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Bucket working bodies with conveyor bottom: systematics and design features

Yu. M. Lyashenko[1], E. A. Revyakina[2], A.Yu. Lyashenko[1]

[1] Shakhty Institute, Branch of Platov South-Russian State Polytechnic University (NPI) (Shakhty, Russian Federation)

[2] Don State Technical University (Rostov-on-Don, Russian Federation)

Introduction. The creation of new types of bucket working bodies of excavators through synthesizing technical solutions to improve the transporting functions of the bottom is considered. These solutions are based on reducing the resistance and energy consumption under digging-in and scooping due to the transition from sliding friction to rolling friction during the movement of the rock mass along the bottom of the bucket.

Materials and Methods. Analysis of the bulk materials handling processes using existing loading appliances identified design flaws that affect the efficiency of their operation. Advanced design diagrams of loading bodies were searched on the basis of the accumulated experience and the study of the morphological features of the existing equipment. Combinatorial analysis of possible combinations of elements with their various qualitative compositions, mutual arrangement, imposed links, and synthesis of new technical solutions for loading and transportation modules are carried out.

Results. The results of the morphological synthesis implementation were the systematization and development of designs of bucket working bodies with a bottom in the form of a roller surface and a closed belt, as well as with a conveyor-type drive mechanism. The application of rollers as a supporting surface of a loaded rock mass causes a decrease in friction forces and in the power capacity of the work process. In addition, rotating rollers provide uniform abrasion of the working surface, which increases significantly the time to the equipment breakdown and increases the process efficiency. Working bodies with a drive mechanism make it possible to activate the interaction of the conveyor bottom in the form of a closed belt with the rock mass and, as a result, to accelerate the process of filling the bucket container.

Discussion and Conclusions. The bucket working bodies described in the paper compare favorably with existing analogues in that they provide a reduction in the time to digging-in, scooping and unloading, a decrease in specific energy consumption, an increase in bucket filling, which ultimately contributes to an increase in productivity. A slight increase in the structural complexity and cost of the working body causes additional capital costs, which are paid back within two to four months.

***Keywords**:* bucket working bodies, loading process, working cycle operations, extraction-and-loading machines, conveyor bottom, roller surface, mechanical transmission, hydraulic cylinder, hydraulic cylinder rod, friction.

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Introduction. The technical level of mining and conveying equipment for surface mining operations is determined by the constructive perfection of both the machine as a whole and its bucket working body[1, 2, 3]. It is possible to increase the technical and performance figures of the equipment through using, first of all, the working bodies of rational designs and parameters.

[1] Podehrni RYu. Mechanical equipment of quarries. 5th ed. Moscow, 2003. 606 p. (In Russ.)

[2] Drozdova LG, Kurbatova OA. Single-bucket excavators: design, installation and repair. Vladivostok, 2007. P. 48–56. (In Russ.)

[3] Khazanovich GSh, et al. Research directions and results of on creation of tunneling equipment of new technical level. In: Proc.Sci.-Pract. Conf. on Actual questions in scientific work and educational activities. Tambov, 2013. P. 148-152. (In Russ).

Analysis of the mechanization means of loading rock using currently operating extraction and loading machines (excavators) identified factors affecting the efficiency of their operation[4]. Fig. 1 shows a bucket of a commonly used design with a smooth bottom.

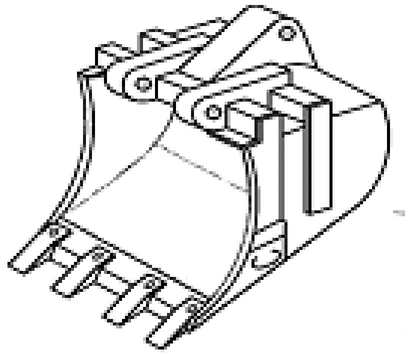


Fig. 1. Bucket working body with bottom in the form of smooth surface

It is established that the design improvement of the bucket working body is aimed mainly at reducing resistance to the bucket penetration into the pile [1]. The work objectives are to systematize new technical solutions of working bodies developed by the authors, in particular, with a conveyor bottom, to analyze their design features and improved working qualities, i.e., to consider the development trends of this class of equipment. Major tasks of the work are as follows:

— rationale for the fundamental approaches to changing the design of the bucket working body elements;

— determination of the functional and structural analysis feasibility to select directions for improving the design of the bucket;

— development of classification features characterizing excavator buckets with reduced resistance to penetration;

— preliminary qualitative assessment of new technical solutions.

Materials and Methods. According to the results of graphic-analytical and physical modeling of the “bucket — rock pile” system, it is found that the resistance to the penetration of the bucket working body into the pile depends significantly on the friction factor of the submerged material over the surfaces of the bucket [2, 3]. When synthesizing technical solutions of bucket working bodies with a constructive novelty, the problem of reducing the friction factor of rocks on the bottom of working bodies through transition from sliding friction to rolling friction was solved [4].

The creation of samples of new types of working bodies is a complex, multi-stage task. The first stage in determining promising design diagrams of bucket working bodies was the study of the accumulated experience and the establishment of morphological features of the existing equipment (Fig. 2).

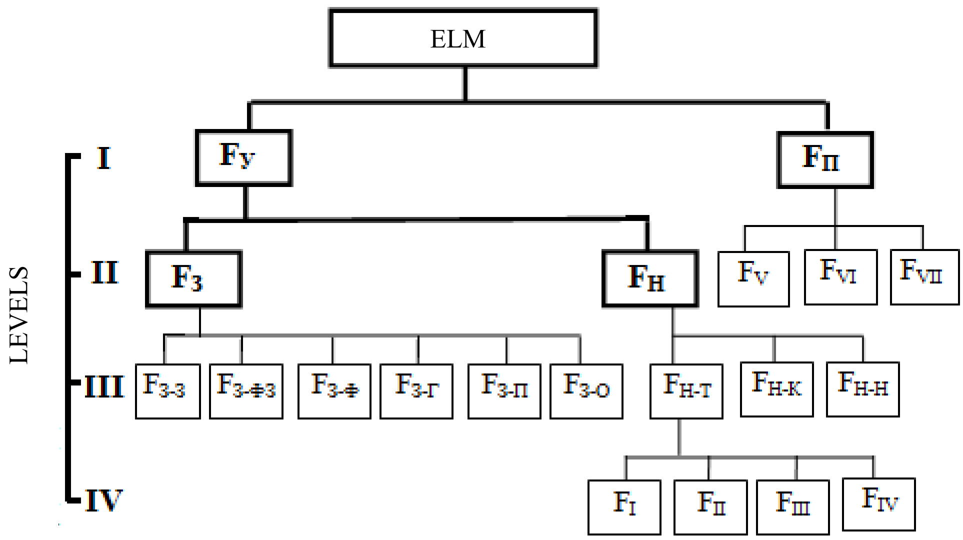


Fig. 2. Functional model of an extraction-and-loading machine (ELM)

[4] Khazanovich GSh, Lyashenko YuM, Nikitin EV. Experimental technique in study of processes of loading and transportation of lumpy rocks. Novocherkassk, 2003. 150 p. (In Russ).

The compiled functional ELM model includes the following set of actions: $F_{у}$ — to remove the rock mass; $F_{п}$ — to provide special motion; F_{3} — to scoop up the rock mass detached from ground; $F_{3\text{-}3}$ — to form the bucket capacity; $F_{3\text{-}ф3}$ — to provide functioning of the tool for formation of the bucket capacity; $F_{3\text{-}ф}$ — to service the face line; $F_{3\text{-}г}$ — to service the face in depth; $F_{3\text{-}п}$ — to transfer the element of forming the bucket capacity to the place of release from the portion of material; $F_{3\text{-}о}$ — to provide releasing the element for forming the bucket capacity from the portion of the material; $F_{н}$ — to accumulate and reload the scooped rock mass; $F_{н\text{-}т}$ — to provide the transportation (displacement) of the rock mass; $F_{н\text{-}к}$ — to provide maintenance of contact with the subsequent vehicle; $F_{н\text{-}н}$ — to provide the accumulation of rock mass; F_{I} — to keep the rock mass in the process of transportation (displacement); F_{II} — to apply an acting force to the rock mass; F_{III} — to transfer the acting force from the drive to the final elements; F_{IV} — to transfer the bearing element with the rock mass detached from the ground; F_{V} — to take up crowd forces and fix the position of the system functional elements; F_{VI} — to convert the energy supplied to the drive into transition of the system kinematic condition; F_{VII} — to combine functional elements of the system for the joint operation.

The proposed differentiation of functional features enables to enter an elemental level of the structure formation of individual mechanisms of extraction-and-loading machines. The impossibility of further fragmentation of the major functions (macrofunctions) into subordinated ones (microfunctions) without a transition from the function to the objective form of their execution was a signal to complete the functional analysis.

Taking into account the developed functional model of the extraction-and-loading machine, a morphological table was worked out, with the help of which the structural and morphological features of a technical solution with a constructive novelty were formed [4] (Fig. 3).

Research Results. The result of the practical implementation of morphological synthesis was the developed design of a bucket with a bottom in the form of a conveyor [5]. The use of a closed belt as a load-carrying body and a supporting surface of the submerged rock mass provides the exclusion of spillage and jamming of the submerged material. This design is characterized by a low friction factor of the rock mass against the bottom in the form of a closed belt resting on rollers. Therefore, a decrease in the energy intensity of the working process, which will provide an increase in the productivity and reliability of the bucket working body, is expected.

The concepts of the efficiency of equipping the working bodies with roller elements when loading rocks were further developed in the novel design of the working body of the loading and transportation module with a cyclic actuator. The proposed loading and transportation module, equipped with a closed belt, differs from the existing analogues in the increased displacement rate of the rock mass; it provides the continuity of loading the material during the cyclic operation of the working body. All this contributes to an increase in productivity and efficiency of the work process while eliminating the possibility of spilling and jamming of particles between the rollers. Equipment of the transport roller in the conveyor bottom with a drive also allows increasing the efficiency of the bucket working body. This solution provides a reduction in the time of penetration, scooping and unloading operations, an increase in the filling of the bucket and, therefore, contributes to an increase in productivity [6].

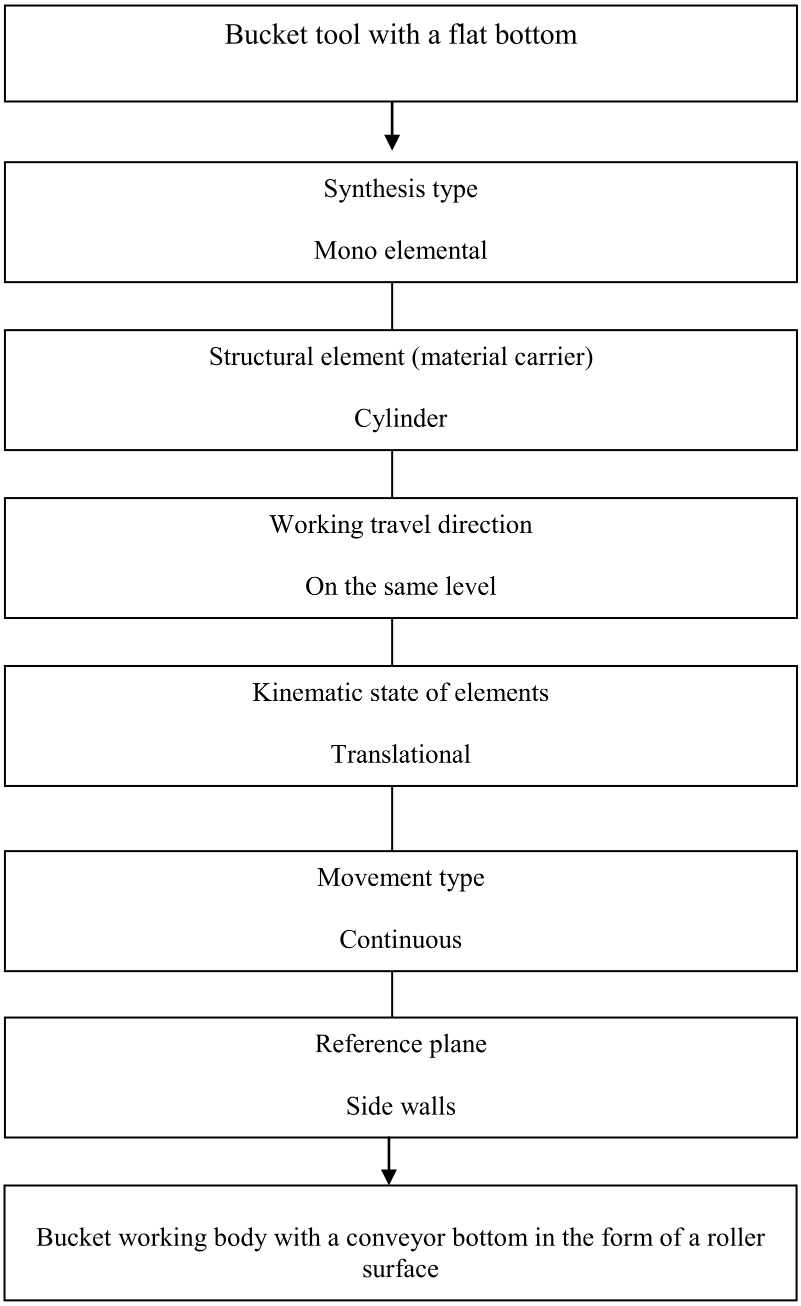


Fig. 3. Formation of structural and morphological features of a structurally novel technical solution

The models of buckets with a conveyor bottom developed on the basis of the above principles form a new constructive and technological group of loading bodies that can be used on excavators, bucket loaders and other handling equipment. Below, these technical solutions are presented through a combination of two groups of structures characterized by a bottom in the form of a roller surface and in the form of a closed belt (Fig. 4) [7]. In turn, structurally, models with a closed belt are divided into non-drive ones and with a belt drive mechanism, which can be implemented from an electric motor with a mechanical transmission and using various options for hydraulic power cylinders.

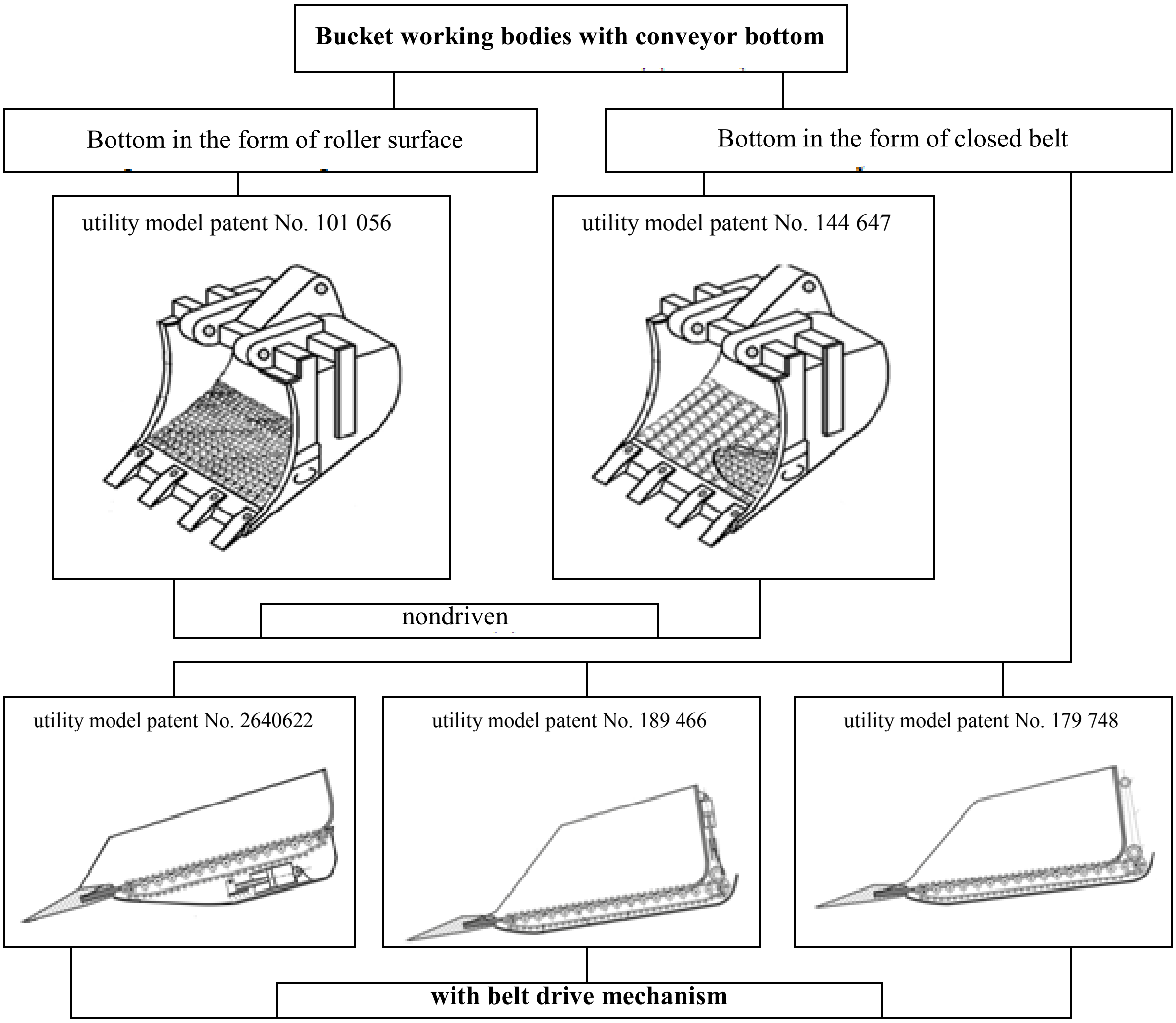


Fig. 4. Systematics of bucket working bodies with a conveyor bottom

Let us consider the design features of nondriven bucket working bodies with a conveyor bottom in the form of a roller surface, in the form of a closed belt, as well as bucket working bodies with a conveyor bottom belt drive mechanism.

Bucket working body with a conveyor bottom in the form of a roller surface [5]**.** According to the proposed design of the bucket working body (Fig. 5), the bottom (3) is made in the form of a surface consisting of a set of rollers (4), which are installed to rotate around the axes (5), fixed on the side walls(2). Before starting, when the process of rock loosening in a quarry is completed, the bucket working body is in front of the pile of lumpy rock mass in the position shown in Fig. 5 b. The filling of the bucket (1) occurs when it is forced to move in the direction of the rockpile. In this case, the cutting edge and bottom teeth (3) cut off a part of the pile material located on the face area. The loosened rock mass slides along the rollers (4) and enters the bucket (1). The rollers (4) rotate under the pressure of the rock mass relative to the axes (5) reducing the resistance to its motion relative to the bottom (3) and contributing to a more efficient filling of the bucket (1).

[5] Lyashenko YuM, Revyakina EA, Lyashenko AYu. RF Patent 101056, 2011. (In Russ.)

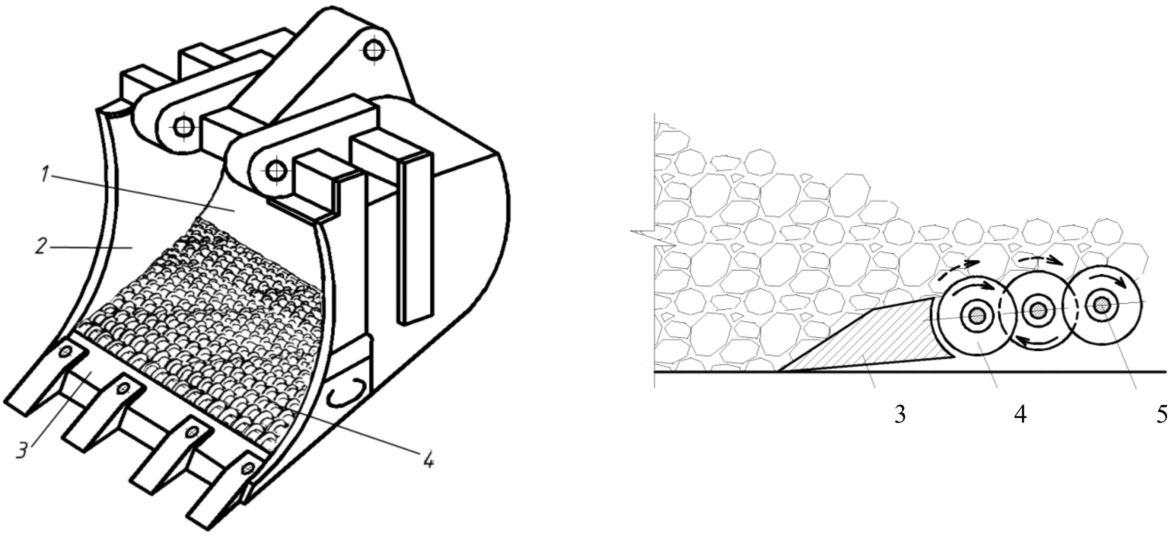
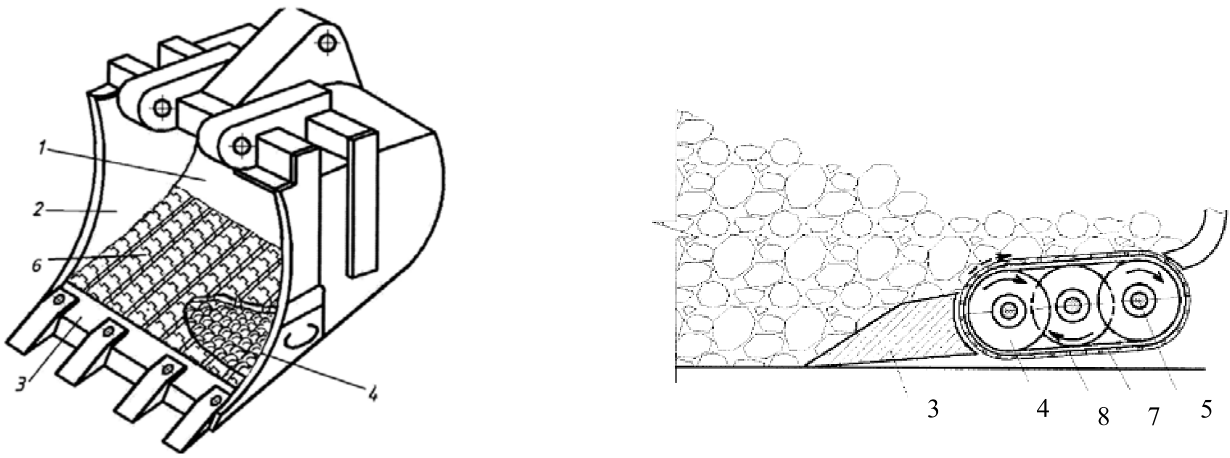


Fig. 5. Design of bucket working body with conveyor bottom in the form of roller surface (*a*) and its position in front of lumpy rockpile (*b*): 1 — bucket capacity; 2 — side walls; 3 — bottom; 4 — a set of rollers; 5 — axis of rotation

The rock mass flow to the place of unloading is carried out in the bucket (1). The bucket is unloaded when it is tilted due to the rock mass flow under the action of gravity. In this case, the sliding of the rock mass in the opposite direction along the rollers (4) rotating in the same direction helps to reduce the unloading time. The use of rollers as a supporting surface of the submerged rock mass provides the workload reduction and a decrease in the energy requirement. In addition, rotating rollers provide uniform abrasion of the working surface, which significantly reduces the risk of equipment failure and increases the process efficiency.

Bucket working body with a bottom in the form of a closed belt (Fig. 6)[6]. The design feature is that the conveyor bottom (3) is made in the form of a closed belt (6) consisting of plates (7) journaled to each other by pins (8). The belt rests on rollers (4) and bends around them. The rollers act as a guiding track during the movement of the top belt of the plate (7). Under the pressure of the belt (6) interacting with the rock mass, the rollers (4) rotate relative to the axes (5) fixed on the side walls (2). The belt (6) moves along the rollers (4). The rock mass enters the bucket (1) along the belt. The use of a closed belt as a load-carrying body and a supporting surface of the rock mass excludes spillage and jamming of the submerged material.



a) *b*)

Fig. 6. Bucket working body with conveyor bottom in the form of closed belt (*a*) and its position in front of lumpy rockpile (b): 1 — bucket capacity; 2 — side walls; 3 — bottom; 4 — rollers; 5 — axis of rotation; 6 — belt; 7 — plates; 8 — pins

Bucket working body with a conveyor bottom in the form of a closed belt connected to the engine through mechanical transmission[7]**.** This design, compared to the previous ones, is able to further intensify the interaction of the conveyor bottom and the rock mass, and, as a consequence, accelerate the process of filling the bucket

[6]Lyashenko YuM, et al. Bucket working body. RF Patent 144647, 2014. (In Russ.)
[7] Revyakina EA, et al. Complex of quarry equipment. RF Patent 2640622, 2018. (In Russ.)
[7] Revyakina EA, Lyashenko YuM, Sergeev VV. RF Patent 179748, 2018. (In Russ.)

(Fig. 7). Possible drive options are described in the technical solutions discussed below.

Here, the conveyor bottom (2) is made in the form of a closed belt (3) enveloping the rollers (4), whose axes of rotation are fixed on the side walls (1). One of the rollers (5) is driven and equipped with the mechanical transmission (6) connected to the engine (7) to move the closed belt.

The rock mass flow on the belt (3) geared by the rotating drive roller (5) through the mechanical transmission (6) from the engine (8), contributes to a more efficient filling of the bucket and reduces the operation time. Thus, the proposed working body compares favorably with existing analogues in that they provide a reduction in the time to digging-in, scooping and unloading; and when penetrating into a rockpile and scooping, it increases the filling capacity and, therefore, improves productivity.

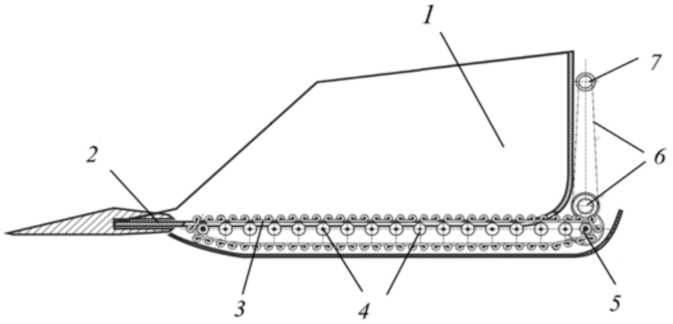


Fig. 7. Bucket working body with conveyor bottom in the form of closed belt connected to the engine through mechanical transmission: 1 — side wall; 2 — bottom; 3 — closed belt; 4 — rollers; 5 — transport (drive) roller; 6 — mechanical transmission; 7 — engine

Bucket working body with a conveyor bottom in the form of a closed belt connected with a drive from two hydraulic cylinders through transmission mechanisms [8]. A diagram of such a working body is shown in Fig. 8. Its conveyor bottom (2) is made in the form of a closed belt (3) enveloping the rollers (4), whose axes of rotation are fixed on the side walls (1). The closed belt drive consists of two hydraulic cylinders (6) and (7) with transmission mechanisms in the form of slides (8) installed in the guides, connecting rods (9) and cranks (10). The , connecting rods (9) are journaled to the slides (8), and the cranks (10) are rigidly attached to the axis of the drive roller (5) under mutually perpendicular displacement.

Equipping the bucket working body with a drive consisting of two hydraulic cylinders with transmission mechanisms of the specified design provides the rotary motion of the drive roller. Mutual displacement of the crank attachment points provides the hydraulic cylinders falling out of the dead centers in a given direction of rotation.

Through supplying the working fluid to the rod cavity of the hydraulic cylinder (6), the motion of its rod and transmission mechanisms, consisting of slides (8), cranks (9) and , connecting rods (10) installed in the guides, is provided. Thus, the drive roller (5) is set in rotation, which provides the belt (3) displacement. In this case, the hydraulic cylinder piston (7) is removed from the extreme position, after which liquid is supplied to its piston cavity, which provides the simultaneous operation of the hydraulic cylinders (6) and (7).

The bucket is filled during the period of its forced displacement towards the rockpile. In this case, the cutting edge and pins of the bottom (2) cut off a part of the material located on the face area. Loosened rock mass enters into interaction with the belt (3) and is transferred by the latter to the bottom (2) filling the bucket working body. The cycle ends in the zero-point return operation of the working body and its preparation for a new working movement and filling.

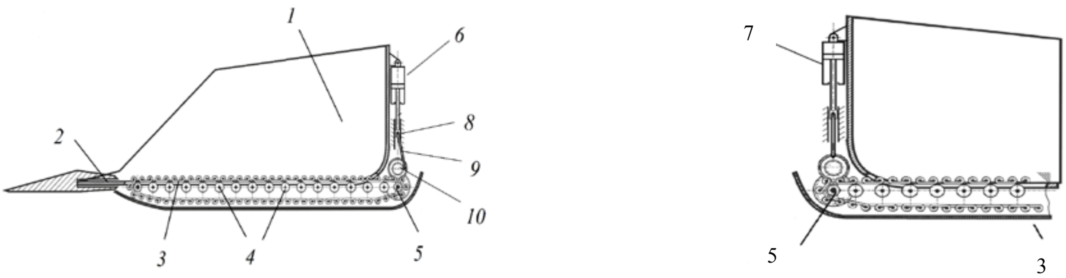


Fig. 8. Bucket working body with conveyor bottom in the form of closed belt connected with a two-hydraulic cylinder drive by transmission mechanisms: 1 — side wall; 2 — conveyor bottom; 3 — belt; 4 — supporting rollers; 5 — drive roller; 6, 7 — hydraulic cylinders; 8 — slides; 9 — connecting rods; 10 — cranks

The design of the belt drive mechanism in the form of a rotating roller driven by two hydraulic cylinders with transmission mechanisms enables to use the bucket working bodies with a conveyor bottom on hydraulic excavators that play a key role in the mechanization of extraction-and-loading operations in quarries. Such excavators account for more than 60% of the total number.

Bucket working body with conveyor bottom in the form of closed belt connected to the drive hydraulic cylinders through locking clamps[9]. The working body diagram is shown in Fig. 9. In this design, the closed belt drive (1) of the bucket working body with a conveyor bottom consists of two hydraulic cylinders (4) with spring-loaded clamps (6) mounted on the rods (5), which engage with the belt (1) under the action of the spring (7) during the forward stroke and freely move during the reverse.

In the process of loading, hydraulic fluid is supplied to the hydraulic cylinder (4). The rod (5) of the hydraulic cylinder extends, the retainer (6) under the action of the spring (7) engages with the belt (1) and sets it in motion. The belt, moving along the rollers (2), transfers the rock mass located on it. The continuity of the transportation of the rock mass is provided through the sequential operation of two hydraulic cylinders (4). Such a conveyor belt drive mechanism simplifies the design of the bucket working body, increases the reliability of the drive, while maintaining the positive effect of the belt drive discussed above in the form of a rotating roller, which is driven by two hydraulic cylinders with transmission mechanisms.

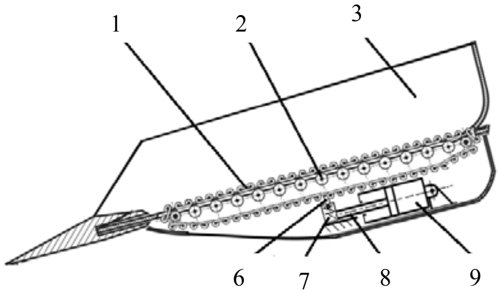


Fig. 9. Bucket working body with conveyor bottom in the form of closed belt connected to the drive hydraulic cylinders through locking clamps: 1 — closed belt; 2 — rollers; 3 — side walls; 4 — hydraulic cylinder; 5 — hydraulic cylinder rod; 6 — retainer; 7 — spring

Discussion and Conclusions. Bucket working bodies with a conveyor bottom can considerably improve the technical level of operated excavators and help to reduce the energy consumption of loading. A preliminary analysis shows that in comparison to the traditional excavator loading bodies with a bottom with a smooth surface, the proposed technical solutions have the following advantages:

— reduction of resistance to implementation;
— increasing the bucket filling ratio;
— decrease in the specific energy intensity of the process;
— increase in the resulting technical productivity.

These advantages will be more pronounced as the bucket capacity of the excavator increases. A certain structural complication of the loading unit cannot significantly affect the cost of the excavator, the estimated additional capital costs are paid off within two to four months.

The method of prioritization [8, 9] is the basis for a comprehensive expert assessment of the options of technical solutions obtained in the course of morphological synthesis. The calculation of the complex priority of bucket working bodies with a conveyor bottom and loading modules with a conveyor bottom made it possible to recognize them as promising with a representativeness of the expert panel of 0.81.

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About the Authors:

Lyashenko, Yurii M., professor of the Transport Safety and Road Infrastructure Management Department, Shakhty Institute, Branch of Platov South-Russian State Polytechnic University (NPI) (1, Lenin sq., Shakhty, Rostov Region, 346500, RF), Dr.Sci. (Eng.), professor, Scopus ID 6603581379, ORCID: https://orcid.org/0000-0002-6553-0163, lumdtn@yandex.ru

Revyakina, Elena A., associate professor of the Cybersecurity of IT Systems Department, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344003, RF), Cand.Sci. (Eng.), associate professor, Scopus ID 57197834319, ORCID: https://orcid.org/0000-0003-1577-2671, revyelena@yandex.ru

Lyashenko, Alena Yu., teaching assistant of the Transport Safety and Road Infrastructure Management Department, Shakhty Institute, Branch of Platov South-Russian State Polytechnic University (NPI) (1, Lenin sq., Shakhty, Rostov Region, 346500, RF), ORCID: https://orcid.org/0000-0002-2896-8043, alyona_lyashenko@mail.ru

Claimed contributorship

Yu. M. Lyashenko: academic advising; formulation of the basic concept, research objectives and tasks. E. A. Revyakina: computational analysis; text preparation; formulation of conclusions. A. Yu. Lyashenko: analysis of the research results; the text revision; correction of the conclusions.

All authors have read and approved the final manuscript.