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Influence of a flat disc on the rectilinear stable motion of the unit of tillage machines

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Abstract. The article discusses the design and operation of a combined unit's flat disk, which is installed within the unit. The study focuses on the torques caused by forces acting on the unit's working parts and the conditions for their balancing. The depth at which the flat disk enters the soil and the required diameter to meet this requirement are also presented. The article includes the results of theoretical and experimental studies to determine the shape and area of the disk segment, where the disk's diameter must be at least 45 cm and the depth of its penetration into the soil is within 14-15 cm.

1 Introduction

Flat disks are fitted in the developed design of the combined unit (Figure 1) [1], after bending and spherical disks. Its job is to guarantee that the combined unit moves steadily in a straight line and that the newly created pushers and egates are parallel to each other and maintain their current distance from one another [2]. The determined parameters of a flat disk are its diameter and depth of immersion in the soil [3].

A lot of research and design work has been carried out on tillage machines and working bodies that ensure their linear smooth movement [4].

The working parts designed to perform this task are divided into two types. The first are fixed working parts that are part of the main working part, an example is the guide plate in the fork body [5]. The relative compressive force it exerts on the plow wall is determined by the following expression.

$$P = \frac{F sin\alpha}{bh} \quad (1)$$

where F is the force acting on the track board, N;

a - the track board installation angle, expressed in degrees, with respect to the plow wall;

b – track board width, m;

h - the depth of sinking the end part of the track board into the plow wall, m.

The second type of working parts, which act as track boards, are flat disks with a horizontal axis, which sink into the soil to a certain depth and move in rotation due to the

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force of friction. They balance the forces acting from the sides by relying on the soil wall at the depth of the sinking. The movement of the unit continues, it rests on this wall [6].

2 Materials and methods

To move the combined unit in a straight line, new blocks must be placed in place of the current ones. The agrotechnical specifications for cotton cultivation state that the main row widths should not differ by more than ±2 cm, and the neighboring row widths should not differ by more than ±5 cm. The flat disks' specific pressure on the soil must not be greater than the allowable value in order to satisfy this requirement. The specified agrotechnical requirements are satisfied when this condition is satisfied. To guarantee that the combined unit moved smoothly and straight forward in the horizontal plane, a flat disk was utilized. The relationship between the parameters of the flat disk and its specific pressure on the soil was theoretically studied. A flat disk with defined parameters was made and installed in a combined unit, and experimental tests were conducted to determine acceptable values.

3 Results and discussion

To guarantee that the combined unit moved smoothly and straight forward in the horizontal plane, a flat disk was utilized. The relationship between the parameters of the flat disk and its specific pressure on the soil was theoretically studied. A flat disk with defined parameters was made and installed in a combined unit, and experimental tests were conducted to determine acceptable values. The flat disks, which guarantee the combined unit moves smoothly and linearly in the horizontal plane, are fitted after the spherical discs (Fig. 1). It is known from agricultural mechanics that if the forces acting on each flat disk are equal to each other, then their equal effector can be assumed to be conditionally placed on the flat disk located in the middle.

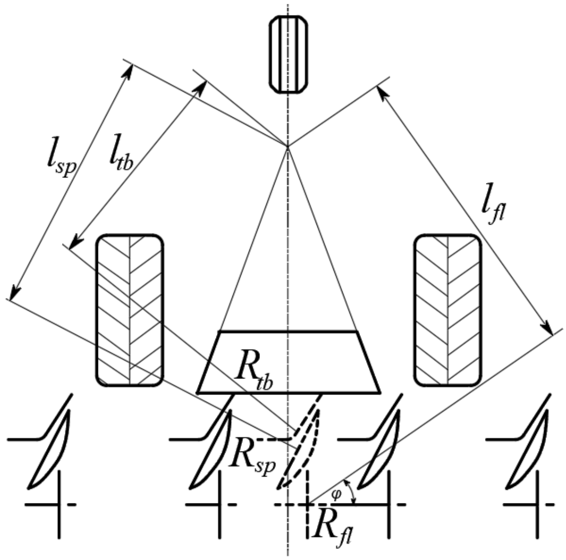

Fig. 1. The scheme for ensuring the stability of aggregate movement in the horizontal plane.

The total of all horizontal forces acting on the working bodies with respect to the tractor suspension mechanism O's instantaneous center of rotation should equal zero in order to guarantee the combined unit's linearity and stable motion in the horizontal plane, i.e[7].

$$\sum M_0 = R_{tb}l_{tb} + R_{sp}l_{sp} - R_{fl}l_{fl} = 0, \tag{2}$$

where R_{tb}, R_{sp}, and R_{fl} are equivalent forces acting on the bending, spherical, and flat disks in the horizontal plane, respectively; l_{tb}, l_{sp} and l_{fl} are the shoulders of equally acting forces placed on the bending, spherical and flat disks, respectively, in the horizontal plane.

From expression (2),

$$R_{fl} = \frac{R_{tb}l_{tb} + R_{sp}l_{sp}}{l_{fl}}. \tag{3}$$

According to the results of our previous research, the value of the force acting on the bender was in the range of R_{tb} = 275 – 300 N[8]. The resistance force exerted by the soil on the spherical disc in the horizontal plane [9]

$$R_{sp} = \sqrt{R_x^2 + R_y^2} = \sqrt{R_x^2 + nR_x^2} = R_x\sqrt{1 + n^2}\ , \tag{4}$$

where n is the coefficient n=0.2–1.2. It is known [16,17]

$$R_x = qS_{sp}, \tag{5}$$

where q- is the relative pressure of the soil on the spherical disk, Pa; S_{sp} -is the surface of the plane cut by a spherical disk, m^2. Once the R_{tb} and R_{sp} forces are determined, the value of the R_{fl} force can be determined. The force acting on the flat disc depends on the relative pressure on its surface and the soil, i.e

$$R_{fl} = \frac{S_{fl}q_h}{cos\,\phi}. \tag{6}$$

where q_h is the specific pressure of the flat disc on the supporting surface, Pa;

S_{fl} -is the base surface of a flat disk, m^2. φ-is the angle of direction of the force acting on the flat disk, in degrees. As mentioned above, the following condition must be met for the combined aggregate to move in a straight line on the horizontal plane.

$$q_h < [q] \tag{7}$$

where [q] is the permissible value of specific pressure applied to the soil by a flat disk, Pa. Considering (7),

$$S_{fl} > \frac{R_{fl}\,cos\,\phi}{[q]}. \tag{8}$$

The shape of the support surface of a flat disc embedded in the soil is in the form of a segment (Figure 2).

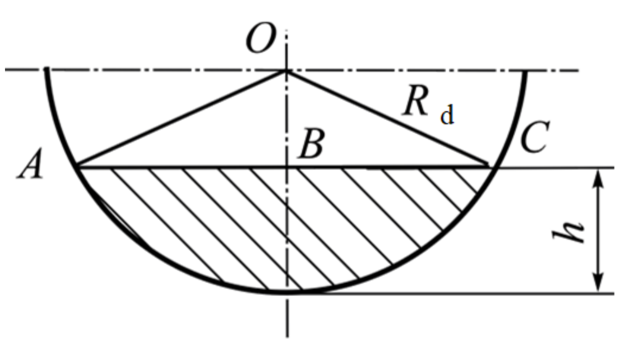

Fig. 2. The scheme of determining the segment-shaped surface of a flat disc resting on the ground.

It is possible to determine the diameter of a flat disk using the expression for calculating the segment surface [10]. From Figure 2.

$$S_{fl} = \pi {R_d}^2 \frac{arccos\frac{R_d - h}{R_d}}{180^0} - (R_d - h)\sqrt{{l_d}^2 - (R_d - h)^2} \tag{9}$$

Considering expressions (9) and (3), (8) is written as follows,

$$\pi R_d{}^2 \frac{arccos\frac{R_d-h}{R_d}}{180^0} - (R_d-h)\sqrt{R_d{}^2-(R_d-h)^2}\rangle \frac{(R_{tb}l_{tb}+R_{sp}l_{sp})}{l_{fl}[q]} cos\phi \qquad (10)$$

taking h=15 cm, R_{tb}=300 N, R_{sp}=2500 N, l_{fl}=240 cm, l_{tb}=187 cm, l_{sp}= 202 cm, q=0.05 MPa, n=1.2, (Numerical calculations based on the expression 10) showed that the radius of the flat disc should be at least 22.5 cm, and its diameter should not be less than 45 cm, in order for the aggregate to move in a straight line on the horizontal plane.The results of the experiment on the influence of the depth of the flat disc immersion on the performance of the unit are presented in Figure 3.

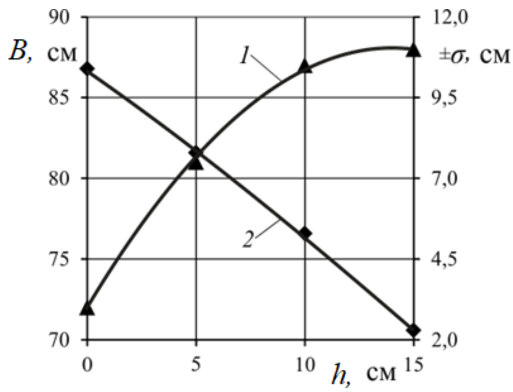

Fig. 3. Variation of the distance (1) and its mean square deviation (2) between the axes of the existing push and the new egate depending on the depth of the flat disc immersion in the soil.

The graph in Figure 3 illustrates how the distance B between the new egate and the current axle increases as the flat disk's depth in the soil rises. At a depth of 14–15 cm, this distance climbs to 88–90 cm. When the depth of the flat disk is less than 14 cm, the tractor deviates from the straight line movement direction due to the lack of supporting surface and starts to turn towards the available field. As a result, the distance between the existing push and new egat axles was reduced compared to the specified one. Increasing the depth of embedment of the flat disc into the soil provided a distance B and reduced the value of the root mean square deviation. Increasing the depth of embedding the flat disc into the soil from 0 to 15 cm significantly reduced the value of the mean square deviation of the distance B from 10.4 to 2.3 cm, and this value remained almost unchanged after the depth increased to 15 cm. Table 1. displays the experiment's outcomes.

Table 1. Results of experiments on the influence of the immersion depth of a flat disk on the performance of the unit.

Name of indicators	**Depth of immersion of a flat disk into the soil, see.**			
	0	**5**	**10**	**15**
distance between existing axis and new axis				
$M_{ўрм}$	72.6	80.4	87.1	88.3
±σ	10.4	7.8	5.3	2.3
Tractor driver turning the steering wheel	always	always	sometimes	no need
Turning the tractor to the side	to the left	to the left	To the left	

The table illustrates that turning the flat disc further into the soil prevented the tractor from turning to one side. The tractor's steering wheel had to be turned in the other direction, or to the right, every time the depth went below 10 cm. There was no need to turn the steering wheel in either direction when the depth was between 14 and 15 cm.

4 Conclusion

Thus, based on the results of the above-mentioned theoretical and experimental studies, the following conclusion was formed:

- it is possible to ensure the linear stable movement of the combined unit by means of a flat disk installed on it;
- the diameter of the flat disk must be at least 45 cm for the tractor with a combined unit to move smoothly in a straight line in the cotton field;
- the depth of the flat disc in the soil is between 14-15 cm, which makes it possible for the unit to move in a straight line.

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