Basic Parameters Substantiation of the Cultivator Working Body for the Continuous Tillage in the System of Ecologically Safe Resource-Saving Agriculture

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Abstract. Obtaining the largest number of products with the least labor and material resources expenditure in agriculture is possible by creating optimal conditions for cultivated plants growth due to the most advanced energy-saving agricultural machines use. Currently used agricultural machines do not fully meet the agrotechnical requirements for the of technological operations implementation, in particular cultivators for continuous tillage. Therefore, there was a need to improve cultivator design, first of all, of its working bodies. The article identifies the main cultivators work drawbacks with serial working bodies on soils prone to wind erosion. On the basis of the research conducted, a new design of the cultivator's working body was proposed, comparative laboratory studies of the cultivator paws were carried out, a well-grounded scheme of the new working body for compliance with the basic requirements of soil-protective, environmentally safe, resource-saving agriculture.

1. Introduction

The saving agriculture technology will be effective only when using the most modern agricultural machinery [1]. Resource-saving technologies are the main basis for solving many agricultural problems [2].

The aim of the work is to develop the most advanced design of energy-saving and environmentally friendly working body of the cultivator for surface tillage.

2. Objects and methods

The main research methods were observation methods directly in the soil cultivation conditions, data from literature sources with cultivators evaluation, as well as data from laboratory studies, while processing experimental data, mathematical modeling methods and results statistical processing were used.

The research object is a technological operation – a continuous surface tillage performed by anti-erosion cultivators. To conduct research of working bodies in the laboratory, a private technique was used; a channel was created; on the upper side walls planes of the channel along its length linear divisions were applied through 0.01 m to measure the “loading hill” a special rail was made. The measurements were made in 3 replicates, then the arithmetic mean values were determined and the
experimental error was calculated. Further, the true parameters of the “hill” were determined by intervals of 0.02 m, they were found as the difference between the heights from the flat sand surface to the lower rail edge and from the hill surface to the same edge.

3. Results and Discussion

The south of Western Siberia belongs to the most erosion-dangerous areas of the country [3]. According to the classification of sloping lands of the Omsk region, over 1.5 million hectares (11.3%) are located on erosion-prone slopes, including arable lands of 758.9 thousand hectares, which is 17.4% of its area.

On soils prone to wind erosion, anti-erosion cultivators are used for surface treatment, which are equipped with articulated legs with a catch width of 0.41 m and mounted on C-shaped racks. Cylindrical springs are used as elastic elements - two for each working member (Fig.1).

![Figure 1. The working body of the cultivator KPE-3,8A: 1 – stand; 2 – paw; 3 – bracket; 4 – spring; 5 – clamp.](image-url)

These elastic elements (springs) are designed to create stable working bodies vibrations from the soil relaxation, and together with the suspension they form oscillatory nodes. For the formation of working bodies stable vibrations when the cultivators work on different soils hardness, a preliminary springs tightening is foreseen: the tightening of more soils on hard soils, and less on soft soils [4].

One of the oscillatory assemblies drawbacks of these cultivators is that the coil springs used as an elastic element do not provide stable oscillations to the working member. In the case when the pre-tightening force is insignificant, the pillars deviate from the vertical and the lancet feet are removed from the horizontal position, which leads to uneven tillage depth.

The unstable oscillations cause of the cultivator’s working body is that the oscillating unit springs have constant rigidity. The stiffness is understood as the load increment ratio at each load step to the spring vertical deformation increment. In other words, with increasing load from soil resistance to the working body, the vertical spring deformation increases in direct proportion to it. The greater the load, the greater the vertical spring deformation, respectively, will receive greater displacement and a lancet paw horizontally and vertically.

To ensure stable oscillations, the cultivator working body requires that the elastic elements rigidity increase with increasing load. The researchers and inventors efforts are aimed at this. This issue is solved in different ways. Some inventors propose to install additional elastic elements in the form of cylindrical springs (Fig. 2), others – to increase the elastic element rigidity of the working body by installing additional springs (Fig. 3). There are a number of inventions in which various variants of cultivators oscillating nodes are proposed [5].
There are a number of inventions in which various variants of cultivators oscillatory knots are offered.

In the scientific literature [6, 7] it is noted that high-quality performance of loosening the soil, cutting weeds, as well as reducing the cultivators traction resistance can be achieved by creating stable vibrations due to elastic suspension elements. Unstable working body vibrations are characterized by variable amplitudes, and this is inextricably linked with the uneven paw movement in a vertical plane, which ultimately leads to poor tillage quality. The permissible working body deviation vertically is considered to be the value regulated by agrotechnical requirements: for cultivators for continuous tillage within +0.02 m. The permissible lancet paw inclination angle to the horizon (the cutting edges plane angle) is within 1 ... 2° [8].

In order to fulfill these agrotechnical requirements, it is necessary to observe one of two conditions: to provide working body oscillations with a constant amplitude with any load arising from soil resistance or to develop such an elastic element that would change its rigidity depending on the load, that is, its elastic characteristic would be curvilinear.

To create the most perfect working body, we have defined the requirements for its design, they must provide: a dense bed for seeds and a uniform depth of treatment; reduction of soil sticking on the paw in front of the stand; decrease in traction resistance; a wide range of working body use in other operations; paw maintainability when it is worn; the lowest cost in the paws manufacture without the expensive pressing and stamping equipment use; energy saving by creating paw oscillations in the horizontal plane; lower metal consumption.

In order to have grounds for changing the working body shape and parameters, laboratory studies were carried out to establish the pattern of its interaction with the soil.
To study the working bodies in the laboratory, a channel was created (Fig. 4), which is a box 3m long, 0.7 m wide with a wall height of 0.1m. On the upper planes of the side walls of the channel along its length linear divisions are applied through 0.01 m. The canal was filled with dry, sifted sand. This material is accepted by us as ideal, it does not stick to the working body and shows the true picture of interaction with it, without distorting its shape and size.

**Figure 4.** Channel overview: 1 – channel; 2 – sand; 3 – leveler; 4 – linear divisions.

To measure the “loading hill”, a special rail was made (Fig.5). On its plane, cuts are made through 0.02 m, in which a vertical ruler was installed to measure the height.

In the channel with the help of equalizer 3 (Fig. 5), which moved along the channel, a layer of sand 0.05 m high was installed and its flat surface formed. The working body was placed in the canal in such a way that the wings blades of the pointed paws rested on its bottom, thereby achieving a constant depth during pulling. Further, the working body moved in the sand at a certain distance from the front wall, it stopped and in front of the paw toe and its wings formed a “hill of loading” and a furrow (Fig. 5). The hill had its own shape and parameters: the length l, the height h and the width b and the furrow also had the shape and dimensions: the depth a nd the soil spread width b1.

**Figure 5.** “Loading hill” measurement scheme: a – height measurement; b – the hill length and width measurement. 1 – canal with sand; 2 – “loading hill”; 3 – rake with tick marks; 4 – ruler for measuring; 5 – working body; 6 – furrow after the passage of the working body; 7 – comb.

The obtained “loading hill” measurement data are given in Table 1, based on the data obtained, it was possible to scale the hill, furrow and ridges formed by the working body and compare them with its geometrical parameters: this is the paw toe departure from the stand l (Fig.6) and l1 is the hill length, the toe height at the paw attachment point to the stand h and the hill height h1, the paw grip width b with the hill width b1.

The difference between these values according to O.V. Vernyaev should be insignificant. He states that the soil amount in contact with the working body surface, they should lift and after the passage to remain in place, not moving in a horizontal plane. He further notes that the deformation zone should not significantly exceed the zone defined by the working body geometrical parameters, and theoretically possible movement in the vertical plane considers the upper toe edge height of the trihedral wedge, therefore, with increasing lift to the rack, the horizontal deformation zone will increase and increase soil up, as well as loading in front of the paw toe.
All of the above does not fully coincide with the results of our research. So the deformation zone in the horizontal plane considerably exceeds the zone defined by the geometrical paw parameters. The distance characterizing the sock departure from the rack attachment point is \( l = 0.21 \) m, and the “hill of loading” length is \( l_1 = 0.408 \) m, which is an increase in the latter by 35\%. The geometric paw grip width is \( b = 0.4 \) m, and the stand frontal surface hill width in the transverse plane is \( 0.5 \) m or an increase of 20\%; the hill height is an increase of 8\%. These data were obtained without taking into account soil sticking to the working body. We assume that with this in mind, the data will be much larger.

The data obtained indicate that the working body existing form and parameters create an increase in the “hill of loading” size, and it is known that when loading a lot of mechanical energy is expended. All this gave us grounds for changing the working body design.

Taking into account the results of a number of researchers [7, 9] and our research, aspects have been developed that formed the basis for the creation of a new working body design. They are the following: paw design team, combined; paw elements are connected into a single whole by their simple installation; lapel paw shape with readjustment to another type of working body; paw elements development with the purpose of its maintainability by replacing individual elements with wear; changing the paw toe design to reduce its sticking capacity and working body traction resistance; an oscillatory unit design for creating horizontal paw oscillations.

### Table 1. The working body testing results of the cultivator KPE-3.8A average value

| Loading hill in front of the symmetry axis in the sides, mm | Loading hill from the side in the transverse plane, mm | Loading hill from the side in the transverse plane, mm Furrow, mm |
|-----------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------|
| Measured after 20 mm                                      | Measured after 40 mm                                 |                                                               |
| 1) 8, 13, 16, 20, 22, 28, 36, 46, 54, 64, 72, measured after 10 mm 80 | 1) 17, 13, 32, 51, measured after 20 mm 61 | 1) 57, 46, 37, 24, 29, 43, measured after 30 mm 60 |
| 2) 13, 14, 16, 19, 25, 30, 41, 51, 60, 68, 77, measured after 10 mm 80 | 2) 12, 10, 32, 46, 62 | 2) 60, 50, 42, 33, 28, 38, 60 |
| 3) 20, 21, 23, 27, 34, 41, 49, 58, 65, 73, 80 | 3) 18, 13, 16, 40, 55, measured after 10 mm 60 | 3) 62, 57, 51, 42, 34, 39, 56, measured after 10 mm 60 |
| 4) 28, 29, 31, 35, 42, 48, 56, 63, 70, 80 | 4) 39, 26, 18, 30, 48, \( \frac{1}{2} \) 20 mm 60 | 4) 62, 55, 51, 49, 47, 46, 56, measured after 10 mm 60 |
| 5) 38, 40, 42, 47, 54, 58, 65, 70, 78, measured after 10 mm 80 | 5) 64, 56, 52, 53, 57, 56, 57, measured after 10 mm 61 |                                                               |
| 6) 52, 56, 59, 67, 70, 73, measured after 10 mm 80 | 6) 62, 50, 57, 55, 53, 57, 57, 58, measured after 10 mm 60 |                                                               |
| 7) 71, 72, 75, 76, 79, 80 | 7) 64, 57, 54, 55, 57, 55, 56, measured after 10 mm 60 |                                                               |

It has been established above that there is every reason to change the working body shape and layout from the elements with regard to the developed aspects. On this basis, it proposed a new design. First of all, it became necessary to replace the team with a one-piece arched paw, that is, to assemble into a single whole of the work items, namely the toe, one-sided right and left wings, and also the pressure plate. These elements can be rigidly connected without changing the lancet paw design, the working body elements between them should be placed according to another scheme [10].

The working body individual elements are the stand 8 (Fig. 6), the cup 10, which is closed at the top by a cover 9 with an entrance from below, left-right wings 1 with vertical cheeks 12, a rubber gasket 5, a lamellar pointed toe 3, a pressure plate 6. The paw layout assembly is a hollow cup 10, in
which one-sided wings 1 are laid under the cheeks 12. The cheeks 12 of the wings 1 are plates. A rubber gasket 5 is installed between the inner planes. Thus, the outer planes of the cheeks are in contact with the inner surfaces of the glass, and the inner planes are in contact with each other through a rubber pad.

![Figure 6](image_url)

**Figure 6.** Fastening elements: a – front view; b – side view; in – top view; g – rear view
1 – wings; 2 – plates; 3 – sock; 4 – screw; 5 – rubber gasket; 6 – pressure plate; 7 – clamping plate bolt; 8 – stand; 9 – cover; 10 – a glass; 11 – stop; 12 – cheeks.

The sock is mounted in a groove, which is made on the frontal glass surface and consists of two plates 2, arranged in parallel and closed at the top by an emphasis. The sock is inserted into the groove so that its upper part rests against the groove stop. From falling out of the sock from the groove, it is fastened with a screw in the lower part (Fig. 7).

![Figure 7](image_url)

**Figure 7.** Tillage serial and new cultivating paws comparison: a – compound cultivator paw; b – serial cultivator paw.

Team paw is mounted on a rack for which the existing rack is cut from the bottom to the glass height from the support plane and weld the glass.

In the working body proposed design as the elastic element is used lamellar rubber, it is a highly elastic material. The working body developed the drawings and manufactured a prototype, which was tested in the soil channel for the formation of a “loading hill” in comparison with the existing working body. As a result of experimental studies of the serial and new cultivator paws in the soil channel, we obtained the dependencies of traction resistance on the cultivator speed, on the tillage depth (Fig. 8, 9).
Comparing their parameters, it is clear that an experienced working body has the smallest values. So the hill length is \( l_1 = 0.346 \) m, \( l_2 = 0.200 \) m; width \( b_1 = 0.486 \) m, \( b_2 = 0.420 \) m; height \( h_1 = 0.130 \) m, \( h_2 = 0.090 \) m; furrow depth \( a_1 = 0.020 \) m; \( A_2 = 0.011 \) m. In percentage terms, it looks like this: an increase in the hill length is 42%, in width 14%, in height 31%, in the depth of the furrow 45%. In connection with this, the traction resistance decreases, the stubble conservation and soil crumbling percentage increases.

This is due to a change in the paw design: the triangular toe is replaced with a lamellar thickness 0.01m. With this toe design, its side edges are vertical and due to this, the toe cuts the soil without lifting it up and forms a gap in front of the stand for its passage, thereby reducing the “loading hill”. In addition, this contributes to the paw wings removal behind the rack in the travel direction, this reduced the paw width in front of the rack, respectively, and the “loading hill” width also decreased.

To implement the paw oscillations in the horizontal plane, it was necessary to change its design. It has become a national team and consists of separate single left-right wings with vertical cheeks (Fig. 6). The assembly node for the team paw is a hollow cup (Fig. 6).

Wings with vertical cheeks are placed into the glass from below, and a rubber gasket is installed between the cheeks, which contacts with its planes to the inner surface of the glass, with the cheeks and the lower pressure plate. Thus, a closed space arises for it.

Since the wings are installed independently of each other and are arranged in a cantilever, each wing will react separately when a load is generated on it.

The technological process of proposed working body interaction is as follows. The working body of the plate toe cuts into the soil and moves at a given depth. At the same time, thanks to the toe design, the soil does not rise up, but moves apart to the sides, a gap is formed and the stand with a smaller soil spread moves along it. The soil, clipped by the paw wings, rises along them and, having reached the rear edges, falls to its former place.

Therefore, loosened soil is less susceptible to loading. This is facilitated by the additionally
developed oscillatory unit. A rubber gasket was taken as an elastic element, which is installed in a closed space and is a highly elastic material.

4. Conclusions

According to the research results we can draw the following conclusions: one of the drawbacks of cultivators oscillatory nodes used for soils prone to wind erosion is that the cylindrical springs used as an elastic element do not provide stable oscillations to the working body, due to this a “hill of loading” is formed in front of the cultivator. This contributes to an increase in traction resistance, respectively, an increase in fuel consumption for processing, as well as uneven seed embedding, which ultimately leads to lower yields and does not comply with the basic principles of energy-efficient, soil-protective agriculture.

Established interaction patterns of the cultivators working bodies with the soil to identify their design flaws when tested in laboratory conditions. It was found that the main cause of poor-quality organs work is sticking, loading the soil and spreading it along the sides with the formation of furrows and ridges.

The proposed new design of the working body, it is made prefabricated, combined.

Differences in the proposed working body design from the serial, are as follows:
- the one-piece stamped lancet paw was replaced by a national team, a combination consisting of working elements: left-right single wings with cheeks and a separately installed pointed lamellar toe;
- elements are connected into a single whole by placing them in a special assembly assembly fixed in the lower rack part;
- the combined paw has the form of an arrow, but if necessary, readjustment is provided. When dismantling the wings, the working body is transformed into a chisel-shaped and can be used at a loosening depth of up to 0.15 m, thereby expanding the area of its application;
- separately installed wings and a sock make it possible to make a paw maintainable, in case of sock wear, it can be replaced;
- a pointed toe plate installation in front of the stand will reduce the contact area with the soil, it will lead to less sticking and lower traction resistance, and therefore, to increase the speed and increase the cultivator productivity, also saves fuel during processing, less damage to the fertile soil layer that meets the requirements of energy-saving, conservation agriculture.

In the design of the working body of the oscillating unit. The proposed working body design allows the horizontal paw wings oscillations due to the installation between the rubber cheeks – a highly elastic material, which, working in a confined space, provides stable oscillations, such oscillations are not present in the existing working bodies. The use of such a design eliminates the need for an oscillatory assembly with a cylindrical spring, therefore the working body is rigidly fixed to the frame, only the paw wings of the paw are subject to fluctuations, this leads to a decrease in the metal content of the entire cultivator, and makes it possible to use it on dump heaps, which increases the cultivator versatility.

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