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Modernized tilling unit

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Abstract. It is noted in the work that the increase in the efficiency of agricultural production in our time is not possible without reducing energy costs. At the same time, the technical means of mechanization of the tillage process have a high material consumption, which leads to an increase in energy consumption, indicating energy and environmental problems. In an effort to improve the quality of soil preparation, expand the functionality of the unit, reduce energy consumption, simplify design and import substitution, the use of known tillage tools has been studied and analyzed. As a result, on the basis of exploratory research, a modernized tillage unit has been developed. The new elements of which are that a chopper module is mounted behind the disk module, consisting of staggered chopper rollers in two rows. The modernized tillage unit considered in the article, developed on the basis of KubGAU, improves the quality indicators of soil cultivation, on which the effective accumulation and consumption of soil moisture depends, reduces energy consumption by increasing the functionality of the unit.

1 Introduction

When cultivating grain crops, special attention should be paid to cultivation technology, including the choice of tillage methods, the selection of modern technical means capable of meeting agrotechnical requirements. One of the important aspects of the formed seed layer is the issue of moisture conservation and moisture accumulation, especially in regions with insufficient moisture [1].

A distinctive feature of effective agricultural production is the reduction of energy consumption, which is most pronounced in the process of tillage and largely reflects the energy problem. At the same time, the qualitative indicators of soil cultivation emphasize the environmental problem, on which the effective accumulation and consumption of soil moisture depends [2]. This explains the relevance of carrying out tillage in accordance with the established deadlines and primary requirements in the cultivation of grain crops [3].

The purpose of these studies is to ensure resource conservation, anti–erosion resistance of the soil, moisture conservation, soil leveling, weed eradication, as well as the sealing of plant residues and organic fertilizers.

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To achieve this goal, the following research objectives are set.

- To develop an upgraded technical tool for the technology of cultivation of grain crops.
- To develop a mathematical model of the dependence of the traction resistance of the upgraded unit on the design parameters and kinematic parameters of the machine, the physical and mechanical properties of the soil.

Table 1. Setting Word's margins.

Margin	**mm**
Top	24
Bottom	16
Left	20
Right	20

2 Materials and methods

The implementation of the tasks is carried out based on exploratory research. During the analysis, it was determined that the Max-Chisel™ tillage unit is known [4], the structural elements of which are concave turbo discs mounted each on a separate C-shaped rack and installed in two rows, chopper rollers (Figure 1), located at an angle to the direction of movement, installed in one row and representing grinding wheels with cutting elements in the form of flat shovels. Chopper rollers contribute to the crushing of plant residues and leveling of the soil after the passage of disc working bodies.

Fig. 1. Chopper rinks of the Great Plains company.

The main disadvantage of the Max-Chisel^{TM} tillage unit is that it is manufactured by Great Plains in the USA, and the dependence of the Russian Federation on imports has a strong impact on final prices and can become an important factor in inflationary pressure.

An analogue of this unit in terms of technical and economic characteristics can be the "Disco-chisel Harrow (discochisel) BDC "Wolverine" [5]. Spherical disk working bodies with a diameter of 560 mm mounted on individual racks forming a disk module are installed in two rows on the discochisel frame. The system of levers, adjustment bars and lanyards make it possible to smoothly adjust the angle of attack in the range from 0° to 30° for each row of discs. Behind the disk module there are two rows of chisel working bodies in the form of deep-groove paws with height-adjustable side knives. Chisel working bodies allow soil loosening to a depth of 20-28 cm, while simultaneously operating the disk module at a depth of 10-18 cm, which is necessary when cultivating row crops and moisture accumulation in the autumn-winter period. When working only with the chisel module, it is possible to carry out deep loosening up to 35-40 cm. The installation of height-adjustable side knives contributes to additional crumbling of the soil layer. Given the need for deep loosening once every 3 years, such manipulation does not lead to a significant increase in labor costs.

An increase in the degree of crumbling is provided by the installation of a slatted spiral roller with a mechanism for adjusting it in a vertical plane.

The depth of processing of the gun can also be adjusted by the angle of installation of the discs, support on the roller or on the suspension of the traction motor.

At the same time, there is a low quality of tillage with discochisel due to the formation of furrows during the passage of disc working bodies, uneven distribution of crop residues, high energy consumption of chisel working bodies.

Based on the analysis and patent search, it was revealed that these qualitative, functional, energy disadvantages, the possibility of simplifying the design were considered in the modernized tillage unit [5, 7].

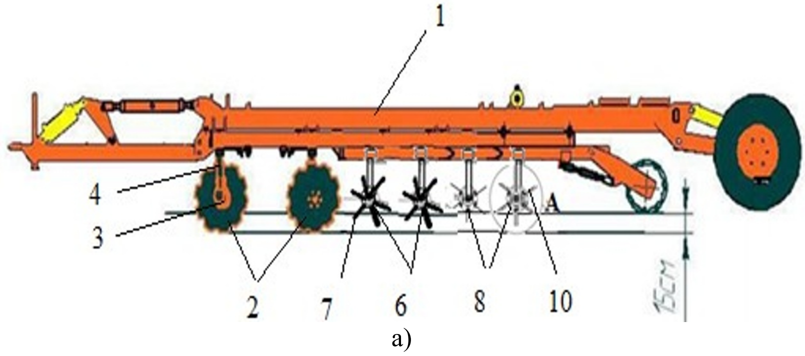
The new elements include the fact that the disk module is followed by a chopper on the frame. It includes chopper rollers arranged in two rows and staggered, which have grinding cutting sections in the form of flat shovels. The zubovaya module is attached to this module, which also contains rollers placed in two rows and staggered with fingers welded and evenly distributed along their perimeter, on which spring teeth are mounted radially and symmetrically on both sides. Chopper rollers and rollers with spring teeth have the same racks with bearing mechanisms as discs and are mounted similarly.

New elements of the device are known in agricultural science, but according to patent and scientific and technical literature, a similar claimed set of features has not been found that allows achieving a technical result.

The novelty lies in the fact that when the unit is working behind the discs, voids are obtained, which are formed by racks, chopper rollers with their grinding cutting sections in the form of flat shovels will fill the soil back into the voids, that is, they will level the soil. Rollers with spring teeth will ensure the lifting and uniform distribution of crop residues and other organic matter on the surface, forming a layer in the form of mulch.

3 Results

In Figure 2 the tillage unit is schematically represented.



a)

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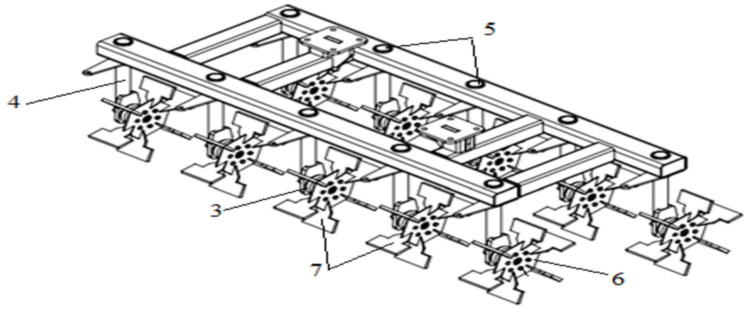

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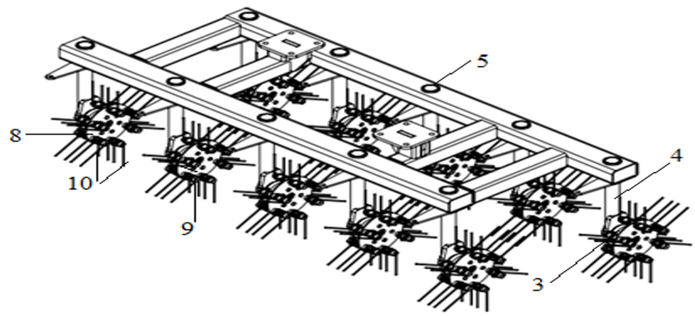

c)

Fig. 2. Modernized tillage unit: in position a – side view; b – chopper module; c – module with spring teeth.

Figure 3 shows a roller with spring teeth, where a is a straight view, b is a left view, c is a right view, d is a top view and e is a drawing of the rink.

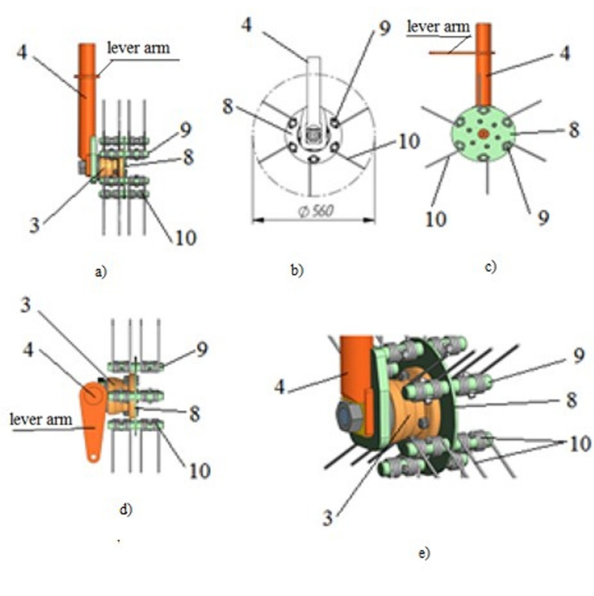

Fig. 3. Roller with spring teeth: a – straight view, b – left view, c – right view, d – top view and e – drawing of the rink.

The "modernized tillage unit" contains a trailer developed longitudinally in length, equipped with sequentially placed modules with main working bodies, a support roller, hydrofected transport wheels, frame 1.

The first is a disk module containing two rows of spherical disks 2 with a diameter of 560 mm, mounted on individual 3 racks with bearing mechanisms 4. The upper part of the racks 4 is mounted in nodes 5 with individual oil presses, with a device providing smooth adjustment of the angle of attack of each row of disks in the range from 0° to 30° in the form of levers, angle of attack adjustment bars and lanyards (not shown in the diagrams). The disk module is followed by the chopper module, which also includes chopper rollers 6 arranged in two rows and in a staggered order having ground cutting sections in the form of flat blades 7. The chopper module is followed by a tooth module attached to the frame 1, which also contains rollers 8 placed in two rows and in a staggered order with welded and evenly distributed along their perimeter there are fingers 9, on which spring teeth 10 are mounted radially and symmetrically on both sides. Chopper rollers 6 and rollers 8 with spring teeth 10 have the same racks 4 with bearing mechanisms 3 as discs 2 and are mounted similarly.

The job is as follows. During tillage, when the energy agent (not shown in the diagrams) moves the frame 1, the disk organs (disks 2 mounted on individual ones with bearing mechanisms 3 on racks 4) rotate, cut stubble, grind plant residues, and mix it with the soil. After them, chopper rollers 6 come into operation, which, with their grinding cutting sections in the form of flat shovels 7, will grind and fill the soil back into the voids formed by disks 2 and racks 4. Thus, chopper rollers will crumble and level the soil. The rollers 8 following them with spring teeth 10 will provide additional loosening, as well as lifting and uniform distribution of crop residues and other organic matter on the surface, forming a layer in the form of mulch, which will then be pressed down by a support roller.

3.1 Theoretical research

The traction resistance of the unit (P) [8] is determined by the expression:

$$P = P_d + P_{c-r} + P_t + f \cdot G_u \tag{1}$$

Where R_d is the resistance of the disk module, H; $P_{c\text{-}r}$ is the traction resistance of the chopper roller, H; R_t is the traction resistance of the roller element with spring teeth, H; G_u is the weight of the unit, N.

The parameters of the disk working bodies and the soil layer cut off by them have a direct impact on the quality and energy indicators during tillage. It is necessary to achieve optimal parameter values, which will help reduce energy consumption to a minimum level [8].

Unfortunately, the mechanics of tillage have not been studied enough, and a significant variation in the physical and mechanical properties of the soil during mining prevents the creation of an accurate mathematical model for determining optimal parameters. We must resort to many different assumptions [9, 10].

The analysis of scientific and technical literature allows us to consider the reaction of the soil to the disk using an analytical expression that establishes the relationship between the horizontal component of the traction resistance of the disk tillage working body and its geometric parameters [11]:

$$P_d = \lambda \cdot G_m \cdot \frac{sin\varepsilon_z \cdot sin\gamma + f \cdot (cos^2\gamma + cos\varepsilon_z \cdot sin^2\gamma)}{cos\varepsilon_z - f \cdot sin\gamma \cdot sin\varepsilon_z} + a \cdot b \cdot \left[k + \varepsilon \cdot v_p^2\right] + a \cdot b \cdot l \cdot \gamma_{ob} \cdot \frac{sin\beta + f \cdot (cos\gamma \cdot ctg\gamma + sin\gamma \cdot cos\beta)}{cos\beta - f \cdot sin\gamma \cdot sin\beta} + \frac{a \cdot b \cdot \gamma_{ob} \cdot v_p^2 \cdot sin^2\gamma \cdot [sin\beta + f \cdot sin\gamma \cdot (ctg^2\gamma + cos\beta)]}{g \cdot (ctg\beta - f \cdot sin\gamma)} \tag{2}$$

Where λ is a coefficient whose value cannot exceed 0.3-0.4; G_m is the weight of the disk module, H; e_z is the rear cutting angle, deg; γ is the angle of the blade bevel formed by the blade line with the direction of movement, deg; f is the coefficient of friction; a is the thickness of the formation (processing depth), m; b is the width of the formation, m; k is a coefficient that takes into account the properties of the soil (σ is the temporary resistance of the soil to separation and φ is the angle of friction) and the geometric shape of the wedge (the angle of crumbling β); the value of this coefficient should be determined experimentally, kN/m; ε is the coefficient of velocity resistance, depending on the properties of the soil and the parameters (geometric shape) of the working surfaces of the organs; v_p is the translational velocity, m/s; l is the length of the formation, m; y_{ob} is the volumetric weight of the soil, N/m^3; β is the crumbling angle, deg; g is the acceleration of gravity, m/sec^2.

Consider chopper working bodies as a rotor with flat knives positioned perpendicular to the direction of movement.

Let's imagine the total power [13] consumed by a rotary working body, consisting of:

$$N = N_p + N_r + N_o, \tag{3}$$

Where N_p is the power spent on overcoming constant resistances, kW; N_r is the power spent on carrying out the cutting process (deformation of soil chips), kW; N_o is the power spent on discarding soil, kW.

According to previous theoretical studies, the total power can be determined by the expression:

$$N = N_n + \frac{v_n \cdot l_p}{S}(k_l \cdot l_n + k_0 \cdot S_{k.s.}) + 0.5\rho_p B h v_n^3 k_{ot}(\lambda - 1)^2 \tag{4}$$

Where v_n is the translational velocity of the unit, m/s; l_p is the length of the cutting arc, m; S is the knife feed, pcs; k_l is the specific reaction of the soil layer, kN/m; l_n is the length of the cutting surface, m; k_0 is the specific resistance of the deformed soil layer, kPa; $S_{k.s.}$ – the average value on the cutting arc, m; p_p – soil density, kg/ m^3; B – the width of the chopper roller knife, m; h - the depth of processing, m; k_{ot} – the ratio of the masses of the discarded and the entire cut soil; λ – kinematic parameter.

The resulting expression characterizes the dependence that arises between the power expended by the chopper roller module, the design parameters of the chopper rollers themselves, the kinematic parameters of the machine and the physico-mechanical properties of the soil.

According to the known total power, the average value of the soil reaction [12] per chopper roller knife $P_{c\text{-}r}$ (H) can be obtained, corresponding to the traction resistance per knife:

$$P_{c-r} = \frac{Nt_p}{zk_z l_p} = \frac{NS}{zv_n l_p}. \quad (5)$$

Where z is the number of knives on one chopper roller, pcs.

Theoretically, the dependence of the traction resistance of the roller section with spring teeth (Figure 4) is determined using the expression [13]:

$$P_z = P_{tr} + P_{rez} + P_{otb} \quad (6)$$

Where R_z is the traction resistance of the roller element with spring teeth, N; R_{tr} – the strength of the soil's resistance to friction, N; R_{rez} – the strength of the resistance of the soil to cutting, N; R_{otb} – the strength of the resistance of the soil to discarding, N.

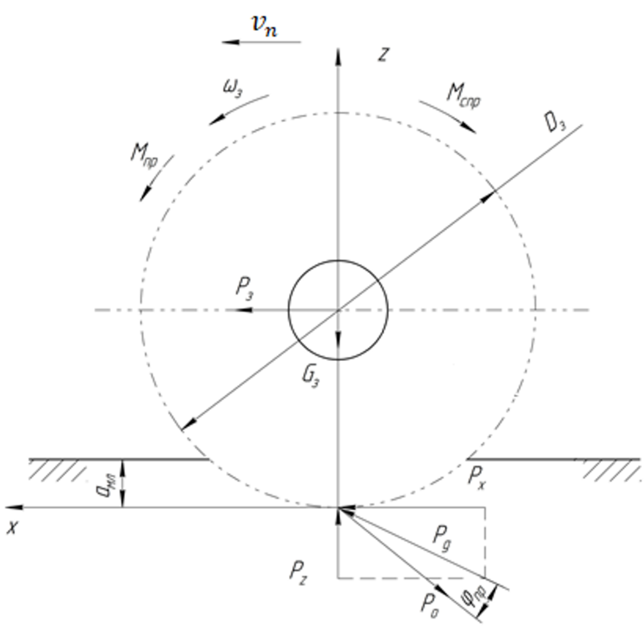

Fig. 4. Diagram of the forces acting on the tooth roller: v_n is the translational velocity of the gun, ω_3 is the angular velocity of the disk, D_z is the diameter of the disk, G_z is the gravity of the disc, P_z is the traction resistance of the tooth disc, M_{spr} is the moment of resistance, M_{pr} is the driving torque, f_{tr} is the angle of friction of the soil, a_{ml} is the depth of tillage with tooth discs, P_g is the resultant of all elementary forces of soil resistance to various types of deformation, P_x and P_z are the components of the resultant of all elementary forces of resistance soils of various types of deformation, P_o – circumferential force.

After substituting into equation (6) the values of the constituent terms, considering the number of k_d tooth discs in the section and the number of k_z^{rab} teeth simultaneously located in the soil, we obtain an expression for determining the traction resistance of a section of a roller with spring teeth as a whole:

$$P_z = k_d k_z^{rab}\{[\pi D_z a_{ml}/(\lambda k_3 sin\alpha)](l_{str}\rho g f_{tr} + k_o) + k_{otb} a_{ml} l_{str}\rho(v_{rez} - v_n)v_{rez}\} \quad (7)$$

Where D_z is the diameter of the tooth disk, m; a_{ml} is the depth of soil mulching, m; λ is an indicator of the kinematic regime; k_z is the number of teeth on the disk, pcs.; α is the angle of inclination of the disk hub to the axis of rotation, deg; l_{str} is the width of the soil chips, m; p is the density of the soil, kg/m^3; g is the acceleration of gravity, m/s^2; f_{tr} is the coefficient of friction of sliding soil; k_o – specific resistance of the deformed soil layer, kPa; k_{otb} – soil rejection coefficient; v_{rez} – cutting speed at the moment of tooth entry into the soil, m/s; v_n – translational velocity of the tool, m/s.

The number of teeth simultaneously located in the soil is determined from the dependence:

$$k_z^{rab} = \beta_{seg} k_z / \pi \tag{8}$$

Where β_{seg} is half of the central angle of the circle segment in which the teeth they are alternately immersed in the soil, hail.

The traction resistance of the unit (P) [8] is determined by the expression:

$$P = P_d + P_{c-r} + P_z + f \cdot G_u \tag{9}$$

Where G_u is the weight of the unit, N.

The dependence of the traction resistance of the unit on the factors of variation, considering its weight, is determined by the formula:

$$\begin{aligned} P = {} & \lambda \cdot G_m \cdot \frac{sin\varepsilon_z \cdot sin\gamma + f \cdot (cos^2\gamma + cos\varepsilon_z \cdot sin^2\gamma)}{cos\varepsilon_z - f \cdot sin\gamma \cdot sin\varepsilon_z} + a \cdot b \cdot \left[k + \varepsilon \cdot v_p^2\right] + \\ & + a \cdot b \cdot l \cdot \gamma_{ob} \cdot \frac{sin\beta + f \cdot (cos\gamma \cdot ctg\gamma + sin\gamma \cdot cos\beta)}{cos\beta - f \cdot sin\gamma \cdot sin\beta} + \\ & + \frac{a \cdot b \cdot \gamma_{ob} \cdot v_p^2 \cdot sin^2\gamma \cdot [sin\beta + f \cdot sin\gamma \cdot (ctg^2\gamma + cos\beta)]}{g \cdot (ctg\beta - f \cdot sin\gamma)} + \\ & + \frac{NS}{z v_n l_p} + k_d k_z^{rab} \{[\pi D_z a_{ml} / (\lambda k_z sin\alpha)](l_{str} \rho g f_r + k_o) + k_{otb} a_{ml} l_{str} \rho \times \\ & \times (v_{rez} - v_n) v_{rez}\} + f \cdot G_u \end{aligned} \tag{10}$$

4 Conclusion

The use of the "Modernized tillage unit" will ensure an improvement in the quality of tillage, an expansion of the functionality of the tool and a reduction in energy consumption. Moreover, the improvement of the quality of tillage is carried out due to a more intensive and versatile effect on the soil in a single pass. Disk, prim and dental modules form a leveled and finely lumpy soil layer with an even seedbed, which makes them indispensable tools for pre-sowing tillage. Thus, the upgraded tillage unit replaces both the discator, the stubble cultivator, and the pre-sowing cultivator.

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