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Investigation of the Combined Disc Harrow Leveller Movement in Longitudinal-Vertical Plane

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ABSTRACT: It is established that the uniform effect of the combined disk harrow leveler on the field surface is achieved mainly by correct choice of the compression spring stiffness of parallelogram mechanism and inclination angle of its rods relative to horizontal, and during operation the longitudinal rods of parallelogram mechanism should work occupying horizontal or close to this position.

KEYWORDS: combined disc harrow, leveler, parallelogram mechanism, compression spring, forced equalizer oscillations, forced oscillation amplitude, level and leveling off the field surface.

I. INTRODUCTION

At present, disc harrows such as BDT-3.0, TDB-3.0 are widely used in our country in preparation of lands for sowing of wheat and secondary crops, as well as in pre-sowing tillage. However, it is known that when these harrows are used, the soil is additionally treated with rakes and harrows to prepare it to the required level for sowing. This leads to an increase in the cost of cultivating the land, including fuel consumption. Based on the above, our institute has developed combined disc harrow, which is used in preparation of lands for sowing of wheat and secondary crops, as well as in pre-sowing tillage on fallow lands, and conducted research to substantiate its parameters [1–4].

It consists of common frame equipped with hanging device of combined disc harrow and working body in the form of spherical disc mounted on it in two rows (disc rippers), tooth leveller (later leveller) and plank leveller-roller. The disc rippers are fixed to the frame by means of special brackets, the leveller by means of parallelogram mechanisms equipped with pressure spring, and the plank roller is installed movable to the frame by means of special pulls, i.e. hinged attached. During the work process, disc rippers in the first row cut, grind and mix the soil and plant remains to one side, while the disc rippers in the second row perform the same process and push the soil to the other side. As a result, plant remains and soil are well shredded, forming a soft layer. Additional shredding, smoothing and compaction of layer surface treated by levelling and roller disc rippers.

This article presents the results of research on longitudinal-vertical motion of combined disc harrow leveller.

II. BACKGROUND OR RELATED WORK

Leading scientists such as M.A.Akhmedjanov, V.N.Sokolov, A.T.Egamov, B.K.Utepbergenov, A.I.Kuchenko, Yu.I.Kuznetsov, K.Muhammadsodikov, M.P.Kalimbetov have conducted research on creation and improvement of levelers, which are part of separate and combined units, as well as the substantiation of their parameters [4–12]. Tractor-implement combinations are increased tractive efficiency and drawbar performance during various soil working operations [13–15]. However, in these studies, interaction processes of combined disc harrow leveler with soil and parameters that provide them with high-energy quality and low energy consumption have not been sufficiently studied. This in turn requires special research.

III. MATERIALS AND METHODS

On investigation the motion of combined disc harrow leveler were used by laws, rules and methods of theoretical mechanics, agricultural mechanics, and mathematical statistics.

IV. ANALYSIS AND RESULTS

Because the physical and mechanical properties of soil are variable, forces R_x and R_z acting on leveller (see figure) are constantly changeable during operation. For this reason, in addition to the forward motion, leveller also acts in vertical direction, i.e. along the *Z*-axis, forced oscillation also acts that change its effect on the ground. As a result, it is not ensured to smooth levelling and smoothing of the field surface.

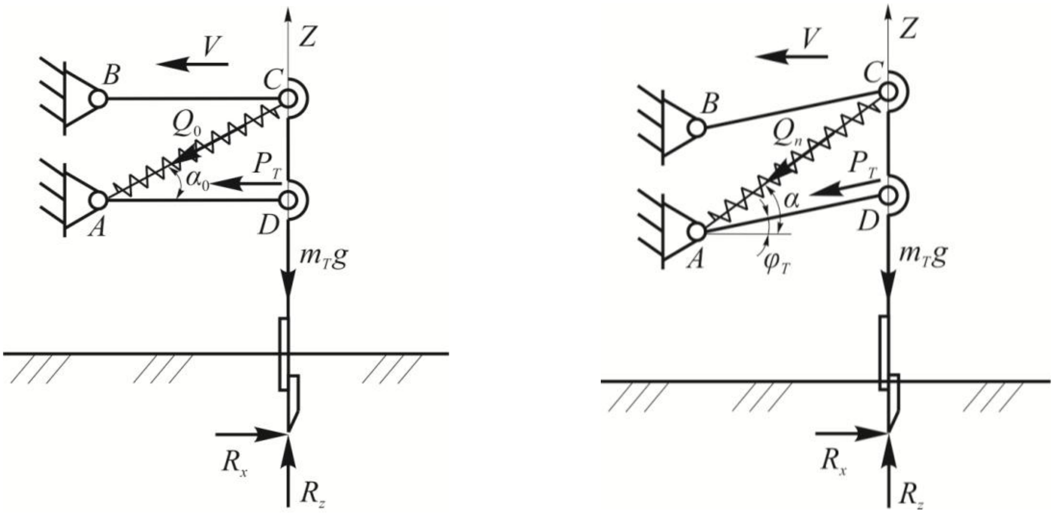
To ensure smooth levelling and smoothing of the field surface, the amplitude of vertical forced oscillations of the leveller should be as small as possible. For this purpose, we form differential equation representing vertical forced oscillations of the leveller according to the calculation scheme shown in figure. It will have the following appearance

$$m_T \frac{d^2Z}{dt^2} = -m_T g - Q_{nv} + R_z - P_T \sin\varphi_T, \quad (1)$$

or

$$m_T \frac{d^2Z}{dt^2} = -m_T g - Q_{nv} + R_z + (Q_{nh} - R_x) tg\varphi_T, \quad (1, a)$$

where m_T - the mass of leveller, kg; Z - vertical coordinate axis, m; t - time, s; Q_{nv}, Q_{mh} - the vertical and horizontal components of compressive force Q_n applied to the leveler by the pressure spring of parallelogram mechanism, N; R_x, R_z - horizontal and vertical components of resistance forces acting on working bodies by the soil, N; R_T - gravitational force applied to the leveller by parallelogram mechanism, N; φ_T - inclination angle of parallelogram mechanism from the horizontal position, degrees.



a, *b* - equilibrium and deviation states of the leveller, respectively

Fig. 1. The scheme for studying of changes in depth of subsidence of leveller

R_z and R_x forces can be expressed as [16, 17]

$$R_z = R_e + R_r + R_{zt} \quad (2)$$

and

$$R_x = R_x^{av} + R_{xt}, \quad (3)$$

where R_e, R_r are the forces linearly related to the amount and rate of soil deformation, respectively, i.e. elastic and resistance forces of the soil, N; R_x^{av} - average value of force R_x, N; R_{zt}, R_{xt} - the variable components of forces R_z and R_x, N.

In the static equilibrium position of the leveler

$$R_e = \Delta_T k_T C_T, \quad (4)$$

$$R_r = 0, \quad (5)$$

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Vol. 7, Issue 5 , May 2020

$$R_{zt} = 0, \qquad (6)$$
$$R_{xt} = 0, \qquad (7)$$
Q_n=Q_0; Q_{nv}=Q_0sinα_0; Q_{nh}=Q_0cosα_0, (8)

where Δ_T - depth of immersion of leveler in the state of static equilibrium, m; k_T - amount of leveller teeth, pcs; C_T - the inflexibility coefficient of soil applied to one tooth of leveller, $\frac{N}{m\cdot(teeth)}$; Q_0 - the initial compressive strength of pressure spring, N; α_0 - the inclination angle of the force vector Q_0 to the horizon, degrees.

When leveller rises above the equilibrium position by a distance of Z.

R_e=(Δ_T – Z) $k_T C_T$ (9)

R_r= – $\dot{Z}$ $k_T b_T$ (10)

R_{zt} = $\Delta R_z(t)$ (11)

R_{xt} = – $\Delta R_x(t)$ (12)

Q_{nv}=(Q_0 + $C_n Z$) sinα (13)

Q_{nh}=Q_0cosα, (14)

where b_T - the resistance coefficient of soil applied to one tooth of the leveller, $\frac{N\cdot s}{m\cdot(teeth)}$; ΔR_{xt}, ΔR_{zt} - variable forces, N; C_n - the inflexibility of the spring, N/m. α - inclination angle of spring to the horizon when compressive force deviates from the leveling equilibrium position, degrees.

Substituting the above values of R_e, R_r, R_{zt}, R_{xt}, Q_{nv}, and Q_{nh} into expression (1) and assuming α = α_0, we obtain following result

$$m_T\frac{d^2Z}{dt^2} = -m_T g - (Q_0 + C_n Z)\sin\alpha_0 + \left[\left(\Delta_T - Z\right)C_T - \dot{Z}b_T\right]k_T + \Delta R_z(t) + \\ + \left[Q_0\cos\alpha_0 - (R_x^{av} - \Delta R_x(t))\right]tg\varphi_T. \qquad (15)$$

When the leveler is in equilibrium

$$-m_T g - Q_0\sin\alpha_0 + \Delta_T C_T k_T + \left(Q_0\cos\alpha_0 - R_x^{av}\right)tg\varphi_T = 0. \qquad (16)$$

With this in mind, we bring Equation (15) to the following form

$$m_T\frac{d^2Z}{dt^2} = -\left[k_T b_T\dot{Z} + \left(k_T C_T + C_n\sin\alpha_0\right)Z\right] + \Delta R_z(t)tg\varphi_T + \Delta R_z(t). \qquad (17)$$

or

$$m_T\ddot{Z} + k_T b_T\dot{Z} + \left(k_T C_T + C_n\sin\alpha_0\right)Z = \Delta R_x(t)tg\varphi_T + \Delta R_z(t). \qquad (18)$$

According to the scheme shown in Figure 1

$$\sin\alpha_0 = \frac{d}{\sqrt{l_{lt}^2 + d^2}}, \qquad (19)$$

where d - vertical distance between the fixed or movable hinges of parallelogram mechanism, m; l_{lt} - the length of longitudinal traction of parallelogram mechanism, m.

Substituting the value of sinα_0 by (19) into expression (18), we obtain the following

$$m_T\ddot{Z} + k_T b_T\dot{Z} + \left(k_T C_T + C_n\frac{d}{\sqrt{l_{lt}^2 + d^2}}\right)Z = \Delta R_x(t)tg\varphi_T + \Delta R_z(t). \qquad (20)$$

$\Delta R_x(t)$ and $\Delta R_z(t)$ assuming that the forces changes by [18] according to the harmonic law, the solution of equation (20) representing the vertical forced oscillations of leveler and its amplitude have following formulas

$$Z(t) = \frac{1}{m_T}\sum_{n=1}^{n_1}\frac{(\Delta R_x tg\varphi_T + \Delta R_z^{av})\cos(n\omega t - \delta_n)}{\sqrt{\left[\frac{k_T C_T\sqrt{l_T^2 + d^2} + C_n d}{m_T\sqrt{l_T^2 + d^2}} - (n\omega)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2(n\omega)^2}} \qquad (21)$$

and

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$$A_T = \frac{1}{m_T}\sum_{n=1}^{n_1}\frac{(\Delta R_x tg\varphi_T + \Delta R_z^{av})}{\sqrt{\left[\frac{k_T C_T\sqrt{l_{lt}^2+d^2}+C_n d}{m_T\sqrt{l_{lt}^2+d^2}} - (n\omega)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2 (n\omega)^2}}, \qquad (22)$$

where n=1,2,…, n_1 - number of harmonics; ω - rotational frequency of variable components, s[-1];

$$\delta_n = arctg\frac{k_T b_T (n\omega)\sqrt{l_{lt}^2+d^2}}{\left(k_T C_T + C_n\frac{d}{\sqrt{l_{lt}^2+d^2}}\right) - m_T\sqrt{l_{lt}^2+d^2}(n\omega)^2}.$$

When the pressure spring mounted vertically, expressions (21) and (22) have following appearance

$$Z(t) = \frac{1}{m_T}\sum_{n=1}^{n_1}\frac{(\Delta R_x tg\varphi_T + \Delta R_z^{av})\cos(n\omega t - \delta_n)}{\sqrt{\left[\frac{k_T C_T + C_n}{m_T} - (n\omega)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2 (n\omega)^2}} \qquad (21, a)$$

and

$$A_T = \frac{1}{m_T}\sum_{n=1}^{n_1}\frac{(\Delta R_x tg\varphi_T + \Delta R_z^{av})}{\sqrt{\left[\frac{k_T C_T + C_n}{m_T} - (n\omega)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2 (n\omega)^2}}. \qquad (22, a)$$

where $\delta_n = arctg\frac{k_T b_T (n\omega)}{(k_T C_T + C_n) - m_T (n\omega)^2}$.

In process of working according to expressions (21), (21, a), (22) and (22, a), the impact degree of leveler on the field surface is depended on its mass (m_T), amount of teeth (k_T), amplitude of variable forces acting on it ($\Delta R_x^{av}, \Delta R_z^{av}$), frequency ($\omega$), inclination angle of parallelogram mechanism to the horizon (φ_T), length (l_{lt}), vertical distance between the hinges (d), the stiffness of pressure spring (C_n), physical and mechanical properties of soil (C_T, b_T). Since the factors $\Delta R_x^{av}, \Delta R_z^{av}$, ω, C_T and b_T are uncontrollable factors, uniform effect of leveler on the field surface can be achieved mainly by stiffness of pressure spring of the parallelogram mechanism and right choice of inclination angle of the traction relative to the horizon. If the longitudinal traction of parallelogram mechanism is provided for in horizontal position during operation, $\Delta R_x(t)$ variable force and hence physic-mechanical properties of soil and change in speed of the aggregate do not affect performance of the leveller. As a result, optimal conditions are created for smooth leveling and smoothing of the field surface.

The operation of longitudinal traction of the parallelogram mechanism in horizontal position during work is achieved by changing mounting height of the parallelogram mechanism to frame or length of column (bracket) connecting the leveler to it.

The differential equation (20), which represents vertical forced oscillations of the leveler in the presence of irregularities on the field surface, has the following form

$$m_T\ddot{Z} + k_T b_T\dot{Z} + \left(k_T C_T + C_n\frac{d}{\sqrt{l_{бm}^2+d^2}}\right)Z = \Delta R_x(t)tg\varphi_T + \Delta R_z(t) - F_u. \qquad (23)$$

where F_u - force of inertia resulting from copying of field surface unevenness by leveler, N.

We assume that the profile of the field surface changes according to the following law in direction of movement of the aggregate

$$Z = Z_0\sin\frac{\pi Vt}{l_s}, \qquad (24)$$

where Z_0 - height of roughness, m; V - speed of the aggregate, m/s; l_s - length of roughness, m.

In it, force of inertia generated by copying unevenness on surface of the softening field

$$F_u = -m_0 Z_0 \frac{\pi^2 V^2}{l_s^2} \sin \frac{\pi V t}{l_s}. \tag{25}$$

With this in mind, expression (23) has following final form

$$m_T \ddot{Z} + k_T b_T \dot{Z} + k_T \left(C_T + C_n \frac{d}{\sqrt{l_{lt}^2 + d^2}} \right) = \tag{26}$$

$$= \Delta R_x(t) tg\varphi_T + \Delta R_z(t) + Z_0 \frac{\pi^2 V^2}{l_s^2} \sin\left(\frac{\pi V t}{l_s}\right).$$

The solutions of this equation representing vertical forced oscillations of leveler and its amplitude are as follows [19]

$$\text{Z(t)} = \frac{1}{m_T} \sum_{n=1}^{n_1} \frac{(\Delta R_x tg\varphi_T + \Delta R_z^{av}) \cos(n\omega t - \delta_n)}{\sqrt{\left[\frac{k_T C_T \sqrt{l_{lt}^2 + d^2} + C_n d}{m_T \sqrt{l_{lt}^2 + d^2}} - (n\omega)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2 (n\omega)^2}} + \tag{27}$$

$$+ \frac{(\pi V)^2 Z_0 \sin\left[\left(\frac{\pi V}{l_s}\right) t - \delta_2\right]}{l_{lt}^2 \sqrt{\left[\frac{k_T C_T \sqrt{l_{lt}^2 + d^2} + C_n d}{m_T \sqrt{l_{lt}^2 + d^2}} - \left(\frac{\pi V}{l_s}\right)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2 \left(\frac{\pi V}{l_s}\right)^2}}$$

and

$$\text{A}_\text{T} = \frac{1}{m_T} \sum_{n=1}^{n_1} \frac{\Delta R_x tg\varphi_T + \Delta R_z^{av}}{\sqrt{\left[\frac{k_T C_T \sqrt{l_{lt}^2 + d^2} + C_n d}{m_T \sqrt{l_{lt}^2 + d^2}} - (n\omega)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2 (n\omega)^2}} +$$

$$+ \frac{(\pi V)^2 Z_0}{l_{lt}^2 \sqrt{\left[\frac{k_T C_T \sqrt{l_{lt}^2 + d^2} + C_n d}{m_T \sqrt{l_{lt}^2 + d^2}} - \left(\frac{\pi V}{l_s}\right)^2\right]^2 + \left(\frac{k_T b_T}{m_T}\right)^2 \left(\frac{\pi V}{l_s}\right)^2}}, \tag{28}$$

where $\delta_2 = arctg \dfrac{k_T b_T \left(\frac{\pi V}{l_s}\right) \sqrt{l_s^2 + d^2}}{\left(k_T C_T + C_n \frac{d}{\sqrt{l_{lt}^2 + d^2}}\right) - m_T \sqrt{l_{lt}^2 + d^2} \left(\frac{\pi V}{l_s}\right)^2}.$

Analysis of expressions (27) and (28) shows that the presence of unevenness on the field surface leads to increase in range and amplitude of change in depth of subsidence of the leveler and, consequently, deterioration of its leveling and cultivation levels. An increase in height of unevenness and speed of movement of the aggregate leads to deterioration of these parameters, and increase in length of unevenness leads to their improvement.

IV. CONCLUSION

The required level of performance of the combined disc harrow leveller is provided by installation angle of longitudinal traction of the parallelogram mechanisms on which they are installed relative to the horizon and right choice of pressure springs stiffness. In process of work, when longitudinal traction of the parallelogram mechanisms works in horizontal or close position, uniform levelling and smoothing of the field surface is achieved.

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