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Knyazkov A. S. (knjazkovaleksejj@rambler.ru),
Doctor of pedagogical sciences, candidate of engineering sciences,
docent Naumkin N. I. (naumn@yandex.ru),
Candidate of engineering sciences, Kupryashkin V.F. (kupwf@mail.ru)
Federal state budgetary academic institution of higher education
“N.P. Ogarev Mordovia State University” (Saransk, Russia)

A METHOD OF REDUCING THE ENERGY INTENSITY OF TILLAGE BY ROTARY HILLERS USING ADAPTIVE WORKING ELEMENTS WITH A CONVERTIBLE CUTTING ANGLE

Annotation

We analyze the energy intensity of soil cutting by rotary hillers and after this, we will make the conclusion about the necessity to keep the constant cutting angle of knives of rotary hiller for reducing energy intensity. The analysis of existing structures of rotary hillers has shown that they provide the constant angle, but only for one operating mode of a rotary hiller. We propose a method of energy intensity reduction by providing the constant cutting angle throughout the range of rotary hillers operating modes and the device for its realization. Preliminary tests of proposed construction confirmed the declared demands, which we made to modern working elements (adaptation to changes of environmental conditions, providing the required quality of soil cultivation, the stability of working unit, reducing energy intensity while increasing productivity and others).

Key words: rotary hillers, cutter of rotary hiller, cutting angle, energy intensity, synthesis, profiling.

At the moment in agriculture, rotary hillers of different constructions are widely used to crumble the soil more intensively, to weed out, and to reduce plant residues, to mix up soil layers, for field leveling and other technological operations.

Milling is one of the ways to cultivate the soil; this process is energy intensive enough and exceeds energy intensity of tillage by other equipment [1, 2, 3]. In this regard, it is more reasonable to mill heavy soil where it is necessary to reduce soil monoliths strongly and where tools with passive working elements (ploughshare) do not guarantee required quality of their working. In this article, on the base of the analysis of well-known and our own researches, we propose a new way to raise efficiency of rotary hillers by the example of self-propelled compact rotary hillers, because of a significant decrease of energy intensity on the base of keeping a constant cutting angle depending on changing environmental conditions and cutting modes.

During milling soil by self-propelled compact rotary hillers, the large part of energy spends on rolling running wheels (grousers) and on the work of the tine rotor [4,5,12]. Less quantity of energy spends on the friction in transmission. There are flutes on many self-propelled compact rotary hillers, which also make extra friction on the bottom of the cart track. In comparison with the first two factors, friction on the bottom of the cart track is insignificant, that is why we could neglect them in our calculations. And the power, spending on tine rotor work, makes from power spending on cutting, destroying and interleaving of soil and power for throwing off soil by a side of cutter. For self-propelled compact rotary hillers, the rotation of horizontal tine rotor directs at clockwise as a result horizontal pushing rotor hiller power appears as a constituent of soil reaction on the working elements. Taking the above –mentioned for determent operation mode of self-propelled compact rotary hillers, energy intensity of soil cultivation can be shown by the following formula [1, 12, 9]:

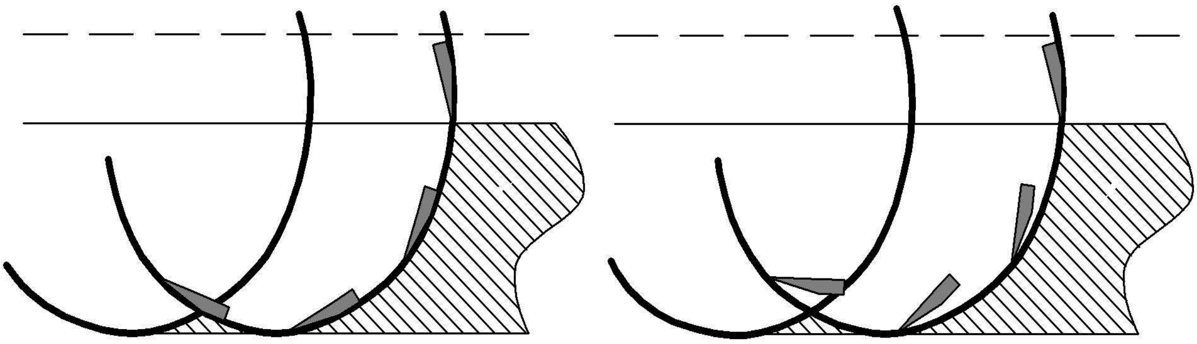
$$E = E_{пер.} - E_{под.} + E_{рез.} + E_{отб.} + E_{тр.} \quad , \quad (1)$$

where $E_{пер}$ – energy intensity of rolling running wheels of self-propelled compact rotary hillers; $E_{под}$ – energy intensity of pushing rotary hiller; $E_{рез}$ - energy intensity of soil cutting; $E_{отб}$ – energy intensity of throwing off soil by cutters; $E_{тр}$ – energy intensity which spends on the friction in transition.

Therefore the efforts, which direct to decrease one of these components, can provide the decrease of energy intensity. However, the main assignment of self-propelled compact rotary hillers is tillage and that is why the main rate of energy connects with cutting, and first of all, the attention will be focused on decreasing of this component of energy intensity.

There are many forms of cutters which are used in the constructions like tine rotor and most applying are L-shaped cutters [9, 12], but the most optional disposition is closed spiral on tine rotor of width rotary hillers, and oncoming spirals with symmetric position in self-propelled compact rotary hillers, that is why the following arguments will be conducted to it.

Extensive researches of energy intensity of tillage by rotary hillers were made by G.F. Popov, in which it was confirmed that rotary hiller energy intensity could be decreased, if the constant cutting angle is provided. During the work of this tine rotor (picture 1.a) each cutter moves along the trochoidal trajectories with the minimal angle of deflection. During this process we can see the minimal resistance of soil by the cutter. Cutter motion (picture 1.b), in the typical tine rotor, passes with changes of cutter angle, that is why the additional cutting resistance appears accompanying additional soil crush and mixing it to free cart track. This increases energy consumption for cutting.

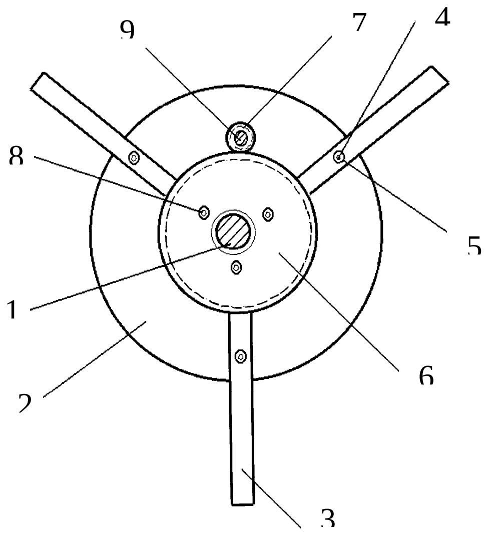
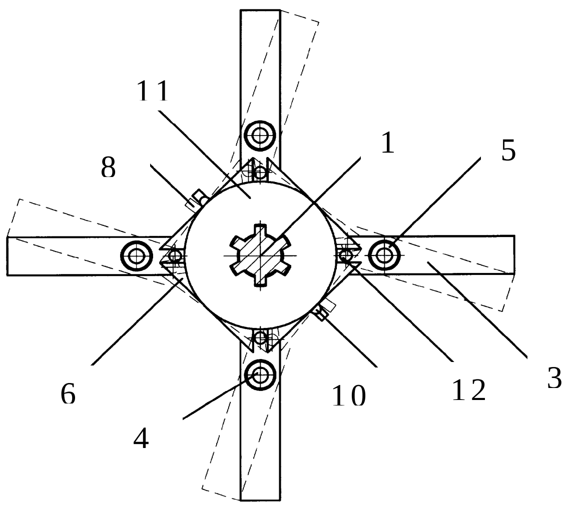
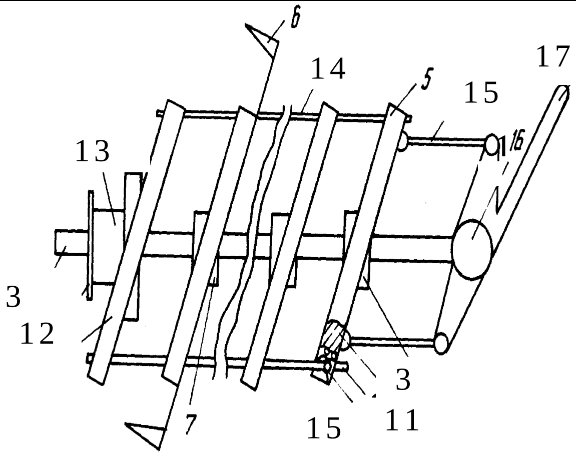


a) b)

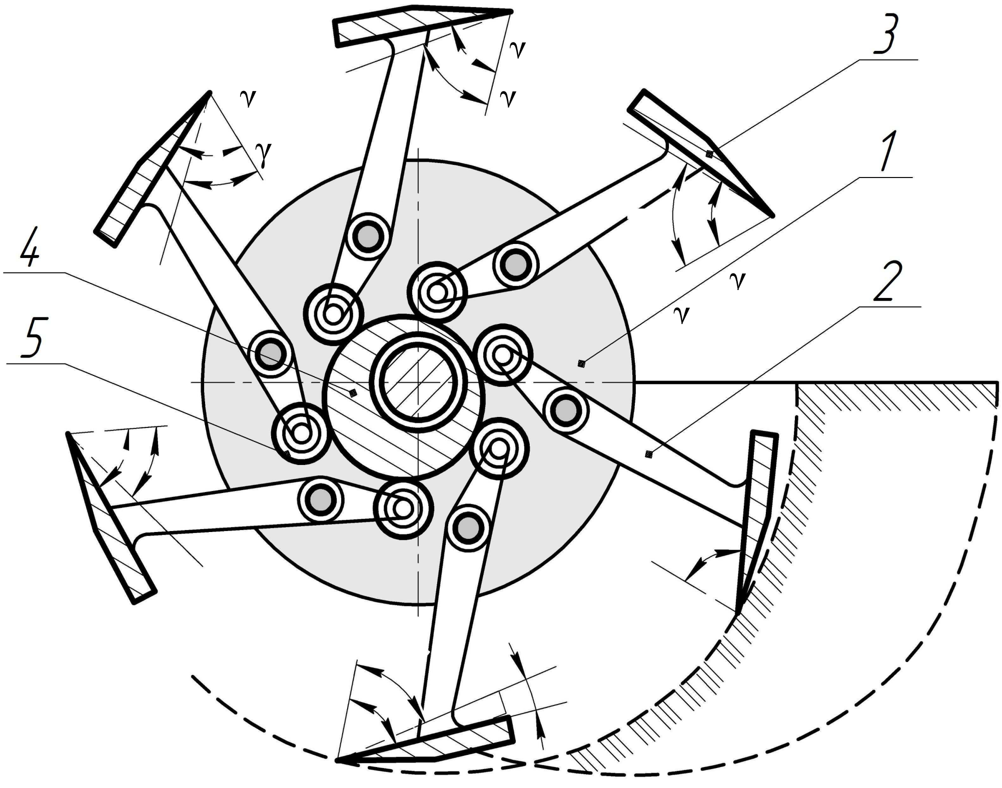
Picture 1 – Trajectory of cutter motion

Therefore, the most important aim is providing to supply the constant cutting angle owing to using special technical decision. Our patent researchers [11, 13, 14] have shown that, there are equipments as patents for the invention and utility models, shown in the table №1.

Table 1 – Results of patent researchers

№	Scheme of device	Principle of work
1		The device works in the following way. An effort is passed by the worm gear of an additional shaft 9 and the gear wheel 7 to regulate gear wheel 6. It turns relatively the main shaft 1 and accordingly to bearing disk 2 for required angle. As bolts 8 are inflexibly fixed on regulative gear wheel 6, and in cutter holes 3 they are not fixed, then they push the cutter ends 3 bringing them to move accordingly to bolts 4, that is why it changes an attack of cutter angle [16].
2		The device works in the following way. The motion of removable disks 11 along the shaft 1, the position of plates 9 is changed, as a result, a washer 6 turns accordingly to a shaft 1 due to shank 8, repeated changes of whole positions in figural plates 9. A washer pivoting 6 puts in motion bolts 12, which turns cutters 3 to the required angle to bearing disks2, connected with cutters 3. [17].
3		The device works in the following way. An effort through the arm 17 passes to rocker 16. An effort changes reciprocal position of drafts 18, connected with a ring 9 of disk 5, attack angle of cutters 6 changes from 0 to 400. Drafts 14 connect with disks 4 and 5 between themselves. And at the same time on the middle rings 8 constantly move outside rings 9 on bolts 11. The device of changing attack angle of cutters 6 connects with middle ring 8 of following disk, placed on opposite end of axle 3 accordingly to driving disk 4. [18].

The disadvantages of these devices are: providing the required cutting angle only for the one mode of working and manual change of this angle, for what it needs to stop a rotary hiller. The last disadvantage was removed in the construction of the rotor by G.F. Popov [12], which consists (picture 2) of section of tine rotor 1, on which there are shanks 2 of cutters 3. The shank 2 is made in the shape of connecting rod, on the one end of which is placed cutters 3, and on the other – it connects with fixed cam 4. During the work, the cylinder 1 rolls and together with all rotary hiller has the translational motion. Because of the cutter shank 3 by the short ends run in by rollers 5 along cam 4, it makes additional curvilinear motion. Combination of the last one with rolling movement of cutters 3 together with tine rotor 1 provides the constant cutting angle for any mode of position of rotary hillers.



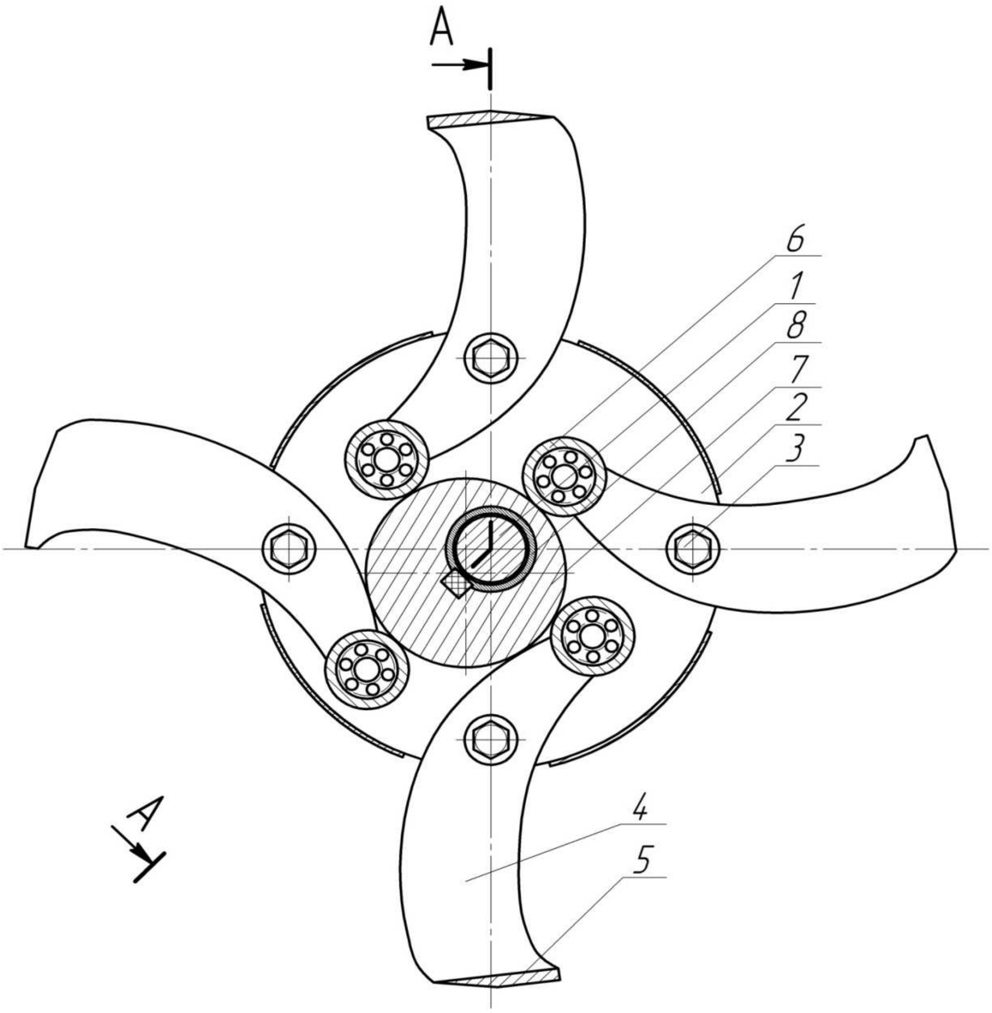
Picture 2 – Rotary hiller with the constant cutting angle

In the construction, it is provided: the constant cutting angle, which removes the extra capacity on friction; required quality of tillage for milling; effective cutting of rhizomes of weeds and removes scattering and dispersion of soil during the all cutting process.

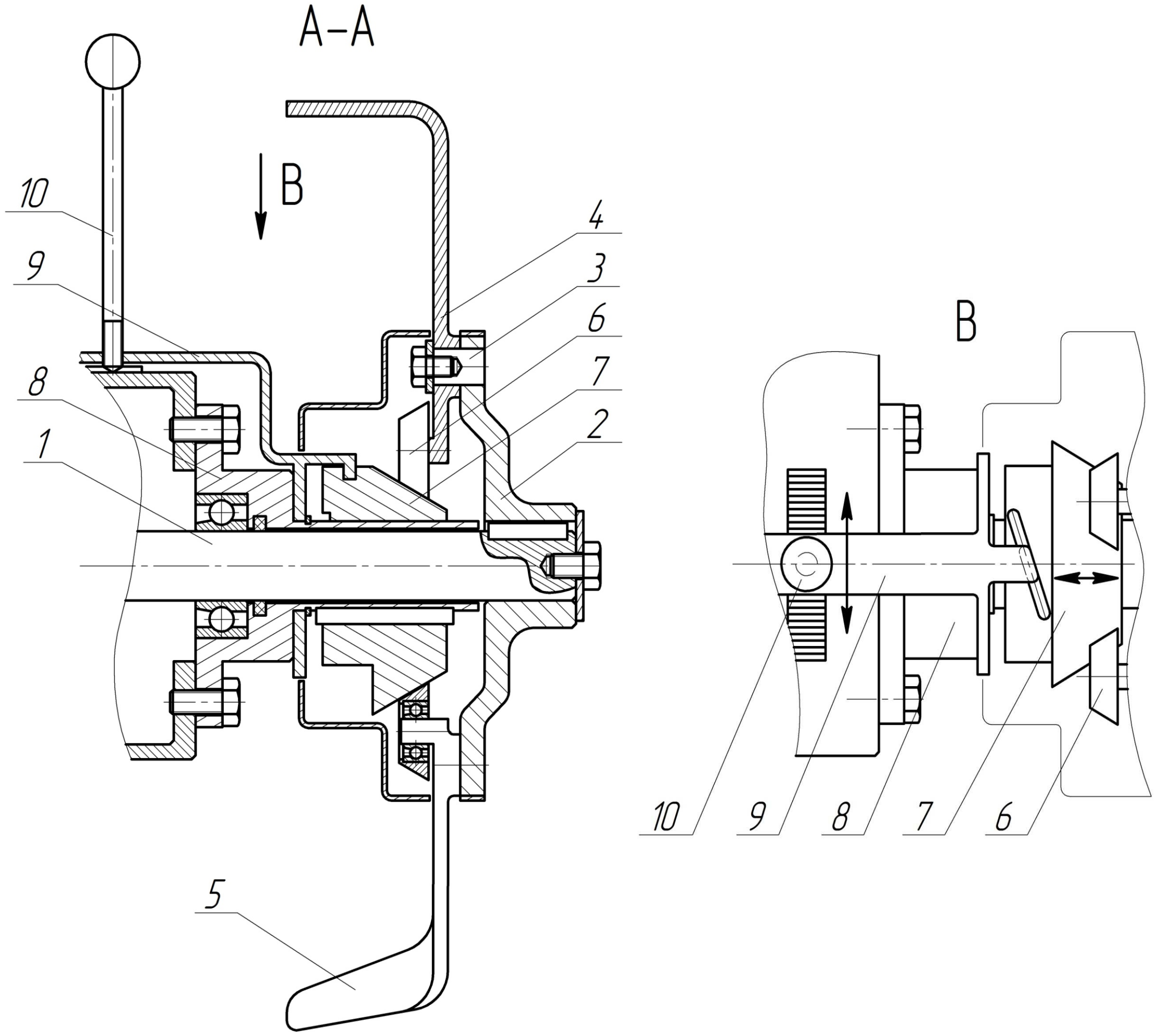
Laboratory tests of this device have shown that the constant cutting angle is provided by decreasing of power, approximately for 30 % in comparison with an ordinary construction of rotary hiller.

Disadvantages of this construction are, that it provides the constant cutting angle only on the one calculated kinetic mode. During the changes of the translational speed of rotary hiller, that could be necessary when there are changes of soil characteristics, cutting angle ceases to be constant, due to increasing of speed, friction appears on the back part of the cutter against uncultivated soil, but due to decreasing – friction of the front part of the cutter, that makes for increasing the energy intensity of cutting.

As the result, authors suggest the rotary hiller which provides the constant cutting angle along all range of changes of its translational speed [15], caused by physical and mechanical features of soil (picture 3 and 4).



Picture 3 – Overview of the device



Picture 4 – Overview of the device

It contains the main shaft 1, with fixed planet carrier 2 on it, with axles 3, where connecting rods 4 are installed floatingly, on the long arm there are 5 cutters, and on the short arm there are moving rollers 6, which rolls conical cam 7, installed on the case 8 with the possibility of the linear movement using a carrier 9 with an arm 10 (picture 4).

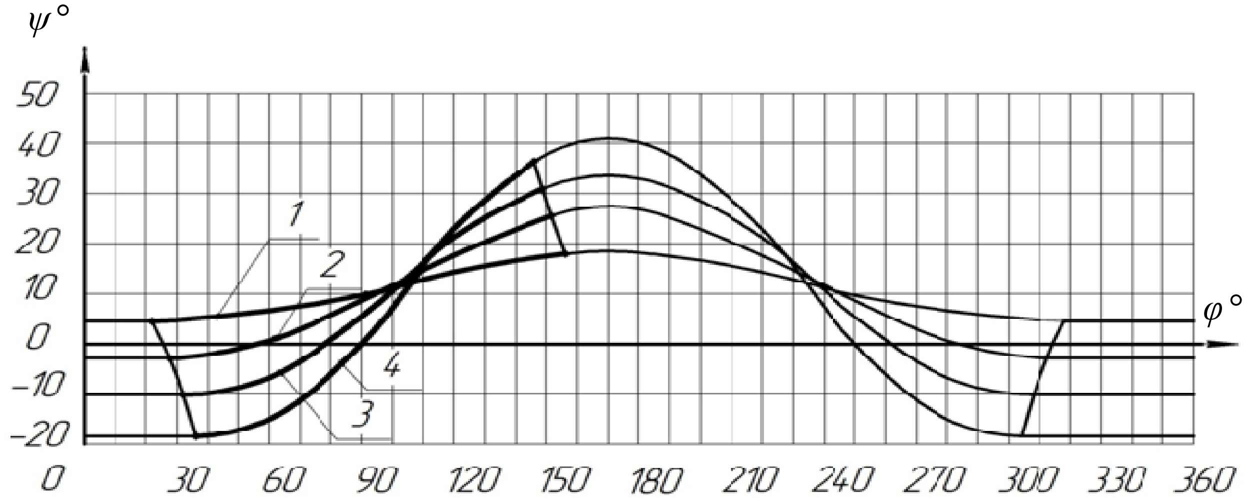
The device works in following way. The main shaft 1 is moving with the carrier 2 with axles 3 and installed connecting rods 4with cutters 5 and conical cam 6 on it. During the rolling of mechanism, a conical roller 6 affects a cam 7, turning connecting rods 4 with cutters 5 around the axle 3; this provides the constant cutting angle. This angle continues to be constant only for determined surface section of a cam 7 according to the onward speed of a hiller. When we increase the speed, the cam 7 starts to move longitudinally on the case 8 due to the carrier 9 with a fixed arm 10 towards the decrease of lateral surface of a cam section, relatively to conical rollers 7, but during the speed decrease, it happens the other way, then rollers 6 affects to the other section of a cam profile, providing the constant cutting angle.

That kind of construction provides the activation of required law of motion of rotary hiller cutters in changing inviromental conditions, in comparison with simple and compact construction of the device.

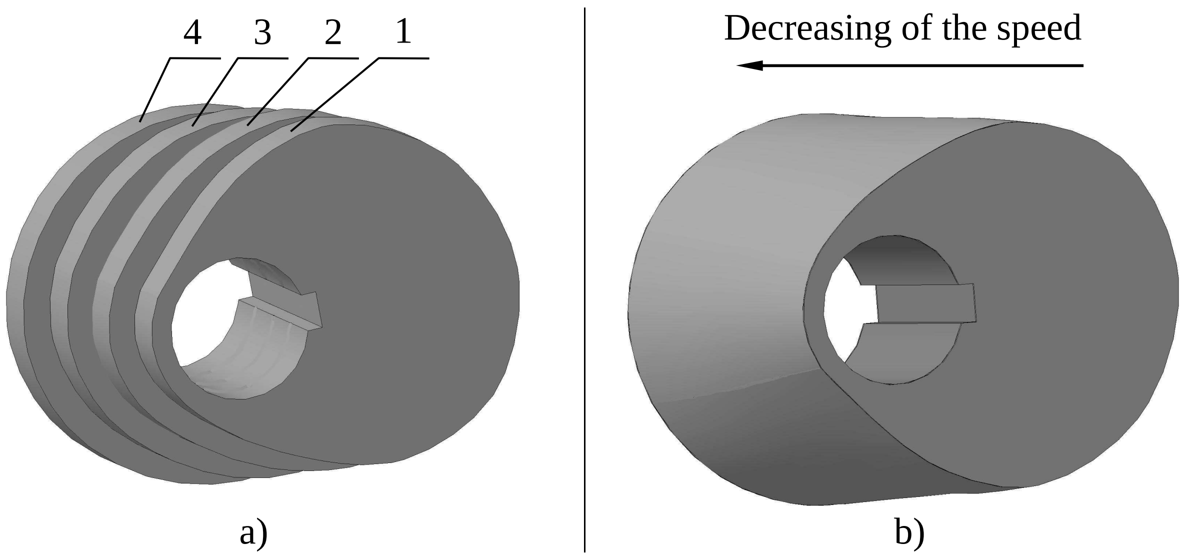
According to the description of the construction, a profile of the cam provides the required law of motion. In these conditions, for realization of rotary hiller cutters, first of all, we have a problem of geometric synthesis (profiling) of a cam surface. This kind of tasks is typical for the theories of mechanisms and machinery [6, 8, 10], during the solving of them, the base is the required law of motion of an output link of a cam mechanism (movement, speed, acceleration). In our case, we have the law, which was experimentally got by authors, empirical dependences of changing the angle of cutter turning ψ from the angle of rotary hiller turning φ, for different speeds of its movement (see. pic. 5). Using the well-known methods of synthesis of cam mechanisms in theories of mechanisms and machinery [10], we have got required profiles of the cam (picture 6).

As we noticed above, in suggested device, the law of motion of the cutter depends on the changes of forward speed of rotary hiller during the constant surface speed of the cutter. That is why for each value of speed it is necessary to determine the cam profile, which could be realized due to using the set of quick-detachable cams with required profiles, installing on the rotary hiller when the forward speed is changed. But this way is not always useful; for example, on cultivating areas with great variable firmness of soil, it is often necessary to change speed of rotary hiller, and consequently it have to stop the tillage and to remove cams.

For the simplification of the construction it can be used a cam with complicated convoluted surface (picture 6 a), each step of which corresponds to the definite forward speed of the rotary hiller. But for all that, the regulation of cutting angle will depend on the quantity of cylindrical tracks. For the surgeless regulation it will be used a “smooth” cam with complicated convoluted surface (picture 6 b), on which the roller of the knife will linearly move along the shaft and will specify the definite law of its movement for any forward speed in the given range. The required work condition of that kind of cam mechanism is locking of the mechanism, it means the continuous touching a running roller of the cam. In this kind of mechanism it will be impossible to provide a constant contact due to the influence of only centrifugal force on the shank and the knife, that is why it will be provided by the force locking [10] (using a spring installed on the shank axle).



Picture 5 – Laws of changing the angle of turning cutter ψ
Depending on the angle of turning rotary hiller φ, properly during forward speed of rotary hiller: 1-4 km/h; 2-3 km/h; 3-2 km/h; 4-1 km/h



Picture 6 – Profile of a space cam, providing the constant cutting angle at different forward speeds:
a) stepped profile (1-4 km/h; 2-3 km/h; 3-2 km/h; 4-1 km/h); б) without steps

On the base of researches, was made and tested a pilot model of working element in the laboratory environment (picture 7) of self propelled compact rotary hiller, providing the constant cutting angle according to the required range of changing its forward speed. Preliminary tests have confirmed declared demands to modern working elements (adaption to environmental changes, keeping good quality of tillage, stability of working unit, decreasing of energy intensity and increasing of productivity and others).

Picture 6 – a pilot model of working element with the constant cutting angle

Consequently, hilling soil is energy intensive process, composed of expenses of capacity for: rolling and pushing of rotary hiller; cutting and throwing off soil by cutters; overcoming friction force in the transmission. More energy intense process is cutting of soil, therefore it needs to decrease this part of energy intensity. As the researches have shown , the energy intensity can be decreased (up to 30%), if the constant cutting angle of tine rotor cutters, but existing methods and constructions do not provide the solution of this problem in changing environmental conditions. As a result the suggested method of decreasing the energy intensity due to providing the constant cutting angle along all range of working modes of rotary hillers and the device for its realization can reduce (up to 30%) energy charges for milling soil, and it can provide good quality of tillage, including heavy and wet soil.

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