Results theoretical study of the form of a front surface of a chisel-cultivator stand

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Abstract. In this article was revised theoretical research forms of stand on agro-energetical indicators of chisel cultivator’s work. For the exception of clogging up of stands with plant remainders, it is important to change their configuration so that the opportunity to stand self-cleaning from plant remainders during the work itself would appear. To find optimal forms of the cross cut there was studied different existing and experimental forms of stand frontal covers. The conducted researches show that asymmetrical frontal cover of stand better cleans from litter, and notably decreases the traction resistance of the soil.

1. Introduction

Clogging the working bodies of tillage machines with plant residues reduces the reliability of the process and worsens the agrotechnical and energy performance of its work. As shown by numerous studies, clogging and sticking of the working bodies largely depends on the shape and parameters of the frontal surface and the cross-section of their racks. [1,2] However, to date, there are no original technical solutions that exclude clogging of the racks of working bodies with plant residues. In this regard, the task was set to develop and justify the shape and parameters of the cross-section of the rack of the working bodies of tillage machines, ensuring its self-cleaning of plant debris. Several cross-sectional shapes of the struts of the working bodies [3,4]

Now consider the condition for the descent of plant residues from the rack. It depends on the shape and cross-sectional parameters of the frontal surface of the rack. The racks of the working bodies of the chisel and other implements always work in loose soil, i.e. after deformation of the formation by the paw. When operating in a loose environment, racks, even with a pointed cutting edge, cannot ensure cutting of plant debris due to the absence of a counter emphasis. Therefore, the frontal working side of racks with a non-streamlined shape can be enveloped by powerful plant residues, contributing to the general clogging of working bodies, especially on soils with high humidity [5, 6, 7, 8].

2. Methods

Racks of working bodies with a rectangular shape of the frontal surface are not subjected to enveloping by plant residues when working mainly on dry soils and in fields with a low content of highly stalk plant residues. When working on wet soils, the sliding of plant residues from the racks sharply decreases due to their breakdown at the sharp corners of the frontal surface, as a result of which the working bodies are periodically clogged [9, 10, 11].
The most intense sliding of plant residues of all types occurs when the racks with a semicircular and oval shape of the frontal surface work. However, with increasing soil speed or moisture, clogging by plant residues occurs[12,13,14].

The force of pressing the plant by the soil to the frontal surface of the strut for all known forms of the cross-section, except for asymmetric, is the same on both sides of the top of the cross-section. This prevents the gliding of plant residues to the side and their descent from the rack, which leads to the covering of plant residues of the latter[15, 16]. In a rack with an asymmetric wedge-shaped cross-sectional shape, due to the displacement of the cutting edge from the middle of the thickness of the rack and the difference in the angles of sharpening the faces, the forces acting on the stem enveloping the rack have different sizes on opposite sides, and the greater width of one of the faces and a smaller angle of inclination provide the glide of the stems along this face and, ultimately, self-cleaning racks from plant residues. However, at this cross-sectional shape, when meeting with the sharp cutting edge of the rack, the plant residues are broken and as a result, the sliding of plant residues along its faces is difficult, and therefore their descent is worsened[17,18].

3. Results and discussion
Taking into account the noted shortcomings of the existing cross-sectional shapes of the struts, at the level of the invention [19, 20] we developed options for the rack of the working bodies of the chisel cultivator with an asymmetric frontal surface having a rounded apex and various shapes of side faces (Figure 1).

Option 1. Stand 1 of the working body (Figure 1, a) has a main supporting body 2 and a frontal surface 3 having an asymmetric cross-section. The frontal surface 3 has a flat face 4, which is smoothly interfaced with the opposite side face 5 of the rack by an arc 6 of radius \( r_m \) and with the adjacent side 7 and the arc 8. The side faces 5 and 7 of the rack are made flat.

Option 2. Stand 1 of the working body (Figure 1, b) also has a supporting body 2, asymmetric, consisting of small 4 and large 5 side faces, frontal surface 3, concave side face 6 and convex side face 7 of the stand. The lateral faces 4 and 5 of the frontal surface 3 are made convex and of different sizes. Face 4 is made of greater curvature, and face 5 is of the lesser curvature. The lateral face 5 of the frontal surface smoothly mates with the smaller face 4 and the lateral face 7. The lateral face 6 of the rack is made concave to the equidistant face 5 by a distance of twice the radius of curvature of the face 4.

![Figure 1. Asymmetric experimental stand with a rounded frontal apex: a) option 1 is with flat side faces, b) option 2 is with convex-concave side faces.](image-url)

Consider the condition for the weeds to leave the frontal surface of the developed racks during the translational movement of the working body, plant residues collide with the front rounded top of the frontal surface of the rack, bend around it and begin to move along with it in the direction of
movement (Figure 2.4), while the drag force of the soil gives a component directed along a flat (large) face in the direction opposite to the direction of movement.

This force tends to move plant debris along the frontal surface of the rack. However, this is hindered by the friction force arising from the interaction of the stand with the soil and plant residues. To ensure their descent from the stand, the force causing the sliding of plant residues along its flat face should be greater than the force that prevents their sliding, i.e.

$$R_c > R_p.$$  \hspace{1cm} (1)

Where $R_c$ is the force that contributes to the sliding of plant residues along the frontal surface of the rack to the side; $R_p$ is a force that prevents the descent along the frontal surface. From Figure 2 we have

$$P_c = N_t = N_c \cot \beta_1$$  \hspace{1cm} (2)

We define the normal force acting on the plant residue from the side of the flat face of the frontal surface of the rack. To do this, we assume that the specific pressure arising in the cross-section of the rack from soil resistance is distributed uniformly around its perimeter.

Then, according to Figure 2,

$$N = q \ast l \ast t$$  \hspace{1cm} (3)

Where $q$ is the specific pressure of the soil on the frontal surface of the rack; $l$ is the length of the flat face of the rack; $t$ is the thickness of the stem of the weed.

We express $l$ in terms of $S, r_M$ and $\beta_1$ of $\triangle ABM$

$$l = AB = \frac{MA}{\cos(90^\circ - \beta_1)} = \frac{MA}{\sin \beta_1}$$  \hspace{1cm} (4)
Because
\[ MA = S - r_M - r_M \cos \beta_1 - S - r_m(1 - \cos \beta_1) \] (5)

\[ l = \frac{S - r_M(1 - \cos \beta_1)}{\sin \beta_1} \] (6)

In view of (3) and (6), expression (2) has the following form
\[ P_c = q \frac{S - r_M(1 + \cos \beta_1)}{\sin \beta_1} t \cdot \cot \beta_1 \] (7)

where \( S \) - is the width of the cross-section of the rack.

The descent of the plant residue from the stand is prevented by the friction forces arising in the sections \( AB, BK \) and \( KC \), i.e.
\[ P_n = F_{AB} + F_{BK} + F_{KC}, \] (8)

Determine the friction force arising from the flat face of the frontal surface of the rack:
\[ F_{AB} = f \cdot N = f \cdot q \cdot l \cdot t \] (9)

where \( f \) is the coefficient of friction of plant residues on the material of the rack.

In view of (6), expression (9) has the following form.
\[ F_{AB} = f \cdot q \frac{S - r_M(1 + \cos \beta_1)}{\sin \beta_1} t \] (10)

Next, we determine the friction force arising along the arc
\[ F_{BK} = f \cdot q \cdot r_M \cdot t(\pi - \beta_1) \] (11)

According to the research of A.N. Zelenin, the friction force arising on the side surface of the strut compared to the friction force arising on its frontal surface is insignificant. Therefore, we will not take it into account in our calculations.

Taking into account (10) and (11), the force that prevents the sliding of plant residues towards the flat face of the frontal surface of the rack is
\[ P_n = f \cdot q \cdot r_M \cdot t \left[ (\pi - \beta_1) - \frac{1 + \cos \beta_1}{\sin \beta_1} \right] + f \cdot q \frac{S}{\sin \beta_1} \cdot t \] (12)

Substituting the value of \( P_c \) and \( P_n \), in (1), we obtain
\[ q \frac{S - r_M(1 + \cos \beta_1)}{\sin \beta_1} \cdot t \cdot \cot \beta_1 \geq f \cdot q \cdot r_M \cdot t \left[ (\pi - \beta_1) - \frac{1 + \cos \beta_1}{\sin \beta_1} \right] + f \cdot q \frac{S}{\sin \beta_1} \cdot t, \] (13)

or
\[ \frac{S - r_M(1 + \cos \beta_1)}{\sin \beta_1} \cdot \cot \beta_1 \cdot t \geq f \cdot r_M \left[ (\pi - \beta_1) - \frac{1 + \cos \beta_1}{\sin \beta_1} \right] + f \cdot \frac{S}{\sin \beta_1} \] (14)
Where, after some transformations and taking into account the fact that \( f = \tan \varphi \), we get

\[
r_m \leq \frac{S(c tg \beta_1 - \tan \varphi)}{(\pi - \beta_1) \tan \varphi \sin \beta_1 + (1 + \cos \beta_1)(ctg \beta_1 - \tan \varphi)}
\]  

(15)

Thus, the condition for the sliding of plant residues toward the flat face of the frontal surface of the rack depends on the angle of its inclination to the direction of movement, the physicomechanical properties of the soil, and plant residues, and also the thickness of the rack.

An indispensable condition for the sliding of plant residues along the flat face of the rack, as can be seen from analysis (15), is

\[
c tg \beta_1 > \tan \varphi
\]  

(16)

Or

\[
c tg \beta_1 < 90^\circ - \varphi
\]  

(17)

Similarly, for the second version of the experimental rack, we obtain

\[
r_m \leq \frac{B \left( \frac{\pi}{2} - \varphi \right)(ctg \frac{\pi - 2\varphi}{4} - \tan \varphi)}{\left( \frac{\pi}{2} + \varphi \right) \sin \varphi + \left( \frac{\pi}{2} - \varphi \right)(ctg \frac{\pi - 2\varphi}{4} - \tan \varphi)(1 - \cos \varphi)}
\]  

(18)

\[
r_b > \frac{B}{\cos \varphi} \left[ 1 - \frac{\left( \frac{\pi}{2} - \varphi \right)(ctg \frac{\pi - 2\varphi}{4} - \tan \varphi)}{\left( \frac{\pi}{2} + \varphi \right) \sin \varphi + \left( \frac{\pi}{2} - \varphi \right)(ctg \frac{\pi - 2\varphi}{4} - \tan \varphi)} \right]
\]  

(19)

where \( r_m, r_b \) are the radius of curvature of the small and large faces of the frontal surface of the rack; \( B \) is the length of the cross-section of the rack.

The calculations carried out according to formulas (15), (18) and (19) at \( \beta_1 = 30^\circ, \varphi = 45^\circ, S = 30 \text{ mm} \) and \( B = 60 \text{ mm} \) show that to ensure the disappearance of plant residues and rhizomes from the stand, the radius value for the first the rack version should be no more than 9.1 mm, for the second – 32.6 mm, and the radius value – at least 51.5 mm.

4. Conclusions

1. Ensuring the sliding of plant debris on the frontal surface of the rack, the radius of its curvature should be at least 28 cm.

2. Taking into account the noted shortcomings of the existing cross-sectional shapes of the uprights, we have developed options for the rack of the working bodies of the chisel cultivator with an asymmetric frontal surface with a rounded apex and various shapes of the side faces.

3. The condition for the sliding of plant residues toward the flat face of the frontal surface of the rack depends on the angle of its inclination to the direction of movement, the physicomechanical properties of the soil, and plant residues, and also the thickness of the rack.

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