

Conference Paper

Design and Justification of a Combined Tillage Machine

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Abstract

The tillage of soil with minimum energy consumption can be achieved by breaking the bonds between soil aggregates with tensile deformations. The design of a combined tillage machine is proposed and its technological parameters are justified. The proposed machine includes a frame with a flat working element with a leg, top and bottom rotary agitators with a drive mechanism placed behind a flat working element above each other. The design feature is that the circumferential velocity of a soil-destroying element of the lower rotary agitator is higher than the translational velocity of a machine, and the circumferential velocity of the upper rotary agitator is higher than the circumferential velocity of the lower rotary agitator. Besides, the proposed shape of a rotary agitator made along the Archimedes' spiral does not allow soil to be collapsed by the back of a cutting edge. This reduces specific energy consumption at high quality of soil loosening. The purpose of the machine is to reduce specific energy consumption of soil treatment. This is achieved by the fact that the axis of rotation of the upper rotary agitator is shifted backwards in the direction of machine movement relative to the axis of rotation of the lower rotary agitator by $h = R \cdot \sin \left(\arccos \left(-\frac{1}{\lambda} \right) \right)$, where R -- radius of the upper rotary agitator, λ -- kinematic parameter characterizing the operation mode of the upper rotary agitator. Thus, the destruction of a pre-stressed soil formation due to tensile stresses caused by the mutual arrangement of working elements and the interconnection of machine operation modes contributes to the reduction of energy consumption.

Keywords: soil, treatment, rotary machine, working element.

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1. Introduction

At present, there are two main trends in the mechanization of soil treatment in Russia and abroad: minimal -- with the use of subsoil tools, including flat-cutting, chisel, as well as combined units, etc., and conventional -- with the use of ploughs. Further improvement of machines will be aimed at improving the quality of soil treatment, reducing its energy consumption and increasing labor productivity [1].

The analysis of existing designs of combined tillage machines showed that there are some problems in ensuring efficient soil treatment. In particular, poor quality of soil

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pulverization by autorotative rollers; absence of the upper rotating rotor, which does not provide quality pulverization of the upper soil layer; soil bulldozing is possible at difficult roller rotation thus increasing the draught resistance [2, 3]. In some combined machines, the soil formation coming from a flat tool is broken between two counter-rotating rotary agitators through bending deformation and compression strain, which increases the energy consumption. Besides, the shape of rotary agitators in the form of screw coiling moves soil in transverse direction relative to the direction of a machine movement, which increases energy consumption and draught resistance of a machine [4, 5].

2. Methods

The purpose of the study is to develop and justify a combined tillage machine to reduce specific energy consumption of soil treatment.

The proposed tillage machine includes a frame 5 with a flat-cutting working element 10 installed on it via a box-section leg 7 (Figure 1), a drive mechanism 1 and 2, lower 9 and upper 4 rotary agitators (RA) arranged one above the other with displacement of a rotation axis of the upper RA backwards in the direction of a machine motion relative to the rotation axis of the lower RA backwards in the direction of a machine motion relative to the rotation axis of the lower RA, a carrier wheel 8 and a leveler 6. A chain belt for the drive of the lower RA 9 is placed in leg 7 of the box section.

When the machine is moving, a flat element 10 cuts the soil in the horizontal plane and deforms the cut soil layer. Moving along the working element, this soil layer gets to rotary agitators 9 and 4 rotating in opposition. The soil layer, leaving a flat working element, runs on soil-destroying elements of the lower RA 9, which are introduced into the soil in the lower part of the layer, and due to the fact that the rotation speed of soil-destroying elements of the lower RA 9 is higher than the translational speed of a machine it destroys the lower part of the layer by extension. At the same time, in the upper part of the layer, the point of the soil-destroying element 3 of the upper RA 4 enters the soil at a point located on a vertical passing through the axis of rotation of the lower RA 9 due to displacement of the upper RA 4 by value h backwards in the direction of a machine movement.

When the point gets into soil, the absolute speed vector of the point of the soil-destroying element 3 of the upper RA 4 is perpendicular to the soil surface, and is therefore directed perpendicular and towards the stress action when the upper part of the layer is extended due to bending of strata as it passes along the lower RA

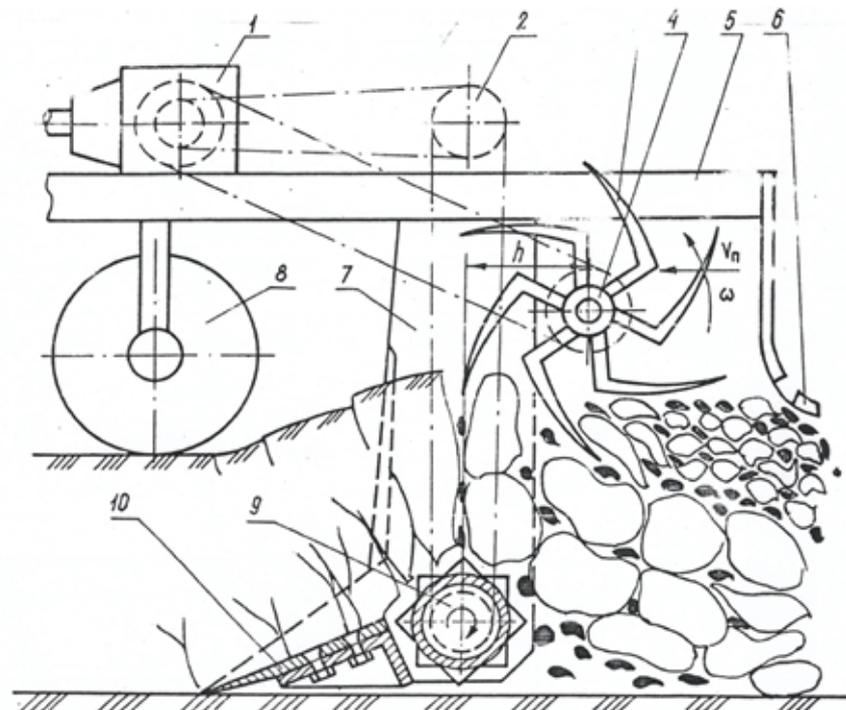


Figure 1: Scheme of proposed combined machine.

9. Consequently, formation failure occurs with less effort. Due to the fact that the circumferential velocity of soil-destroying elements 3 of the upper RA 4 is higher than the circumferential velocity of soil-destroying elements of the lower RA 9, the separation of soil elements in the upper part of the formation is done through breaking.

Thus, the destruction of a pre-stressed soil formation due to tension stresses caused by the mutual arrangement of working elements and the interconnection of machine operation modes contributes to the reduction of energy consumption.

The shape of soil-destructive elements 3 of the upper RA 4 in the form of curved teeth, the outer part of which is described by the Archimedes' spiral equation, allows the soil-destructive element to be buried in soil without being swept by its outer part, since during movement in the soil none of the points of a soil-destructive element goes beyond the trajectory described by its point. This allows using a small value of a kinematic parameter λ . The increase of λ to eliminate the above-mentioned disadvantage increases energy consumption for kinematic energy of soil particles as well as cutting.

It is known that the ultimate soil strength at tensile strain is 2 times less than at shear strain and 10 times less than at compression strain [6]. Consequently, the tillage of soil with minimum energy consumption can be accomplished by breaking the bonds between soil aggregates through the stretching strain.

3. Results

In order to justify the shape of a soil-destroying element, it is necessary to consider the conditions of its movement in the soil with minimum energy consumption (Figure 2).

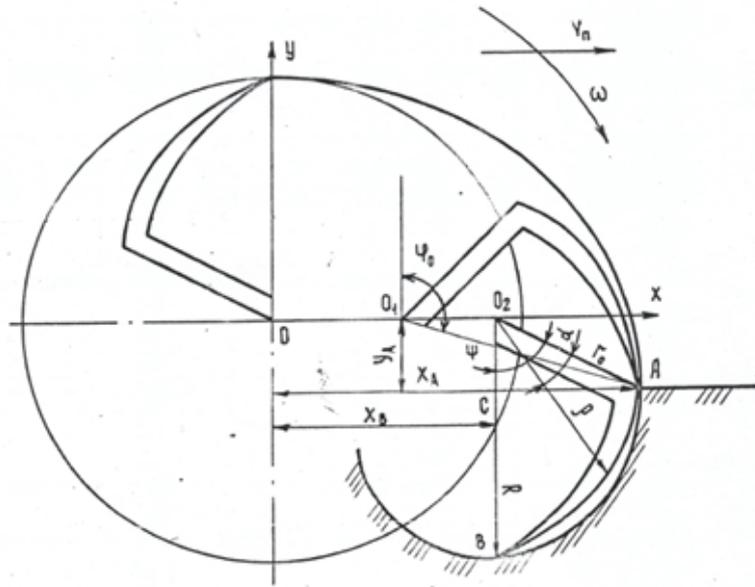


Figure 2: Scheme of interaction of a working element with soil.

The optimal energy consumption will be such soil-destroying element, the rear side of which does not collapse soil in front. Based on this requirement, let us describe the profile of the rear side of the soil-destroying element by the Archimedes' spiral equation.

The parameters of the Archimedes' spiral in order to achieve this effect shall be closely related to other design parameters and operating modes of a machine.

Hence, a soil-destroying element is buried in the soil without being swept by its back side, since during movement in the soil none of the points of the soil-destroying element goes beyond the trajectory of its point.

Let us write this equation in the coordinate system:

$$\rho = r_0 + \frac{R - r_0}{\psi} \cdot \alpha, \tag{1}$$

where ρ -- current value of the polar radius;

α -- current value of a knife turning angle;

r_0 -- minimum value of the polar radius, defined here by the expression:

$$r_0 = \sqrt{(O_2C)^2 + (AC)^2}. \tag{2}$$

According to the scheme 2 $O_2C = Y_A AC = X_A - X_C$.

Coordinate value $X_C = X_B$, где X_A, X_B, X_C, Y_A -- coordinates of corresponding points.

Proceeding from it, we will have:

$$r_0 = \sqrt{(Y_A)^2 + (X_A - X_B)^2}. \tag{3}$$

After substituting the coordinate values in formula (3), we get:

$$r_0 = \frac{R}{\lambda} \sqrt{\left[\arccos\left(-\frac{1}{\lambda}\right) + \sqrt{\lambda^2 - 1} - \pi \right]^2 + 1}. \tag{4}$$

The rotation angle of the polar radius when $\rho = R$:

$$\psi = \arccos \frac{R}{\sqrt{\left[\arccos\left(-\frac{1}{\lambda}\right) + \sqrt{\lambda^2 - 1} - \pi \right]^2 + 1}}. \tag{5}$$

By substituting the values in the following formula, we get:

$$\rho = \frac{R}{\lambda} \left[\sqrt{\left[\arccos\left(-\frac{1}{\lambda}\right) + \sqrt{\lambda^2 - 1} - \pi \right]^2 + 1} + \frac{\lambda - \sqrt{\left[\arccos\left(-\frac{1}{\lambda}\right) + \sqrt{\lambda^2 - 1} - \pi \right]^2 + 1}}{\arccos \frac{1}{\sqrt{\left[\arccos\left(-\frac{1}{\lambda}\right) + \sqrt{\lambda^2 - 1} - \pi \right]^2 + 1}}} \cdot \alpha \right]. \tag{6}$$

The proposed design of a combined machine provides for the displacement of the upper rotary agitator backwards in direction of a machine motion relative to the lower agitator by the value determined by the following formula:

$$h = R \cdot \sin(\pi - \varphi_0), \tag{7}$$

where $\varphi_0 = \arccos\left(-\frac{1}{\lambda}\right)$ -- rotation angle of the upper rotary agitator when a soil-destroying element gets into the soil, provided that at the moment of contact with the soil the vector of absolute speed of a point of a soil-destroying element is directed vertically downwards;

R -- radius of the upper rotary agitator;

λ -- kinetic parameter characterizing the operating mode of the upper rotary agitator.

After substituting φ_0 into the formula (7), we will get:

$$h = R \cdot \sin\left(\arccos\left(\frac{1}{\lambda}\right)\right) \tag{8}$$

One of the conditions of formation destruction by tensile deformation in the proposed design is the envisaged relationship of operating modes of upper and lower rotary agitators between each other and with the motion speed of a machine-propelled unit.

This relationship is expressed as inequality:

$$V < R_H W_H < R W, \tag{9}$$

where R and W -- radius and angular velocity of the upper rotary agitator;

R_H and W_H -- radius and angular velocity of the lower rotary agitator;

V -- speed of a machine.

Considering that $\lambda = \frac{RW}{V}$ or $V = \frac{RW}{\lambda}$, we get:

$$\frac{R \cdot W}{\lambda} < R_H W_H < R \cdot W$$

By dividing all parts of inequality into $R \cdot W$, we get:

$$\frac{1}{\lambda} < \frac{R_H \cdot W_H}{R \cdot W} < 1.$$

Taking into account that $i = \frac{W}{W_H}$, we get the final expression:

$$\frac{R_H}{R} < i < \frac{\lambda \cdot R_H}{R}.$$

4. Conclusion

The advantage of a proposed machine compared with its analogues is that it provides the destruction of soil formation mainly during tensile deformation.

Besides, the proposed shape of the rotary agitator made along the Archimedes' spiral does not allow the soil to be collapsed by the back of the working edge. All this reduces specific energy consumption with high quality of soil loosening.

Specific energy consumption for the treatment of each tilled hectare is reduced by about 25% compared to its analogues, which will allow increasing the productivity of soil processing units, reducing duration of works and obtaining a significant economic benefit.

Conflict of Interest

The author has no conflict of interest to declare.

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