Improving stability of movement of machine section for soil preparation and seeding

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Abstract. The subject research is operation of a combined machine for soil preparation and seeding of sunflower and corn seeds. Technological process of machine operation with installed guides, passive rotating flat discs with flanges (which properly ensure movement of soil along the plough share to loosening-separating device), a sowing device, a seed tube, a furrow former, a rotor, a separating grid, a parallelogram mechanism, a spring, a share is described. Dynamic prerequisites for increasing uniformity of depth of groove formation and seed placement in depth in soil are considered. Values of length of links of parallelogram mechanism, initial angle of their installation and stiffness of spring, values of deviations of combined machine section from given depth of movement of plough share are determined. It is proved that with an increase in length of levers of parallelogram mechanism, maximum deviations of section increase. An increase in initial angle of inclination of levers of parallelogram mechanism causes an increase in maximum deflections. As spring stiffness increases, maximum deflections decrease. Relevance of study lies in ensuring stability of copying soil surface by working bodies of combined machine while depth of seeding remains unchanged along entire length of movement, which will make it possible to increase movement speed and unit width. Target group of consumers of information in the article - designers, specialists involved in development of tillage machines.

1. Introduction
The development of sowing machinery for a long time was aimed mainly at increasing productivity, that is, at increasing working speeds, working width, tractor power, and in this respect, there is significant progress.
The technology based on the use of combined machines has a positive effect on reducing energy costs by reducing the number and depth of processing, combining mechanical operations in one unit – processing, sowing [1, 2].

Therefore, such combined machines, which in one pass provide the preparation of the seedbed and sowing, are usually called direct seeding-machines [3].

Direct seeding-machines are of three types:

- strip loosening type of the soil with a wavy disc;
- undercutting type with seed distribution under the duckfoot tine;
- combined type, combining cutting-type working bodies and coulter systems.

The evaluation criterion in this case is the indicator of uniform distribution of seeds along the depth. They are used for sowing grain crops on treated and untreated soils with preserved stubble.

Direct seeding-machines with pruning tines or seeding-machines with tine coulters are used for sowing grain crop seeds over stubble or under-cultivated soil. Such a coulter performs several operations simultaneously - loosening the soil, removing weeds, sowing seeds.

The advantages of direct seeders are that they provide loosening of the soil only in the seeding zone and create the necessary contact of the seeds with the soil. Direct seeders in Western Europe, which has light soils, provide “no-till” soil preparation. In the conditions of the USA, Canada and the forest-steppe of Ukraine on soils of medium and heavy texture, as practice has shown, the "zero" technology does not provide the creation of the necessary contact of seeds with the solid phase of the soil. Therefore, in our conditions, direct seeders are promising, providing soil cultivation in the seedbed.

Direct seeders with flat-cutting plough shares ensure the implementation of the most promising method of sowing - spread sowing. This removes weeds across the entire working width of the seeding machine, and the presence of seed bins in them contributes to an increase in their productivity.

The disadvantages of such machines include the fact that they can provide the required agricultural technology for the cultivation of grain crops and the uniformity of seeding in depth only on leveled fields where plowing is not used in the main sowing system. In addition, they cannot work in an environment with a large amount of crop residues and weeds.

2. Purpose of the article

Research of the working bodies of the combined sowing machine, which increase the uniformity of the seeding depth.

3. Materials and methods

Known developed by V.F. Pashchenko combined machine for soil preparation and sowing of sunflower and corn seeds, see patent No. 1077588.

The machine consists of a frame, six working sections, an ejector device, support wheels and markers. The working section includes a frame, a parallelogram mechanism, a plough share with a furrow former, guide discs with a flange, a separating grid, a rotor, a sowing device of a SUPN-8 seeder, a box for seeds and a seed tube.

The working process of the machine proceeds as follows. The soil, cut by the plough share, is fed by means of the guide discs to the loosening and separating device. At the same time, the seeds from the sowing device are fed through the seed tube into the wedge-shaped soil groove formed by the furrow cutter. The rotor traps soil clods between the knives and the separating grid, crumbles and transports them. Fine soil particles pass through the gaps of the separating grid and cover the seeds placed in the groove. When tedding the soil along the separating grid, large particles are pushed to the surface, small ones spill down.

An important factor that ensures an increase in the yield of agricultural crops is the uniform distribution of seeds in depth in the soil.
Therefore, along with other technical and technological requirements for tillage and sowing machines, an important requirement is the uniformity of the depth of soil cultivation and seeding.

In this case, such requirements relate to the depth of the formation of the groove in which the plant seeds should be placed.

Modern science is increasingly recommending to production the use of a soil-protective system of tillage by reducing the depth of cultivation, the number of mechanical treatments, or by combining a number of technological operations. This technology achieves the preservation of the soil structure, eliminates excessive soil compaction, increases its resistance to erosion processes [4].

Tillage machines with active-passive working bodies are less energy-intensive and more reliable in operation. These include the "Dokuchaevskaya" PRSM-5 soil-cultivating loosening-separating machine (stratifier) [5, 6].

Production tests of the proposed types of machines show that the best performance in work is given by the type of machines equipped with special working bodies and a coulter system for the consistent implementation of the technological process of soil preparation, and sowing.

It was found that the uniformity of the coulters is determined by their ability to follow the soil relief [7,8]. This is the main agrotechnical requirement for the sowing machine - ensuring the stability of copying the soil surface while the depth of seeding remains unchanged along the entire length of the movement.

4. Results and discussion

To solve this problem, it is necessary to have the equations of motion of the combined machine as a whole. Since it is practically impossible to draw up such equations taking into account the exact dimensions of structural elements and their location, it is advisable to limit ourselves to considering the equations of motion of its equivalent circuit (figure 1), i.e. build a computational model of the functioning of the machine in question.

![Figure 1. Scheme of sections of the combined machine equivalent to the structural one.](image)

The section of the combined machine can be considered as a system consisting of the following links:

- frame of section 1, on which guide discs 2, plough share 3, separating grid 4, rotor 5 and support-press wheel are installed 6. The axes of the discs, the rotor, the wheel and the separating grid with the plough share are rigidly connected to the frame of the section;
• spring 7, which ensures the mobility of the section frame with the working bodies attached to it, allows the support-press wheel to follow the field relief and contributes to the stable movement of the working bodies in the soil at a given depth;
• four-link parallelogram mechanism 8 provides plane-parallel movement of the section frame with working bodies;
• machine frame 9 with copying wheels 10, the axles of the wheels are rigidly connected to the frame.

Such a structural combination of working bodies with the frames of the section and the machine is carried out in order to ensure both fractional separation of the soil and uniform distribution of seeds along the depth. In this case, the task becomes to ensure the most minimal value of the deviation of the position of the seeds relative to the track of the support-press wheel.

The solution to the problem is carried out by selecting the stiffness of spring 7, the dimensions of the links of parallelogram mechanism 8 and the initial angle of their inclination to the horizontal plane \( \varphi_0 \).

Let us refer the system under consideration to the fixed Cartesian coordinates \( x \) and \( z \). The direction of rotation of the links of the parallelogram mechanism is clockwise, we take it as positive.

To solve the problem, in the first approximation, it can be assumed that with the floating position of the valve of the hydraulic distributor of the tractor in the steady-state operating mode \( V_M = const \), the frame of the combined machine, copying the sinusoidal surface of the field, moves according to the law

\[
\begin{align*}
  x_f &= V_M t \\
  z_f &= \mu \cdot \sin \lambda \cdot x_f - a_5,
\end{align*}
\]  

where \( x_f, z_f \) – coordinates of the center of mass of the machine frame and its support wheels, m; \( t \) – time, s; \( \mu, \lambda \) – constant coefficients depending on the topography of the field; \( a_5 \) – distance from axis \( x \) to the center of mass of the machine frame and its support wheels, m.

The soil will be considered as an elastic medium, and the rim of support-press wheel 6 will be considered non-deformable.

We will also assume that the forces applied to the discs, the share and the rotor are reduced to some resultant forces that have a constant value, as for the reactions applied to support-press wheel 6, based on the available data, we can take

\[
\begin{align*}
  R_{KX} &= f \cdot C_S \cdot \Delta_S, \\
  R_{KZ} &= C_S \cdot \Delta_S,
\end{align*}
\]

where \( R_{KX}, R_{KZ} \) – vertical and horizontal components of the forces applied to the wheel, N; \( C_S \) – soil hardness, N/m; \( f \) – rolling coefficient; \( \Delta_S \) – value of soil deformation, m.

Let us determine the value of soil deformation through the angle \( \varphi \) of rotation of the links of the parallelogram mechanism. Then we get

\[
\Delta_S + z_C - z_f = [\sin(\varphi_0 + \varphi) - \sin \varphi_0] + a_5,
\]

where \( z_C \) – coordinate of the center of mass of the section, m; \( l \) – length of arm AB, m.

\[
\begin{align*}
  z_C &= \mu \cdot \sin \lambda (V_M t - V_M t_1) \\
  t_1 &= \frac{l \cos (\varphi_0 + \varphi) + a_b}{V_M}
\end{align*}
\]
where $a_o$ – distance from axis O of wheel 6 to hinge B of the link of the parallelogram mechanism in the horizontal plane, m.

Then

$$z_C = \mu \cdot \sin \lambda \left( V_M t - l \cos(\varphi_0 + \varphi) - a_o \right)$$

After substituting the values $z_C$ and $z_f$ into equation (2), we get

$$\Delta_S = \left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right] + \mu \cdot \sin \lambda \cdot V_M \cdot t - \mu \cdot \sin \lambda \left( V_M t - l \cos(\phi_0 + \phi) - a_o \right)$$

(3)

Considering that soil deformation occurs only when the section is displaced in the positive $z$ direction, we get

$$\Delta_S = \frac{\left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right] + \mu \cdot \sin \lambda \cdot V_M \cdot t - \mu \cdot \sin \lambda \left( V_M t - l \cos(\phi_0 + \phi) - a_o \right)}{2}$$

Then

$$R_{KX} = f \cdot C_S \left\{ \frac{\left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right] + \mu \cdot \sin \lambda \cdot V_M \cdot t - \mu \cdot \sin \lambda \left( V_M t - l \cos(\phi_0 + \phi) - a_o \right)}{2} + \right\}$$

(4)

$$R_{KZ} = C_S \left\{ \frac{\left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right] + \mu \cdot \sin \lambda \cdot V_M \cdot t - \mu \cdot \sin \lambda \left( V_M t - l \cos(\phi_0 + \phi) - a_o \right)}{2} + \right\}$$

(5)

As an independent (generalized) coordinate of the system under consideration, it is convenient to take angle $\varphi$ of rotation of the link of the four-link parallelogram mechanism AB relative to the hinge A. Then the differential equation of motion of the section will be written as

$$\frac{d^2 \varphi}{dt^2} = Q_\varphi$$

(6)

where $T$ – kinetic energy of the system, Nm; $Q_\varphi$ – generalized force, Nm.

Before writing down the expression for the kinetic energy of the system, we note that in the problem being solved, if we take the rotation of disks 2, rotor 5, wheel 6 to be uniform and the forces of resistance to their rotational motion constant, then there is no need to draw up the equations of motion of the latter. Taking this into account, the expression for the kinetic energy of the system will be written

$$T = \frac{1}{2} M_C \left( x_C^2 + z_C^2 \right)$$

(7)

where $M_c$ – mass of the section, kg; $x_C$, $z_C$ – coordinates of the center of mass of the section, m.

Expressing $x_C$ and $z_C$ from the geometric conditions in terms of the values $x_f$ and $z_f$, differentiating them in time and substituting them into equation (7), we obtain
\[
T = \frac{1}{2} M_c \left[ V_M^2 + 2V_M l \phi \sin(\phi_0 + \phi) + l^2 \phi^2 \sin^2(\phi_0 + \phi) + \mu^2 \lambda^2 V_M^2 \cos^2 \lambda V_M t + 2 \mu \lambda V_M \cos \lambda V_M l \phi \cos(\phi_0 + \phi) + l^2 \phi^2 \cos^2(\phi_0 + \phi) \right]
\]

(8)

Since

\[
\frac{\partial T}{\partial \phi} = M_c l \left[ V_M \sin(\phi_0 + \phi) + l \phi + \mu \lambda V_M \cos \lambda V_M t \cos(\phi_0 + \phi) \right],
\]

\[
\frac{d}{dT} \frac{\partial T}{\partial \phi} = M_c l \left[ V_M \phi \cos(\phi_0 + \phi) + l \phi - \mu \lambda^2 V_M^2 \sin \lambda V_M t \cos(\phi_0 + \phi) - \mu \lambda V_M \phi \cos \lambda V_M t \sin(\phi_0 + \phi) \right]
\]

we get

\[
\frac{d}{dT} \frac{\partial T}{\partial \phi} = M_c l \left[ l \phi - \mu \lambda^2 V_M^2 \sin \lambda V_M t \cos(\phi_0 + \phi) \right]
\]

(9)

To determine the generalized forces, we will use the law of virtual displacements. Then, if we bring all the reactive forces to hinge B of the link of parallelogram mechanism 8, using the theorem on the parallel transfer of forces, we obtain

\[
\partial A_{\phi} = \left[ R_x l \sin(\phi_0 + \phi) + R_z l \cos(\phi_0 + \phi) + C_{SP} (h - z_c) l \cos(\phi_0 + \phi) - \right. \]

\[
\left. \left. -R_x l \sin(\phi_0 + \phi) - R_z l \cos(\phi_0 + \phi) \right] d\phi \right.
\]

where \( R_x, R_z \) – horizontal and vertical components of the resultant forces applied to the disks, rotor, plough share, separating grid and section weight, N; \( C_{SP} \) – spring tension, N/m; \( h \) – spring pretension, m;

\[
R_x = R_{fx} - R_{dx} - R_{lx} - R_{fx},
\]

\[
R_z = M_{CG} - R_{lz} - R_{dz} - R_{pz}
\]

where \( R_{lx}, R_{dx}, R_{lx}, R_{dz}, R_{pz} \) – horizontal and vertical components of the resultant reactive forces applied to the share, discs and rotor; \( R_{fx} \) – force of resistance to friction of the soil against the separating grid, N.

Since

\[
z_c = l \left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right]
\]

then, taking into account equations (4), (5) and (9), we obtain

\[
Q_{\phi} = R_x l \sin(\phi_0 + \phi) + R_z l \cos(\phi_0 + \phi) + C_{SP} l \cos(\phi_0 + \phi) \times
\]

\[
\times \left\{ \left[ h - l \left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right] \right] - C_{SP} \left[ \cos(\phi_0 + \phi) + f \sin(\phi_0 + \phi) \right] \times \right. \]

\[
\left. \left. \left[ l \left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right] + \mu \cdot \sin \lambda \cdot V_M \cdot t - \mu \cdot \sin \lambda \left( V_M t - l \cos(\phi_0 + \phi) - a_0 \right) \right] \right\} \right.
\]

\[
\times \left\{ \left[ l \left[ \sin(\phi_0 + \phi) - \sin \phi_0 \right] + \mu \cdot \sin \lambda \cdot V_M \cdot t - \mu \cdot \sin \lambda \left( V_M t - l \cos(\phi_0 + \phi) - a_0 \right) \right] \right\} \right.
\]

\[
(10)
\]

(10)
Substituting expressions (8) and (10) into equation (6), we obtain a computational model of the functioning of the section of the combined machine for seeding and the fractional distribution of soil along the depth of the sowing layer:

\[
\ddot{\phi} = M cl [R_x \sin(\phi_0 + \phi) + R_z \cos(\phi_0 + \phi)] + \frac{C_{SP} \cos(\phi_0 + \phi)}{M cl} 
\times \left\{ h - l [\sin(\phi_0 + \phi) - \sin \phi_0] - \frac{C_S [f \sin(\phi_0 + \phi) + \cos(\phi_0 + \phi)]}{M cl} \right. 
\times \left[ (l [\sin(\phi_0 + \phi) - \sin \phi_0] + \mu \cdot \sin \lambda \cdot V_M \cdot t - \mu \cdot \sin \lambda (V_M t - l \cos(\phi_0 + \phi) - a_0)^2 \right]^{1/2} 
+ \left. \frac{\mu \lambda^2 V_M^2 \sin \lambda V_M t \cos(\phi_0 + \phi)}{l} \right\} + (11)
\]

The differential equation was solved by the Runge-Kutta method. Then the obtained value of angle \( \phi \) was substituted into equation (3) and the values of the deviation of the section of the combined machine from the given depth of tillage and seeding were found.

For the calculation, it was taken as: \( R_x = -700 \) N, \( R_z = -40 \) N, \( h = 0.08 \) m, \( M_c = 88 \) kg, \( C_S = 80000 \) N/m, \( f = 0.02 \), \( \mu = 0.04 \), \( \lambda = 0.5 \), \( V_M = 2.2 \) m/s.

The values of length \( l \) of the links of the parallelogram mechanism, the initial angle of their installation and stiffness of spring \( C_{SP} \) were changed, and various values of the deviations of the section of the combined machine from the given depth of the share stroke were determined. The oscillation pattern of the section is shown in figure 2. The dependence of the numerical values of the maximum deviations of the section of the combined machine is shown in figure 3.

![Graph](image_url)

**Figure 2.** The nature of the deviation of the section of the combined machine from a given depth of tillage.
Figure 3. Dependence of the maximum deviation of the combined machine section relative to the specified working depth.

The data of the graph (figure 3) indicate that with an increase in the length of the levers of the parallelogram mechanism from 0.2 to 0.4 m, the maximum deviations of the section increase by 3 times; with an increase in length from 0.2 to 0.6 m – five times. An increase in the initial angle of inclination of the levers of the parallelogram mechanism from 0 to 100 causes an increase in the maximum deviations by 28.5%, and from 0 to 200 – by 185%. With an increase in the spring stiffness from 1000 to 3000 N/m, the maximum deflections are reduced by 50%, and from 1000 to 8000 N/m – by 100%.

5. Conclusion
To increase the stability of the movement of the section of the combined machine, the length of the links of the parallelogram mechanism and the angle of their inclination to the horizontal plane must be chosen as small as possible, and the spring rate close to 8000 N/m.

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