. The structure and functions of the cutting tool were analyzed in different periods of time. The essence of a rock breaking tool was revealed using the method of cognition of the essence of things by A. Schopenhauer [29]. The research also involved the methods of observation, scientific analysis and generalization. The factual information was the accumulated knowledge about design variants and application experience of cutting picks on heading and shearing machines in mines in Kuzbass, Russia and in the world.

Research findings

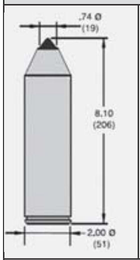
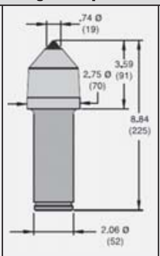
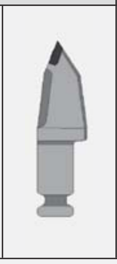
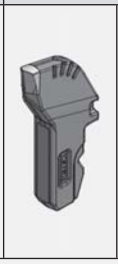
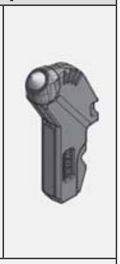
Dialectical opposites and their contradictions in cutting picks

A cutting pick is essentially a material concentration of destructive energy. Such concentration results from the creation of the energy space in the form of a tip or a nose. In the course of history, humans filled the energy space in a cutting pick with different matters inalterably acuminated into a point or a line.

A cutting pick started from selection or sharpening of natural products (wooden or stone) by a human up to getting a scrubber or a chipper [5]. During subsequent evolution, a human being learnt to fill the tip or nose space with a bronze, iron or steel matter [1]. By now, it is possible to cut a matter by another matter tapered to a plasma jet or a laser beam [30].

Regarding a cutting pick of a mining shearer, its essence is hardness which cuts another hardness by a cutting point. The cutting point allowed reaching a high penetration strength even when a weak human being broke a very strong rock by a hammer pick or a hack [5]. Cutting picks for mining shearers are nowadays manufactured by many producers both in Russia and abroad. Consequently, there is a wide variety of shapes of cutting picks, their designs, sizes, methods of mounting and fastening on a shearer, qualities of materials, etc. Cutting picks may be radial picks, set on the cutting head of a shearer in perpendicular to the cutting plane, and tangential picks set on the cutting head at an angle to the cutting plane [1]. The **Table** describes the types of the present-day cutting picks and their characteristics.

Types of shearer cutting picks

Tangential picks			Radial picks	
				
Characteristics				
Rod-type conical cylinder, rotary [31]	Stepped-type conical cylinder, rotary [31]	Flat edge, fixated [1]	Flat edge, fixated [32]	Flat cone, fixated [32]

The analysis of various shearer cutting tools, their shapes and designs, generalization of the results and their correlation with the essence of a cutting pick made it possible to reveal the opposites of the notion and their logical connection. The essence (E) of a cutting pick on the way of materialization into an occurrence (O) by means of resolution of dialectical contradiction (DC) passes a series of stages (**Fig. 1**):

— space and matter (S–M);
— matter and shape (M–Sh);
— shape and structure (Sh–St);
— structure and design (St–D);
— design and technology (D–T).

Performance of each duality shows up as a certain quality of a rock breaking tool (effectiveness, energy/output ratio, material consumption, safety, efficiency, operational economy), which leads, finally, to competitive ability of an occurrence named a rock breaking tool.

Interaction of opposites has a contradictory and ambiguous nature. Resolution of dialectical contradiction contained in the pair of dialectical opposites has a trend and ensures a certain level (high, medium, low) of a quality of a tool. Removal of contradiction in a duality can lead to both improvement or worsening of other properties of a tool. For example, the current increase in operational economy of rock fracture by tangential-rotary picks results in the higher energy/output ratio and lower safety of the process as compared with the earlier used radial edge cutters.

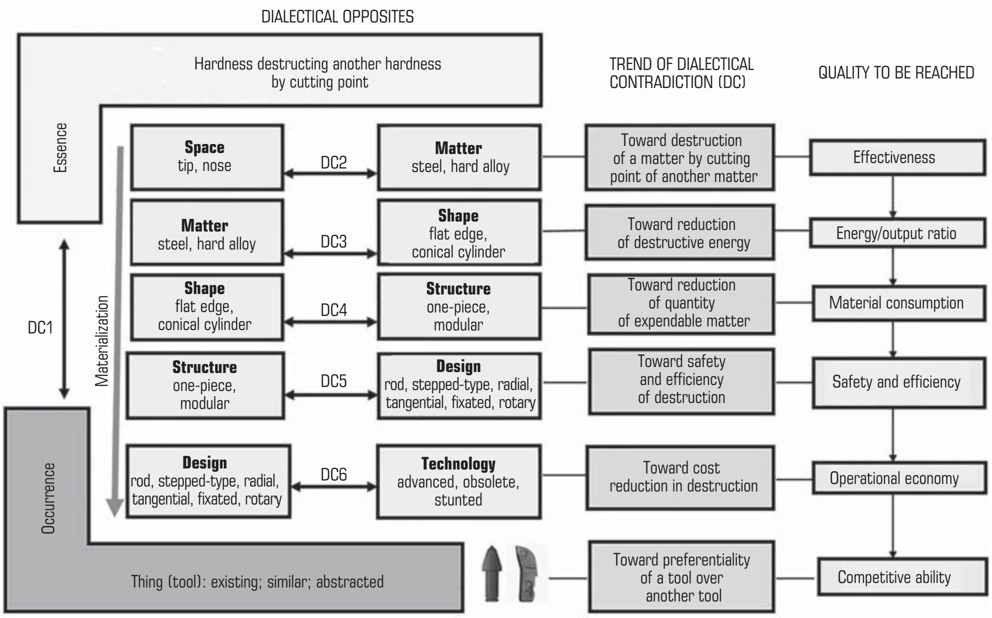


Fig. 1. Dialectic of essence of mining shearer cutting tool

Let us discuss the listed above opposites and their interaction. The main pair of opposites Essence–Occurrence features dialectical contradiction DC1 which means the tendency of an essence to the complete and exact materialization as a specific thing, and the inability of the latter to do the same. Resolution of this contradiction runs as saltatory evolution with gradual improvement of the occurrence and its qualitative replacement, for instance, when a stone cutter is replaced by a bronze cutter, a bronze cutter is the replaced by an iron cutter, etc.

In the second S–M pair, there were and are DC2 between the human necessity to break a stronger matter and the nonconforming fill of the tip or point space of a cutting pick to meet this requirement. Effectiveness of destruction of a matter to be achieved needed to find a stronger and deformation-resistant matter of a cutting pick. That is why a wooden matter was replaced by a stone matter, then, by a bronze, steel, water, hard alloy, diamond, and, in the recent years, by a plasma and laser matter [33].

Physical properties of the matter of a tool (density, hardness, viscosity, heat resistance, wear resistance) are the framework for the formation of such quality as the effectiveness, i.e., the achieved result of destruction of a matter by another matter. The modern capabilities of steel and hard-allow materialization of a rock breaking tool ensure its effectiveness and enable cutting very strong and abrasive rocks at great depths.

The M–Sh duality in a cutting pick is supposed to minimize energy spent for destruction and governs the energy/output ratio of rock fracture by a cutting pick. A flat edge shape of a hard-alloy matter ensures low cutting force spent to separate a piece of rock from rock mass by a radial pick [34]. At the same time, there are some difficulties in manufacture of such picks, rapid wear of the pick edges, with formation of blunt areas needed to be sharpened, as well as high probability of chipping of the edges and their short service life [1]. The DC2 contradiction was resolved 30 years ago by reshaping of the picks into conical cylinders with engineering of the tangential-rotary picks.

The contradiction DC3 of the next Sh–St stage is defined by the need to cut down consumption of the matter of a pick in destruction of another matter, and conditions the level of the material content of the disintegration process. Both flat and cylindrical shapes of a one-piece pick lead to quick discard of the whole tool after runout of its small working part. The modular structure of the cutting tool offered a possibility to save a steel matter within a series of operating cycles by means of replacement of only a worn component [23].

The unity of the structure and design (St–D) is governed by the fact that the structure is the main arrangement of a design or a series of designs. At the same time, St–D act as the opposites in an ensemble named a "thing", and reflect the inside and outside of the latter. The dichotomy of a thing governs the constitutional appearance of DC5 contradictions between these sides. The trend toward improvement of the sides of the duality in terms of safety and effectiveness of the destruction process creates the certain qualities of rock cutting tools.

A progressive design proposed by scientists for a cutting pick is not a guarantee of a high-quality tool with a long service life. Here we face the contradiction DC6 of the D–T duality governed by technological capacities and organizational capabilities of a certain producer to manufacture a cost-effective item of an innovative design.

A specific item (a thing materialized from an essence) manufactured within a certain design and using a certain technology of transformation of a matter, and set in a mine may become existing, i.e. conforming with the essence, and highly competitive. The item may be only similar to the essence of a pick manufactured using an obsolete technology which produces a pick of the required shape and design, but of a low quality, a short service life and low economy. It also may happen that a pick is far from its essence because of using inadequate materials, or due to a technological failure, which leads to discard of the pick and to economic loss caused to a consumer.

An existing pick within its range of application preserves its tip or nose space for a long time, which resolves the space–time contradiction in favor of the former and ensures preferentiality of a tool over another tool. This contradiction, which is a content of another system, will be discussed in the next study.

Mechanism of resolution of dialectical contradictions

Resolution of dialectical contradictions is a global tool of advance of everything that exists [35, 36]. A contradiction contains an impetus for self-modification, a source of development, a force that converts a thing into something else [37, 38]. Regarding a rock breaking tool, we consider the resolution mechanism of dialectical contradictions between opposites (see Fig. 1) in terms of the St–D opposites and their DC5.

A structure and a design, as dialectical opposites of a thing, participate in the continuous process of origination and resolution of contradictions, which is supposed to be as follows. First, individual and weak discrepancies or disagreements arise between the sides. Accumulation of nonconformities between the structure and design leads to the growing gap between the opposites and to the appearance of differences. Extreme difference reached between the sides of a duality results in the formation of a contradiction up to a confrontation. The resolution may be achieved by [37]:

- alteration of one of the sides;
- bilateral alteration of both opposites;
- removal of both opposites and their replacement by a new duality.

Removal of nonconformities by a human being leads to the evolutionary perfection of a tool and relax but fail to eliminate completely the tension between opposite sides. Removal of the tension finally happens as an evolutionary jump, or as an essential change of the content of a thing. This dialectical mechanism of development of a cutting pick is illustrated in **Fig. 2**.

A radial pick (RP) widely applied by the late 1900s in the coal industry possessed a fixated flat design with a working edge representing an edge of a cobalt tungsten prism. The pick was a one-piece structure with rigidly connected components. The pick was a satisfactory tool for practitioners in terms of its operating qualities kept for a long time. However, step-by-step accumulation of the structure and design nonconformities 1 resulted in growing discontent with the quality of the item, initiation of difference 1 inside the duality and in appearance of contradiction 1. Resolution of the latter (ResC1) took place in favor of the design and led to a tangential-nonrotary pick (TNP) possessing better operating qualities. Finally, the pick experienced a jump in its cutting capacity and production efficiency ΔEf_1.

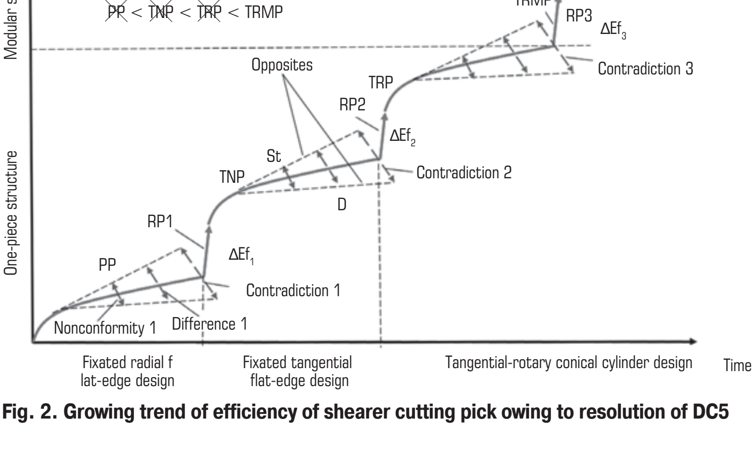


Fig. 2. Growing trend of efficiency of shearer cutting pick owing to resolution of DC5

At the end of the next cycle of the tool development, new contradiction C2 arose inside the St–D duality, which was resolved in favor of the design again. A novel tangential-rotary pick (TRP) ensured a jump in the quality and in the efficiency ΔEf_2 of the tool. By now, the tool of this design is the main rock breaking tool used on heading and stoping machines [1, 34].

At the same time, the increasing concern of advanced societies over low resource-saving and high waste production in industries in the early 2000s placed new standards for the resources used in mining. New nonconformities appeared and grew in DC5. The reached levels of metal consumption, efficiency and cost of rock cutting were no more satisfactory for the users of cutting picks. New contradiction 2 was resolved with time in favor of the structure with engineering of a modular version instead of a one-piece tool. The incremental efficiency ΔEf_3 of a tangential-rotary modular pick (TRMP), alongside with the resource-saving, exceeded the performance of the earlier structure owing to multiple usability of the tool. The quantity of rejected metal reduced, and re-use of the accumulated worn picks became possible [39, 40].

The trend of increasing the pick efficiency grows cyclically in the course of time. Intra-cyclic evolution of a cutting pick occurs in accordance with the first law of dialectic by way of accumulation of quantitative changes with a subsequent jump in quality [41]. The jump comes to life in accordance with the second law of dialectic — the unity and struggle of opposites [41]. Regarding the third law of dialectic (negation of the negation) in improvement of a rock breaking tool, the tangential pick TNP appeared as the negation of a radial pick and eliminated its contradiction 1. Then, the fixated design of the tool accumulated contradiction 2 and gave place to the tangential-rotary design TRP. The best thing negated a good thing which, in its, turn, appeared as a result of the negation of the earlier flat design RP which was a good thing in its time. This relationship can be expressed as follows:

~~RP~~ < ~~TNP~~ < ~~TRP~~ < TRMP.

Every next structure–design relation outclasses and negates the previous relation. That is why RP and TNP stopped to be used and gave place to TRP [1] which also were negated with time and replaced by TRMP [42].

Discussion

Dipping into the essence of the notion of a "cutting pick" revealed a system of dialectic opposites on the way of materialization of an essence into a certain thing. The described sequence of elements and their contradictory relations exposes the mechanism and logic of dialectic perfection of a rock breaking tool by a human being. This avenue of development starts from effectiveness, i.e., feasibility of destruction of a matter by another matter, and goes up to the best performance or the highest competitive ability.

The dialectical opposites in the notion of a "cutting pick" and the mechanism of resolution of their contradictions allow shifting to the analysis of the quality of the tool and the quality of the tool work in a mine — destruction of coal–rock mass. The tendencies of the change in these qualities with the change in the cutting pick design are illustrated in **Fig. 3**.

The main quality of a cutting pick — efficiency, i.e. amount of broken rock during service life — increases with improvement of the design. Cost per unit of rock cutting decreases. At the same time, rejection of edge-type designs of RP and TNP, and transition to the conical variant of the working part of the cutting tool led to a decrease in the grade of coal products: the percentage

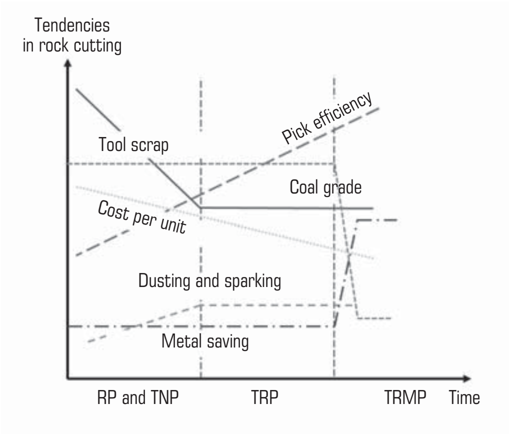


Fig. 3. Tendencies in rock cutting by different design picks:
RP – radial pick; TNP – tangential-nonrotary pick; TRP – tangential-rotary pick; TRMP – tangential-rotary modular pick

of the unwanted fine particles and dust grew significantly up to 60–70% [6, 19]. Dusting at cutting and heading faces increased, and the working environment of miners worsened. Cutting of rocks by a conical pick involves intense sparking [18]. The need to suppress dust and sparks necessitated improvement of water spray systems at faces. The existing systems need high water flow and not always operate faultlessly. Rocks get over-wetted, it becomes difficult to perform shipment of such rocks, and productivity of shearers drops.

As the working part (15–20% of weight of a cutting pick) wears off, the tool goes to scrap as its operation is no more possible and regulations require installation of a new tool. In the meanwhile, 80% of the pick remain unworn but this metal goes to scrap nevertheless, which is wasteful for the mine economy and for resource saving. Replacement of a one-piece structure of a conical pick by a modular structure, and engineering of TRMP moved DC4 to a next level of interaction. Preservation of the holding module for a long time allows a substantial reduction in the amount of metal scrap and an increase in the metal saving during coal–rock mass cutting [42].

At the same time, the higher safety of work and the better grade of coal leads to the aggravation of the dialectical contradiction in the structure–design pair. The need to resolve this contradiction increases relevance of research aimed at improvement of structure and design of a cutting tool. For another thing, the other contradictions require scrutinizing and finding new solutions for changing their interactions.

Summary

1. The exhibited hierarchical scheme of dialectic opposites in the notion of a rock breaking tool is a flat representation of a dialectical level-wise spiral of the tool evolution sent upward from an essence to the materialization in the form of a thing, through space, matter, shape, structure, etc. with resolution of contradictions at each step.

2. The quality of a rock breaking tool is mostly governed by interaction of a certain pair of dialectic opposites.

3. The interaction of dialectical opposites in a cutting pick features a contradictory jump-wise evolutionary behavior which conditions the cyclic improvement of the rock breaking tool.

4. The relation of qualities of a rock breaking tool helps disclose its operational insufficiency and shows the need of the in-depth study of interaction between the found dualities and aggravating contradictions between them.

Conclusions

Generalizing the aforesaid, we can derive a formula of the proposed mechanism –– the dialectical mechanism of rock breaking tool improvement –– as a converter of interaction energy of contradictory forces, including interaction of six pairs of dialectical opposites, their step-by-step involvement in materialization of an essence of a tool in a specific thing, the jump-wise evolutionary cyclicity of appearance and resolution of dialectical contradiction inside dualities, and connection of each pair with a certain quality of the tool, and enabling understanding philosophical depth of the process of the tool evolution, setting courses, predicting results and managing the process of improvement of the tool qualities.

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TRACKING PREVENTION IN ROLLER CONE BIT DRILLING

In the world practice of open pit mining, drilling is mainly carried out using roller cone bits. The cost of drilling totals 25–40% of the overall cost of mining. One of the factors which worsen drilling efficiency is tracking which occurs when spiked teeth of the cones fall into the same craters cut during previous rotations of the bits, and which increases wear of the drilling tool and decreases the rate of drilling.

This article proposes a calculation algorithm for the contact paths of teeth in the peripheral rows of roller cones using actual involutes of toroidal surfaces in the periphery of the well bottom. The algorithm provides a sufficiently accurate mesh of coverage of the well bottom periphery by tricone drill bits with the offset spin axes of roller cones with a view to preventing tracking.

The proposed algorithm can be used for the design and reasonable selection of the roller cone bits with regard to geological conditions of drilling.

Keywords: *roller cone bit, tracking, peripheral teeth row, path, contact points, coverage mesh, tooth*

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Introduction

At the most open pit mines in the world, drilling operations mainly use roller cone bits, except for drilling in very strong and hard rocks which are drilled with diamond drill bits [1, 2].

Reduction of drilling cost is achievable through the optimized choice of the drilling mode and drilling tool [3]. Optimization of geometrical parameters, headway cost saving and increase in durability of drill bits are the source of enhanced efficiency of the drilling tools [4, 5].

One of the most common phenomena which decrease efficiency of well bottom drilling is tracking [6, 7].

Tracking occurs when destructive elements — tungsten–carbide or steel teeth — fall into the craters cut during previous rotations of a drill bit. Drilling efficiency drops as a result as the well bottom breaks at the contact with tooth surfaces rather than