The study of the stability of the movement of the frontal working bodies of the combined aggregate for sowing seeds of re-crops, depending on the depth of tillage

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Abstract. This article theoretically investigates the stability of the movement of frontal working bodies for strip tillage of an energy-saving combined aggregate for sowing seeds of re-crops, depending on the depth of tillage.At the same time, a differential equation was compiled that describes the change in the working depth of tillage by the frontal working bodies of the aggregate.Based on the equation, the dependences of the change in the amplitude of the depth of tillage by the section of the working bodies of the combined aggregate and the stiffness of the pressure spring were studied.

1 Introduction

Targeted research is being carried out all over the world to develop new resource-saving technologies for preparing fields for sowing re-crops and their implementation, to develop scientific and technical foundations for improving existing machines to ensure resource saving in the process [1-5].

In the republic, special attention is paid to reducing the labor intensity and energy intensity of agricultural production, resource saving, growing crops based on advanced technologies, developing and using highly efficient agricultural equipment [6-10].

Long-term scientific studies of resource-saving tillage technologies show that the development of resource-saving combined aggregates that perform several processes at once, combining tillage and sowing of re-crops seeds, is relevant task.

In addition, high-quality preparation of grain fields freed from winter crops and the development of a combined aggregate for sowing seeds of re-crops in accordance with agrotechnical requirements based on the agronomic background of the cultivated field are important [11-13].

The variability of the physical and mechanical properties of the soil and, consequently, the forces acting on the working bodies of the aggregate, lead to a change in their immersion depth and an uneven depth of tillage, which in turn adversely affects the required sowing quality and seed germination.

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Based on the foregoing, we study the uniformity of the movement of the frontal working bodies of the combined aggregate for sowing seeds of re-crops [14-16], depending on the depth of tillage.

We accept the following restrictions:

- the aggregate moves at a constant speed;
- friction forces in the hinges of the parallelogram mechanism are very small and do not affect the movement of the working bodies in the longitudinal-vertical plane;
- linear and angular vibrations of the cultivator frame do not affect the working depth of the device;
- the suppor wheel of the aggregate is constantly pressed to the ground;
- sections of the parallelogram mechanism working bodies work in a horizontal position in the equilibrium position, and their deviation from this position is a small angle

2 Methods

Using these restrictions and the design schemes presented in Fig. 1, we form the following differential equation representing the change in the depth of tillage by the working bodies [17, 18].

$$m\ddot{Z} = mg + \sum R_Z + Q_n - N_Z\,, \tag{1}$$

in this$\Sigma R_Z = R_{\ddot{y}Z}$ - $\Sigma R_{\partial Z}$.

We assume that the vertical reaction force N_z acting on the support wheel from the ground consists of the forces N_d and N_m, which are linearly related to the magnitude and rate of soil deformation [17], i.e.

$$N_z = N_\partial + N_m. \tag{2}$$

When working bodies are in a state of static equilibrium

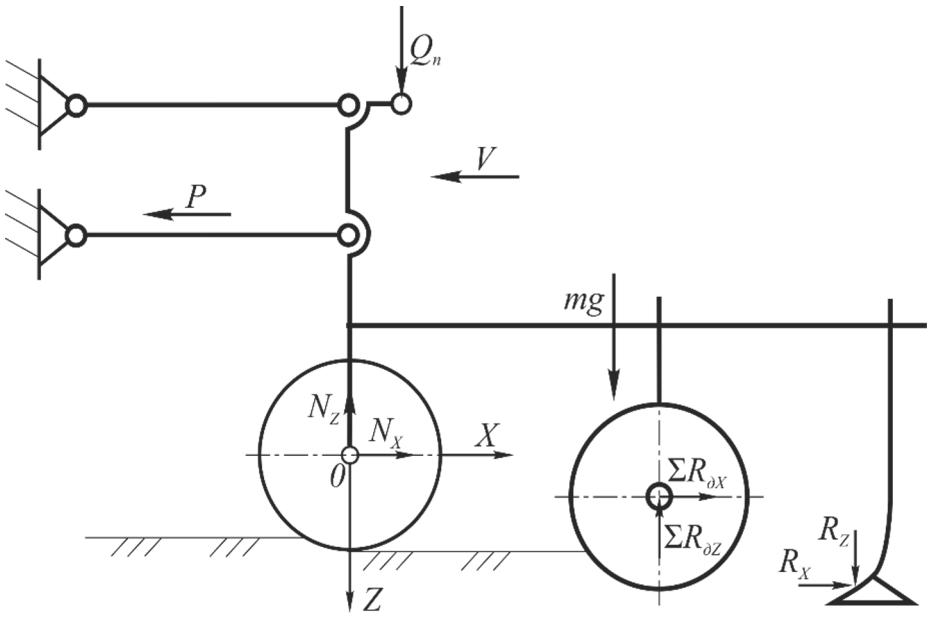

Fig. 1. Scheme of studying the change in the working depth of the working bodies.

$$N_\partial = \Delta_{cm} \cdot C_m B_m; \tag{3}$$

$$N_c = 0; \tag{4}$$

$$Q_n = Q_n^0, \tag{5}$$

In tis Δ_{cm} –deformation of the soil under the action of the support wheel, in the position of the working bodies in a state of static equilibrium m;

C_m –coefficient of soil stiffness per unit width of the rigidity of the support wheel H/м^2;

B_m- support wheel hub width, m

Δ_{cm} in expression (3) can be determined by the following expression [5]

$$\Delta_{cm} = \frac{3\left(mg + Q_n^0 + \sum R_Z\right)^2}{4q_0^2 B_m^2 D_m^3}, \tag{6}$$

In this q_0 –soil volumetric compaction coefficient, N/m^3;

D_m –diameter of the support wheel, M;

Q_n^0 –the initial pressure force of the parallelogram mechanism pressure spring of the, i.e.

pressure force when the working bodies are in a state of static equilibrium, N.

When the working bodies (support wheel) moves at a distance Z below the equilibrium position:

$$N_\partial = \left[\Delta_{cm} + Z\right] C_m B_m, \tag{7}$$

$$N_m = \dot{Z} b_m B_m, \tag{8}$$

$$Q_n = Q_n^0 - ZC_n, \tag{9}$$

In tis b_m –soil resistance coefficient per unit width of the support wheel N/m^2;
C_n– spring rate, Н/м.

According to (2)-(5) and (7) - (9), equation (1), representing the change in the tilling depth of the working bodies under the action of the forces Rx and Rz, takes the following form:

$$m\ddot{Z} = mg + Q_n^0 - ZC_n - \left[\left(\Delta_{cm} + Z\right)C_m + b_m\dot{Z}\right]\cdot B_m \sum R_Z. \tag{10}$$

We accept that the forces ΣRZ acting on the working bodies change according to the harmonic law, i.e.

$$\sum R_Z(t) = R_Z^n + \sum_{n=1}^{n_1} \Delta R_Z^n \cos n\omega t, \tag{11}$$

In this $R_Z^n - R_Z(t)$ average value of power, H;
$\Delta R_Z^n - R_Z(t)$amplitude of variable force components, N
n=1, 2, …, n_1–harmonic number;
n_1–number of the last recorded harmonic;
ω –rotation frequency of power change ΔR_Z^n, s-1.
We substitute expression (11) into expression (10) and obtain

$$m\ddot{Z} = mg + Q_n^0 - ZC_n - \left[\left(\Delta_{cm} + Z\right)C_m + b_m\dot{Z}\right]\cdot B_m + R_Z^n + \sum_{n=1}^{n_1} \Delta R_Z^n \cos n\omega t \tag{12}$$

When the working bodies are in a state of static equilibrium.

$$mg + Q_n^0 - \Delta_{cm} C_m B_m + R_Z^n = 0. \tag{13}$$

Taking this expression into account, we write equation (12) in the following form

$$m\ddot{Z} + b_m B_m \dot{Z} + \left[C_m B_m + C_n\right]Z = \sum_{n=1}^{n_1} \Delta R_Z^n \cos n\omega t \tag{14}$$

Or

$$\ddot{Z} + \frac{b_m B_m}{m}\dot{Z} + \frac{\left(C_m B_m + C_n\right)}{m} Z = \frac{1}{m}\sum_{n=1}^{n_1} \Delta R_Z^n \cos n\omega t \tag{15}$$

It can be seen from the expression (15) that the immersion of the support wheel into the soil and, consequently, the change in the working bodies tilling depth are represented by an inhomogeneous secondary differential equation.

3 Results and discussion

The solutions of the equation (15) that determine the change in the tilling depth of the working bodies and the maximum amplitude of these changes are as follows.

$$Z(t)=\frac{1}{m}\sum_{n=1}^{n_1}\frac{\Delta R_Z^n\cos(n\omega t-\delta_n)}{\sqrt{\left[\frac{(C_mB_m+C_n)}{m}-(n\omega)^2\right]^2+\left(\frac{b_mB_m}{m}\right)^2(n\omega)^2}},$$

(16)

$$A=\frac{1}{m}\frac{\Delta R_Z^n}{\sqrt{\left[\frac{(C_mB_m+C_n)}{m}-(n\omega)^2\right]^2+\left(\frac{b_mB_m}{m}\right)^2(n\omega)^2}},$$

(17)

In this

$$tg\delta_n=\frac{b_mB_m(n\omega)}{(C_mB_m+C_n)-m(n\omega)^2}.$$

The following condition must be met to ensure a uniform tilling depth:

$$A\le 0{,}5\Delta h, \tag{18}$$

In this Δh–allowable change of tilling depth, m.
Based on expression (17), inequality (15) can be written in the following form

$$\frac{1}{m}\sum_{n=1}^{n_1}\frac{\Delta R_Z^n}{\sqrt{\left[\frac{(C_mB_m+C_n)}{m}-(n\omega)^2\right]^2+\left(\frac{b_mB_m}{m}\right)^2(n\omega)^2}}\le 0{,}5\Delta h.$$

(19)

From the analysis of this expression, it can be seen that the uniformity of the tilling depth for a set operating mode is satisfied mainly due to a change in the stiffness of the parallelogram mechanism pressure spring.

Taking the parameters:

C_m=1,7·10^3 Н/м^2; B_m=0,1 м; b_m=51,2·10^3 Н·с/м^2; ΔR_z^n=300 Н; m=70 кг; n=1; ω=2 с$^{-1}$; φ_n=10°; μ=0,3, we draw a graph of the amplitude of the change in the depth of processing of the working bodies, depending on the stiffness coefficient of the pressure spring of the parallelogram mechanism (Fig. 2).

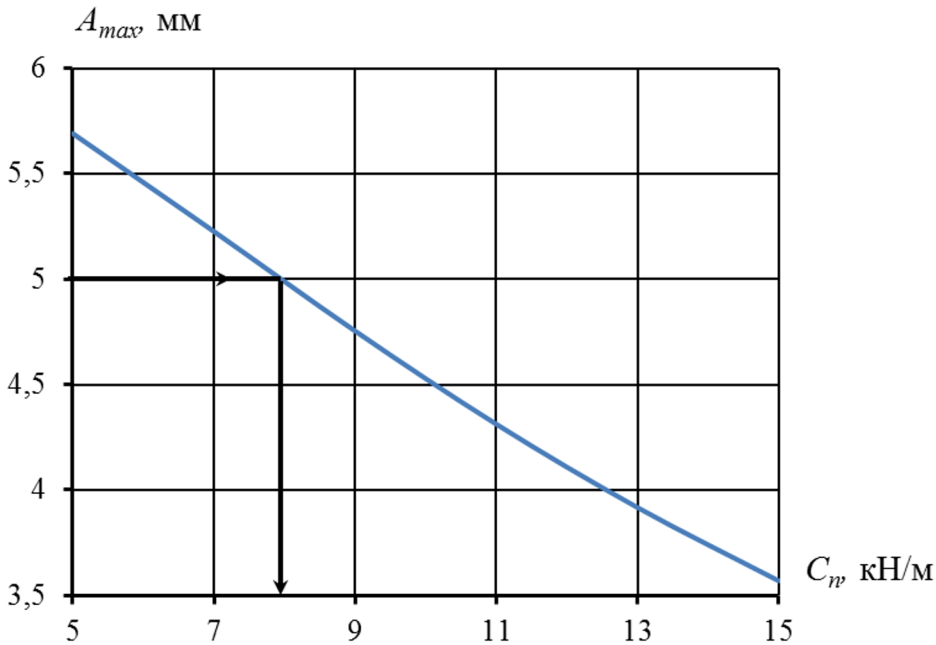

Fig. 2. Graph of the change in the amplitude of the change in the till depth of the working bodies depending on the spring rate (C_n).

4 Conclusion

As a result of the above theoretical studies, the amplitude of the change in the working depth of the aggregate working bodies is taken equal to Δh = 1 cm.It is graphically established that the spring stiffness of the parallelogram mechanism must be at least 82.7 N/cm. It is determined that the compression force of the spring section of the aggregate, applied to the parallelogram mechanism, must be respectively not less than 334.5 N.

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