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INNOVATIVE WORKING BODIES OF CONSTRUCTION PRODUCTION MACHINES WITH CYCLOIDAL MOTION

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ABSTRACT

The paper presents new (innovative) designs of the working bodies of construction machinery with cycloidal movement, developed by the authors. Structural solutions of machines are obtained using the properties of cycloidal curves and cycloidal bodies of constant width in working bodies that perform complex (cycloidal) movement. The use of mutually bending satellite curves in the working bodies of construction machinery and their cycloidal movement made it possible to obtain rational geometric shapes of the working bodies with the minimum possible specific energy consumption of the working process and to expand the technological capabilities of the machines.

In the working body of the machine, the properties of mutually bending cycloidal curves and bodies of constant width are used. The cross-section of the working body is a flat triangular shape. The points of this figure, when rotating around two parallel axes, describe curved lines-hypocycloids with rectilinear branches. This feature of the movement of the working bodies along the inter-envelope curves is used in the slitting machine. It allowed you to get the minimum possible energy consumption for the workflow. The cutting machine with cycloidal movement of working bodies exceeds the performance of other basic machines in terms of productivity, specific energy consumption for the working process and has significantly smaller dimensions and weight, due to the cycloidal movement.

Keywords: *Construction Machinery, Productivity, Cycloidal (Complex) Movement, Working Body, Hypocycloid, Planetary Gear, Central Gear, Carrier, Satellite, Rotor.*

1. INTRODUCTION

Modern construction production machines (MSPs) have sufficient productivity, but limitations are holding back the growth of machine productivity. These limits include the size of the working bodies and the speed of the working bodies. The analysis of research on improving the design of construction production machines allowed us to establish that the existing (traditional) machines have "exhausted" the reserves for further productivity improvement. To solve this problem, it is necessary to develop fundamentally new machines with complex (cycloidal) movement of working bodies, or to improve existing machines with the use of fundamentally new working bodies in them [1-2].

The generalizing criterion for the rationality of the working bodies of construction production machines is their economic efficiency, achieved by increasing the productivity and durability of the tool, reducing the resistance to destruction, digging, cutting and operating costs. One of the main conditions for the rational design of the rotor is considered, perhaps, a low energy consumption of cutting. To reduce the energy consumption of the cutting process (digging), the cutting parts of the RO should be given a shape and size that ensures a minimum zone of destruction in the side parts of the slot [3-5].

The working equipment of construction production machines with cycloidal movement of working bodies, designed to perform certain operations, consists of a working body that directly interacts with the materials and loads

being developed, reloaded or moved; actuators that provide the specified movements of the working body, and load-bearing structures that receive loads from the working body and transmit them to the frame of the base machine. In working equipment with planetary motion, the driving force from the drive to the corresponding elements of the working equipment is transmitted through the eccentric drive shaft to the satellites and the corresponding rotor (usually the planetary gearbox is built into the body of the working body). In the MSP, schemes with cycloidal forms of working bodies (rotors) are used, for which the properties of epi - and hypocycloids are used. The radii of the guide and generating circles R, r should be treated as integers that differ by one (1/2, 2/3, 3/4, etc.). Running the constructed curve together with a fixed circle around a moving circle, we get a family of curves with an external and internal envelope. The working body of an ICP with a cycloidal movement can be made according to a cycloid (epi - and hypo -), or an envelope (external or internal) of a family of curves (epi - and hypo-) [6-12].

In addition to the trajectory of movement and the size of the links of the working equipment, which determine the configuration and size of the zone of its action, the kinematics of the working equipment is also determined by the speeds and accelerations of its individual links (the rotor and the eccentric shaft) [7]. Obviously, if there are no restrictions imposed on the speed of the working bodies due to their specific interaction with the environment, then the increase in speed, in terms of increasing the productivity of the machine, is very significant [8]. As a rule, planetary mechanisms provide the possibility of obtaining large gear ratios with relatively smaller dimensions compared to other types of gear mechanisms. The use of planetary mechanisms as integrated gearboxes will make it possible to widely use high-speed rotary piston engines in modern SMEs [9-10].

The purpose of the work is to improve the existing machines of construction production by using fundamentally new working bodies with cycloidal movement.

2. RELATED WORKS

The generalizing criterion for the rationality of the working bodies of construction loaders is their economic efficiency, achieved by increasing the productivity and durability of the tool, reducing the resistance to destruction, digging, cutting and operating costs. One of the main conditions for the rational design of the working body is considered to be the lowest possible energy consumption of digging (cutting) [11-14]. Working equipment of construction production machines (MSPs) with cycloidal movement of working bodies, designed to perform certain operations, consists of a working body that directly interacts with the materials and loads being developed, reloaded or moved; actuators that provide the specified movements of the working body, and load-bearing structures that receive loads from the working body and transmit them to the frame of the base machine [15]. In working equipment with planetary motion, the driving force from the drive to the corresponding elements of the working equipment is transferred through the eccentric shaft-the carrier to the satellites and the corresponding rotor (usually the planetary gearbox is built into the body of the working body) [16]. In the MSP, schemes with cycloidal forms of working bodies (rotors) are used, for which the properties of epi - and hypocycloids are used. The radii of the guide and generating circles R, r should be treated as integers that differ by one (1/2, 2/3, 3/4, etc.). Running the constructed curve together with a fixed circle around a moving circle, we get a family of curves that have an external and internal envelope. The working body of an ICP with a cycloidal movement can be made according to a cycloid (epi - and hypo -), or an envelope (external or internal) of a family of curves (epi - and hypo-) [17-20].

In addition to the trajectory of movement and the size of the links of the working equipment, which determine the configuration and size of the zone of its action, the kinematics of the working equipment is also determined by the speeds and accelerations of its individual links (the rotor and the eccentric shaft) [21]. Obviously, if there are no restrictions imposed on the speed of the working bodies due to their specific interaction with the environment, then the increase in speed, in terms of increasing the productivity of the machine, is very significant [22]. As a rule, planetary mechanisms provide the possibility of obtaining large gear ratios with relatively smaller dimensions compared to other types of gear mechanisms. The use of planetary mechanisms as integrated gearboxes will make it possible to widely use high-speed rotary piston engines in modern SMEs [23-25].

2. METHODS

At the Department of "Transport Equipment and Organization of transportation" (TT and OP) The Kazakh Automobile and Road Academy (KazADI) named after L. B. Goncharov conducted system-analytical studies of "Machines with cycloidal working bodies". As a result of the research, machines with cycloidal working bodies were developed. Examples of the spheres of specific objects (products) are given – five examples and technical documentation for them. These machines have a world-wide novelty. All machine designs are patented in our country.

The work has a "know-how", which includes the following parts:

- methods for calculating the kinematic, dynamic and energy-power parameters of the working bodies of SMEs with cycloidal motion;
- ideas for designing new machines with cycloidal forms of working bodies and with cycloidal movement;
- directions of patenting new machines with cycloidal motion RO;
- plans for theoretical and experimental research.

As a result of the system-analytical studies, we found that the most successful schemes of machines include machines with cycloidal movement of the RO. In these machines, schemes with cycloidal RO forms are used, for which the properties of epi - and hypocycloids are used. The RHO contour can be made a cycloid or an inner envelope of the hypocycloid family. Among the various schemes of cycloidal machines, the simplest is the hypocycloid scheme with a fixed body, a rotating rotor and an internal envelope of the hypocycloid family, which was mainly used in our new machines [26-28].

In these machines, ROS with planetary (cycloidal) motion are used to obtain which the properties of hypocycloids are used. Usually, such curves are obtained when a point lying outside the circle 2 (point M) moves, which rolls without sliding along the inner side of the stationary circle 3 (Figure 1) [29].

If the constructed hypocycloid 1 is rigidly connected to the guide circle 3 and the latter is rolled around the generating circle 2, then the points of the hypocycloid describe a family of curves of hypocycloids 4, which have outer 5 and inner 6 envelopes (see Figure 1). The contours of the outer and inner envelopes have z branches and z vertices, i.e. one less than the hypocycloid itself. The contour of the inner envelope is inscribed in the contour of the hypocycloid, and the contour of the hypocycloid is inscribed in the contour of the outer envelope [30]. The center of the inner and outer envelope is the center of the generating circle. When the generating circle is rolled along with the associated inner envelope along the guide circle, the vertices of the inner envelope contour describe the same initial hypocycloid. The branches of the inner envelope roll with some sliding along the contour of the hypocycloid. Among the many variants of the relations of the radii R/r, the most appropriate from the point of view of their use in the kinematic schemes of the ICP are the variants of the relations: R/r = 3/2; 4/3; 5/4, etc. [31].

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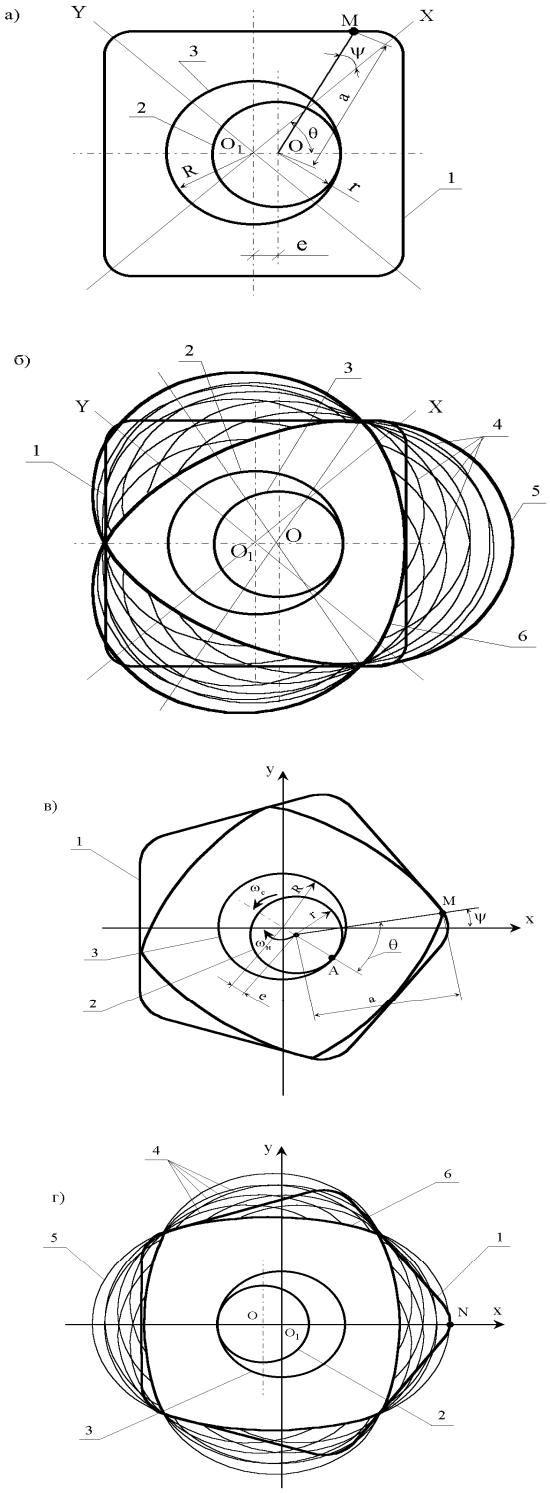


a) hypocycloid at $z = 3$; b) external and internal envelopes at $z = 3$;
c) hypocycloid at $z = 4$; d) external and internal envelopes at $z = 4$.
Figure 1: – Hypocycloid formation

The hypocycloid lines described by the vertices of the inner envelopes are close in shape to a regular triangle (for R/r = 3/2); a square (R/r = 4/3); to the pentagon (R/r = 5/4) , etc.

In the contour of a hypocycloid consisting of four branches (square) for z = 3 and c = 3, an equilateral triangle with convex sides (the inner envelope), arbitrarily oriented in it, is inscribed (see Figure 1, b). In the contour of a hypocycloid consisting of five branches (a regular pentagon) at z = 4 and c = 4, a square with convex sides (inner envelope) is inscribed (see Figure 1, d) , etc.

The cross-section of the working body of the machine is a flat polygonal figure, the points of which, when rotating around two parallel axes, describe curved lines-hypocycloids. Depending on the value of the shape parameter "c", the branches of the cycloid can be concave, convex, or have rectilinear sections.

When the working bodies rotate around two parallel axes, the vertices of each of the sections will describe identical cycloids with straight branches, and the lateral generators of the sections will roll with some sliding along these branches, as on guides. It is this feature of the movement of the working bodies (along the mutually bending cycloidal curves) that is proposed to be used in the SME, which allows us to obtain the minimum possible energy consumption for the working process. The working bodies (RO) of the machines are made according to cycloidal curves (a body of constant width) and they move along mutually bending cycloidal curves. Due to the change in the speed of movement of the RO (they move unevenly according to a certain law), a pulsed (vibrational) effect on the processed material is obtained, which reduces the digging force (cutting) and, accordingly, the energy consumption for the working process [32-35].

We conducted system-analytical studies of "Machines with cycloidal working bodies". The results of the studies are shown in Table 1.

Table 1 – Machines with cycloidal working bodies

Machines	Advantages of these machines
1. Transport and loading and unloading machines (loaders, rotary excavators)	– simplified design; – increase productivity; – expanding functionality; – reduce the metal consumption of the machine and increase the reliability of operation; – minimum specific energy consumption of the working process.
2. Earthmoving machines (continuous operation)	
3. Machines for track work (SCHOM, VPR, VPO)	
4. Machines for crushing stone materials (roll crushers, jaw crushers, cone crushers)	– reducing the size of the working bodies; – increase productivity; – expanding technological capabilities.
5. Manual machines for cutting and cutting sheet materials (metal, rubber, plastics)	– reducing the size of the working bodies; – improving the productivity and quality of cutting processing; – expanding technological capabilities.
6. Machines for finishing works (processing of floors: mosaic and parquet, grinding of metal surfaces)	– processing in hard-to-reach places; – reduced metal consumption and improved reliability; – automation of the production process; – increase productivity; – improving the quality of processing.

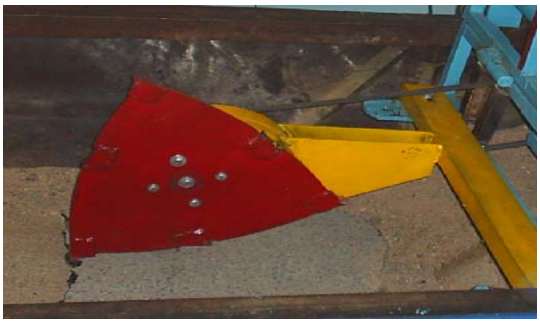
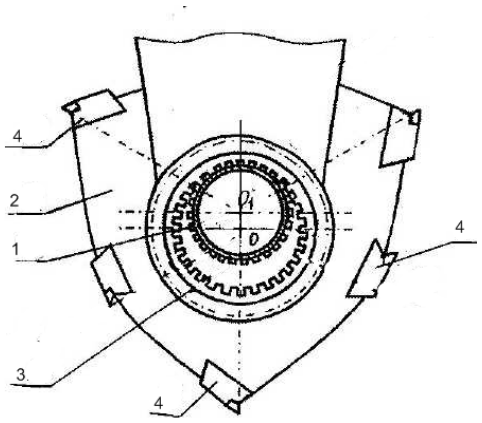
In these machines, ROS with cycloidal forms are used, for which the properties of epi - and hypotrochoids (shortened epi - hypotrochoids) are used. Among the various schemes of cycloidal machines, the simplest is the hypocycloid scheme with a fixed body, a rotating rotor and an internal envelope. According to this scheme, we have developed machines with cycloidal RO and with cycloidal movement, which are indicated in Table 1.

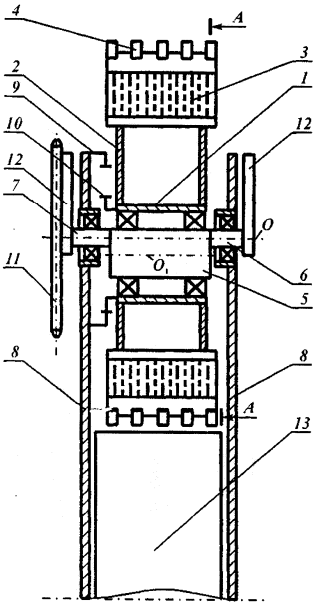
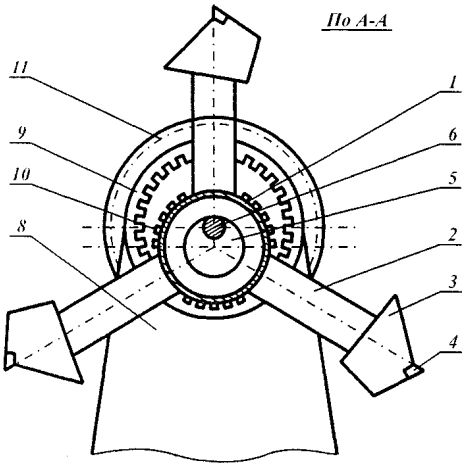
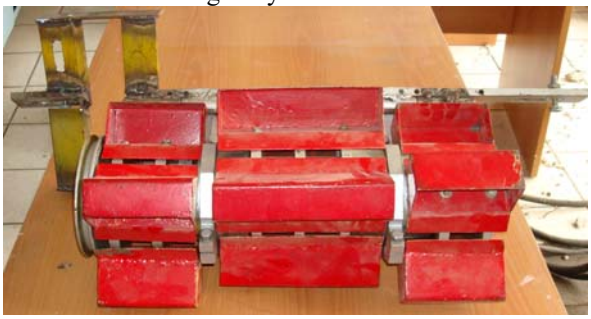
All machines are "protected" by patents of the Republic of Kazakhstan, they have developed technical documentation [36-37].

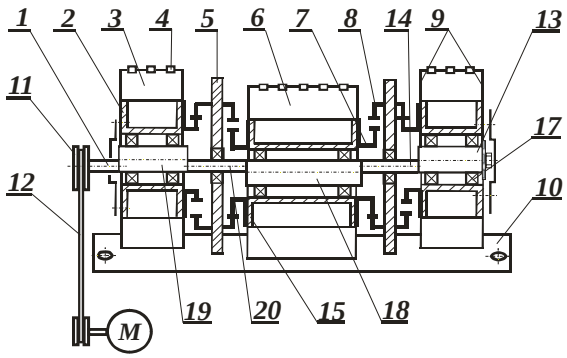
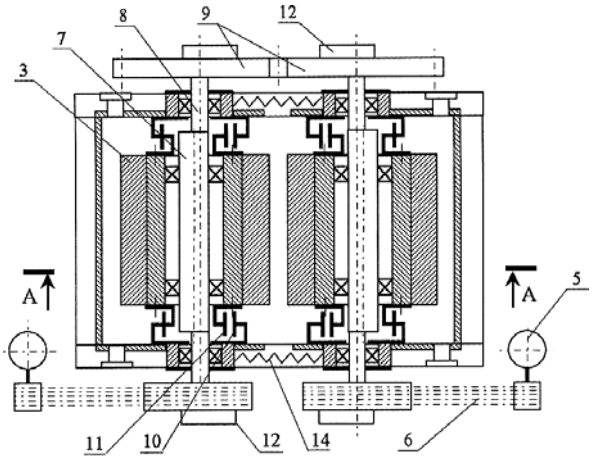
Thus, at the Department of" TT and OP", thanks to a systematic innovative approach to the problems that have arisen in technology, a theoretical basis has been created for the design of rotors with cycloidal motion, which have an undoubted advantage over their analogues. The design solutions of the machines (seven machines) and the technical documentation for them have been developed (see Table 2).

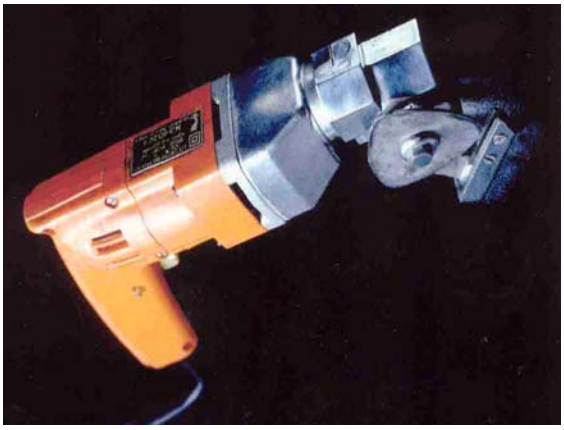
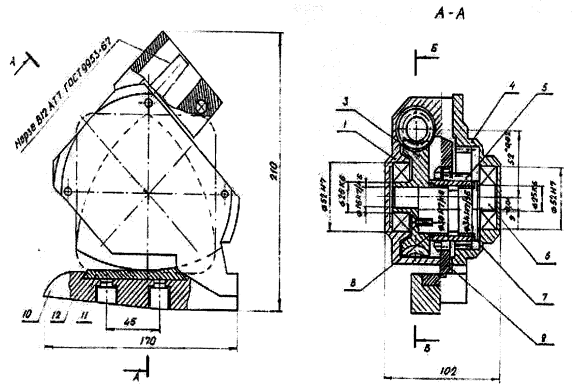
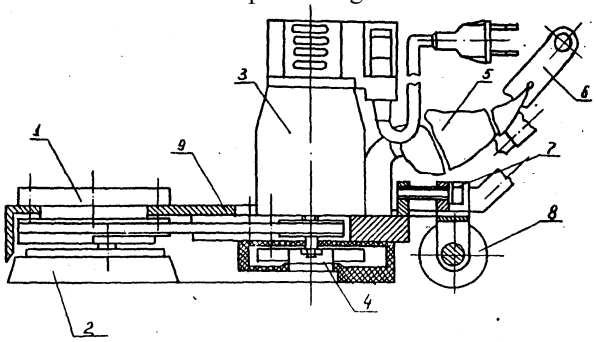
The theoretical formulas obtained in this paper for determining the parameters of machines give only approximate representations of them. To get more accurate data and check the calculated data, it is necessary to use the results of experimental studies of the technological parameters of new machines. We conducted an experimental approbation of theoretical studies and design solutions on the example of three experimental samples of new machines with cycloidal movement of RO: crushing machines, polishing and grinding machines and scissors for cutting sheet materials (Table 3). Experimental testing of theoretical studies has shown that the theoretical formulas are sufficiently reliable and can be recommended for engineering calculations (the discrepancies between the calculated and experimental values are in the range of 10.3-12.8 %). According to all the main indicators, machines with cycloidal movement of working bodies are superior to similar machines by an average of 15 % and higher (see Table 3) [38].

Table 2 – Construction production machines with cycloidal working bodies and cycloidal movement

№ п/п	Machine design	Features of the machines	Patents
1	2	3	4
1.	Slot cutting device   1 – gear wheel (pinion); 2 – working body; 3 – gear wheel;	The design of the working bodies with cycloidal movement provides a vibration effect on the material being developed when cutting the road surface, allows you to increase the cutting speed (productivity); reduces the energy consumption of the cutting process.	Innovation Patent of the Republic of Kazakhstan No. 21718. Device for cutting slits / Alpysbaev S. A., Akhmetov M. F., Li S. V., Musin K. S., Akhmetov G. M. Published on 15.09.2009. Byul. No. 9

	4 – cutter		
2.	Working body of the earthmoving and throwing machine  1 – the rotor; 2 – bucket; 3 – bucket bottom; 4 – cutter; 5 – eccentric neck; 6,7 – support necks  8 – arrow; 9 – central gear wheel; 10 – satellite; 11 – slave sprocket; 12 – counterweight; 13 – receiving conveyor	Provides the planetary movement of the rotor and the movement of the bucket points of the same name along the same trajectories – hypocycloids with acceleration, which allows for the inertial unloading of buckets of a given trajectory with a relatively simple design.	Preliminary patent of the Republic of Kazakhstan No. 17570. Working body of the earthmoving and throwing machine / Alpysbaev S. A., Li S. V., Shin B. S., et al. Publ. 14.07.2006. Byul. no. 7
3.	Working body of a small loader 	The cycloidal movement of the bucket rotor allows the unloading of the trapped cargo from the gondola cars, providing sufficient productivity by increasing the speed of the drive	Preliminary patent of the Republic of Kazakhstan No. 17570. Working body of the earthmoving and throwing machine / Alpysbaev S. A., Li S. V., Shin B. S., et al.

	The working body is made of 3-section to reduce the dynamic loads on the shaft. The cycloidal movement of the working body makes it possible to intensify the interaction of the buckets with the material being developed	shaft.	Publ. 14.07.2006. Byul. no. 7
	 1-eccentric shaft; 2-rotor; 3,6-buckets; 4-teeth; 5-trolley; 7-satellite; 8 – gear wheel; 9-side walls; 10-frame; 11-pulleys; 12-drive; 13, 18, 19-central eccentric necks; 14, 20-support necks; 15-bucket; 17-bearing		
4.	Crusher with cycloidal roll movement   3-crushing plate; 5-electric motor; 6-V-belt	The size of the cross-section of cycloidal rolls is more than two times smaller than in conventional roller crushers, which significantly reduces the overall dimensions and metal consumption of the crusher design. When the volume of the crushing chamber is cyclically changed, the width of the discharge slot is constant, the maximum productivity and the specified size of the final product are ensured.	Patent of the Republic of Kazakhstan No. 29666. Roll crusher / Kabashev R. A., Li S. V., Rabat O. Zh. Kabashev A. R. Publ. 16.03.2015. Byul. no. 3

	transmission; 7-carrier; 8 - drive eccentric shaft; 9-gears; 10-crown wheel of planetary gear; 11-ca-tellit; 12-counterweights; 14-spring;		
5.	Electromechanical scissors   1-body; 2-worm; 3 – worm wheel; 4-central wheel; 5-satellite; 6 – eccentric shaft; 7-bushing; 8-bushing; 9-movable knife; 10-knife body; 11-anti-cutting plate; 12-gasket.	The work of the scissors is based on the use of the features of the hypocyclic movement of the movable knife, which ensures a constant gear ratio, the quality of cutting sheet and roll materials.	Patent of the Republic of Kazakhstan No. 31859. Manual electric scissors / Kabashev R. A., Li S. V., Rabat O. Zh., Kadyrov Zh. N., Kabashev A. R., Agabekova D. A. Published on 28.02.2017. Byul. No. 4
6.	Device for mechanical processing of floors  1-a planetary mechanism; 2 – a working tool; 3-a collector electric motor with a switch and a current-carrying cable; 4 – a fan device; 5-a dust collector; 6 –	The working tool of the machine is made with a triangular profile and all its three vertices describe the same line-a hypocycloid that coincides with the contour of the square, so it is possible to process the floor covering in hard-to-reach (corner places)	Patent of the Republic of Kazakhstan No. 33251. Device for mechanical processing of floors / Li S. V., Rabat O. Zh, Kabashev A. R., Kadyrov Zh. N., Murzakhmetova G. A., Ni V. M. Published on 26.10.2018. Byul. No. 7

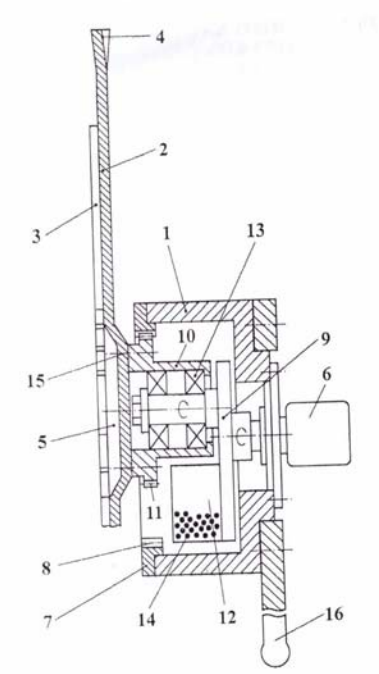
	a control handle; 7-a V-belt transmission; 8-a running device; 9-a machine frame.		
7.	Atraumatic Surgical Circular Saw+  1-housing, 2-disc blade, 3-cutting end protrusions, 4-teeth, 5-landing and mounting recess, 6-electric motor, 7-disc, 8-internal teeth, 9-disc, 10-satellite gear, 11-external teeth, 12-counterweight, 13-bearings, 14-steel balls, 15-screw	When the electric motor shaft rotates, the satellite gear wheel is rolled inside the gear space of the stationary gear wheel, while performing a planetary movement along a complex trajectory. The edges of the teeth of the saw blade perform a complex hypocycloidal movement, while there is no significant mechanical impact on the material.	Patent Republic of Kazakhstan №33603. Atraumatic surgical disk saw / / Li S. V., Kadyrov Zh. N., Works O. Zh., Kabashev A. R., Aekeeva Zh. N. Publ. 08.05.2019. Byul. No. 19

Table 3 - Analysis Of The Effectiveness Of Creating New Smes With Cycloidal Movement Of The Working Body

№	Name of the machines	Name of parameters				Implementation efficiency, in units.	
		Production duration (operational)	Specific energy consumption per workflow	Overall size. dimensions (LxBxH), mm	Machine weight, kg.	Price in units.	Economy. effect.
1.	Crusher for building materials	$П_Э$=16 m^3/hour	$1{,}1\frac{kw \cdot h}{m}$	2100 1800 1480	2800	8500	14300
	SM-12B crusher (analog)	$П_Э$=14 m^3/hour	$1{,}3\frac{kw \cdot h}{m}$	2230 1640 810	3300	10000	

2.	Полировально-grinding machine MPR-01	$П_Э$=30 m^2/hour	$0,09\frac{kw \cdot h}{m}$	450 360 (180x2) 450	20x2= 40	650	700
	Parquet grinding machine SO-139	$П_Э$=10 m^2/hour	$0,14\frac{kw \cdot h}{m}$	550 270 450	19	360	
3.	Scissors for cutting materials NP-01	$П_Э$=2,5 m/min	$0,17\frac{kw \cdot h}{m}$	170 182 210	1,5	70	250
	Cutting shears H7-5507	$П_Э$=1,5 m/min	$0,32\frac{kw \cdot h}{m}$	257 75 150	1,85	80	

4. RESULTS AND DISCUSSIONS.

Modern SMEs have sufficient productivity, but constraints constrain productivity growth. The experimental-industrial samples of machines presented in Table 1 exceed the indicators of other basic machines in terms of productivity, specific energy consumption for the working process and have significantly smaller dimensions and weight, due to the cycloidal (complex) movement of the working bodies. In general, the efficiency of using new machines with cycloidal movement is significant. Due to the change in the speed of the RO movement, a vibration effect occurs on the material being developed, which leads to a decrease in the energy intensity of the working process. An important positive feature of the new type of RO MSPs is that they can operate at speeds significantly higher than those of traditional MSPs, i.e., machine productivity increases.

Thus, using the properties of cycloidal curves and bodies of constant width, as well as the cycloidal (planetary) movement of working bodies, we have developed new innovative designs of working bodies of construction production machines.

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