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Research of the Vibration Movement of the Combined Machine Straightener in the Longitudinal-Vertical Plane

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ABSTRACT

In the article, a theoretical study of the vibration behavior of the combined machine leveler used in the preparation of land for planting, caused by the variation of the forces acting on it in the longitudinal-vertical plane as well as the results of experimental researches conducted on studying the influence of the angle of deviation of the parallelogram mechanisms with leveler to the horizon, the mean square deviation of the heights of unevenness on the field surface, and the level of soil compaction. Theoretical researches are based on the laws and rules of theoretical mechanics and the theory of vibrations, and experimental researches are based on UzDst 3412:2019 "Experiment agricultural technics. Machines and devices for depth tillaging the surface of soil. Programs and methods of experiments" was conducted on the basis of the regulatory document. In this case, it was found that the amplitude of vertical forced vibrations of the leveler has a minimum value due to the reduction and elimination of the effect of the forces acting on the parallelogram mechanisms with the combined machine leveler installed in the horizontal or close to it when working, and due to the reduction and elimination of the effect of the variability of the physical and mechanical properties of the soil.

INTRODUCTION. Currently, in our country, land preparation for sowing seeds is carried out separately many times by means of medium and heavy toothed harrows, chisel-cultivators and various levelers [1].

However, this leads to the deterioration of the physical and mechanical properties of the soil, a lot of moisture loss from the soil, and an increase in fuel consumption and other costs. In addition, the machines used for tilling the land before planting do not meet modern requirements such as minimal and economical tillage. Based on the above, in the scientific-research institute of agricultural mechanization, in the cultivation of cotton, grain and other agricultural crops, all technological processes are performed in one pass through the field for processing the land before planting, that is, loosening the land to a specified depth, forming a soft soil layer on the surface of the field, leveling and a combined machine was developed to ensure that it is compacted at the required level [2-6]. The machine consists of a frame, a suspension device installed on it, supporting wheels and working bodies, which, depending on the process to be performed, consist of a softener and bullet-shaped claws, a leveler, and a plate roller, which are arranged in a row on the frame.

Materials and methods. The leveler of the combined machine consists of a leveling part 2 connected to the frame by means of a parallelogram mechanism 1 equipped with a compression spring, and soil pushers 3 installed in its front part (Fig. 1). pushing to the side, i.e. in the transverse direction, fills their edges, and the leveling part pushes the unevenness occurring in the longitudinal direction to the depressions. As a result, the surface of the layer processed by the machine is ensured to be leveled at the required level and evenly in the longitudinal and transverse directions [7].

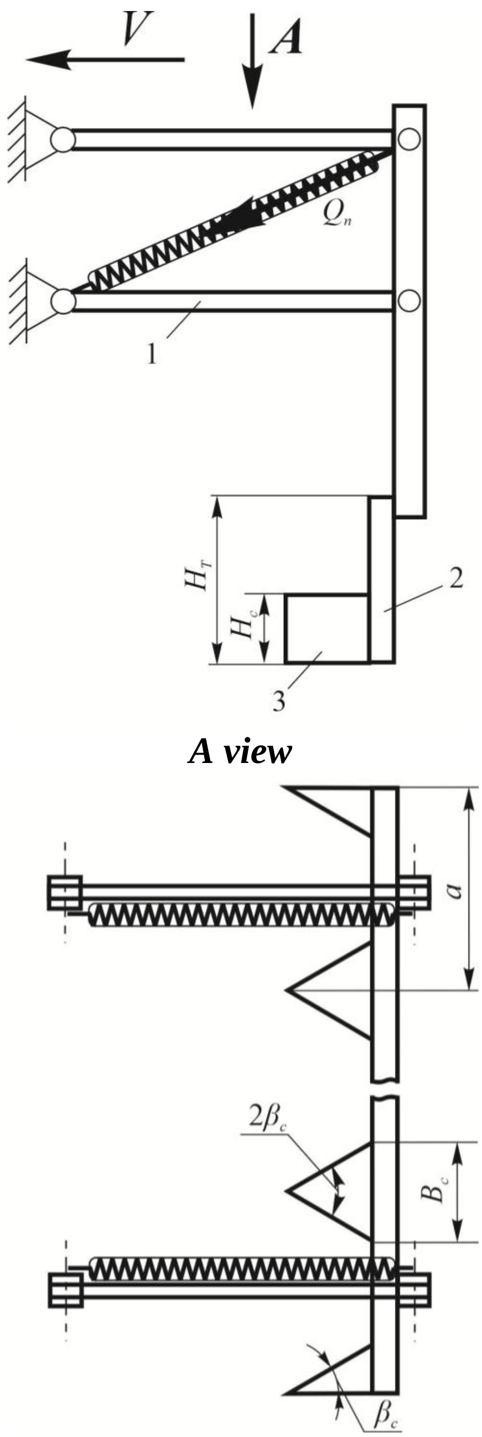


Figure 1. Scheme of the combined machine leveler

The article uses the laws and regulations of theoretical mechanics and the theory of vibrations, as well as the regulatory document UzDst 3412:2019 “Experiment agricultural technics. Machines and devices for depth tillaging the surface of soil. Programs and methods of experiments” [8-10], theoretical and experimental researches were carried out to study the vibration behavior of the combined machine leveler in the longitudinal-vertical plane.

Results and discussion. Longitudinal forces $R_m^{б}$ and $R_c^{б}$ and R_m^{t} and R_c^{t} exerted by the soil on its leveler during the operation of the combined machine due to unevenness on the field surface and changes in the physical and mechanical properties of the soil (where $R_m^{б}$, R_m^{t} are longitudinal and vertical forces acting on the leveling part of the leveler, N; R_c^{t}, $R_c^{б}$ – longitudinal and vertical forces acting on the soil pushers of the leveler, N) reaction forces (Fig. 2) are constantly changing. For this reason, the leveler, in addition to moving forward with the machine, also performs a forced oscillating movement in the vertical direction along the Z axis, which causes a change in the level of its influence on the soil. This has a negative effect on the leveler's performance.

The level of influence of the pronounced vibrations of the leveler on its performance depends on the amplitude of the vibrations: the smaller the amplitude, the less the negative impact of the leveler's vibrations on its performance. To determine the ways to achieve this, it is required to formulate the differential equations of forced vertical vibrations of the leveler and find its solution [11].

To construct the differential equation of forced vertical oscillations of the rectifier, we accept the following assumptions [12]:

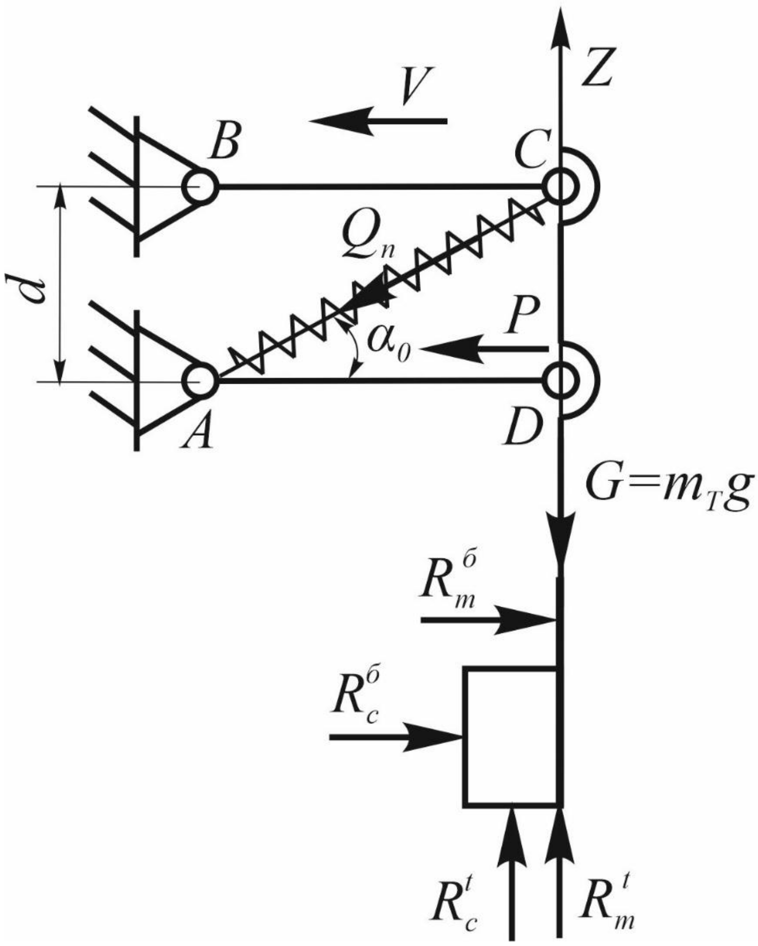
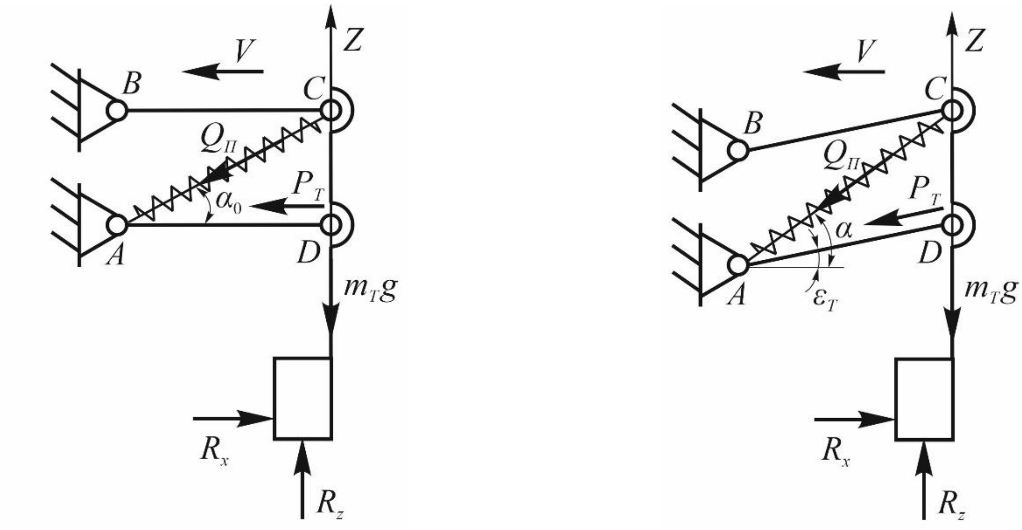


Figure 2. Forces acting on the leveler in the longitudinal plane during work

- the combined machine moves at a constant speed during the work process;
- the friction forces on the hinges of the parallelogram mechanism are very small and do not affect the movements of the leveler in the longitudinal-vertical plane;
- angular and linear vibrations of the frame of the combined machine due to its hinged connection by means of a parallelogram mechanism do not affect the working process of the leveler;
- in the equilibrium state of the leveler, the longitudinal pulls of the parallelogram mechanism work in a horizontal position, and their deviation from this position in the process of work is a small angle.

Taking into account these accepted allowances, the differential equation of vertical vibrations of the leveler according to the calculation scheme presented in Figure 3 will have the following form:



a) *б)*

a, *b* – balance of the leveler and out of balance situations

Figure 3. Computational scheme for the study of the oscillating movement of the leveler in a vertical vertical plane

$$m\frac{d^2Z}{dt^2} = -mg - Q_{nm} - P\sin\varepsilon + R_m^t + R_c^t, \qquad (1)$$

where *m* – is the mass of the leveler, kg;

g – acceleration of free fall, m/s^2;

Q_{nm} – is the vertical component of the tension force of the pressure spring of the parallelogram mechanism, N;

P – is the pulling force applied to the leveler by the parallelogram mechanism, N;

ε – is the angle of deviation of the longitudinal torques of its parallelogram mechanisms from the horizontal when the leveler is out of balance, °.

From the scheme presented in Fig. 3

$$P\cos\varepsilon + Q_{nб} = R_m^б + R_c^б, \qquad (2)$$

where $Q_{nб}$ – is the longitudinal component of the tension force of the pressure spring of the parallelogram mechanism, N.

From (2), we get the following

$$P = \frac{R_m^б + R_c^б - Q_{nб}}{\cos\varepsilon}. \qquad (3)$$

Taking this into account, expression (1) becomes:

$$m\frac{d^2Z}{dt^2} = -mg - Q_{nm} + R_m^t + R_c^t - (R_m^б + R_c^б - Q_{nб})tg\varepsilon. \qquad (4)$$

We can express sums of vertical and longitudinal forces in this expression as follows [9].

$$R_m^t + R_c^t = R_д + R_m + R_{zt} \qquad (5)$$

and

$$R_m^{б} + R_c^{б} = R_x^{ў} + R_{xt}, \quad (6)$$

where R_{∂}, R_m – are the elastic and viscous forces of soil friction, N;

$R_m^{ў} - R_m^{б} + R_c^{б}$ average value of longitudinal forces, N;

R_{zt}, R_{xt} – respectively, $R_m^t + R_c^t$ and $R_m^{б} + R_c^{б}$ variable constituents of forces, N.

Taking into account the expressions (5) and (6), the expression (4) will have the following form

$$m\frac{d^2Z}{dt^2} = -mg - Q_{nm} + R_{\partial} + R_m + R_{Zt} - (R_x^{ў} + R_{xt} - Q_{nб})tg\varepsilon. \quad (7)$$

In the static equilibrium state of the rectifier

$$R_{\partial} = \Delta_{cm} S_m C_m; \quad (8)$$

$$R_m = 0; \quad (9)$$

$$R_{zt} = 0; \quad (10)$$

$$R_{xt} = 0; \quad (11)$$

$$Q_n = Q_0; \quad (12)$$

$$Q_{nm} = Q_0 \sin\alpha_0; \quad (13)$$

$$Q_{nб} = Q_0 \cos\alpha_0, \quad (14)$$

where Δ_{cm} –is the depth of immersion of the screed into the soil in the state of static equilibrium, m;

S_m – the surface of the leveler support plane, m^2;

C_m – is the stiffness coefficient of the soil per unit surface of the leveler support plane, N/m^3;

Q_0 – is the initial tension force of the pressure spring of the parallelogram mechanism, N;

α_0 – Q_0 is the angle of deviation of the force vector to the horizon, °.

When the leveler is raised a distance Z above the equilibrium position

$$R_{\partial} = (\Delta_{cm} - Z) S_m C_m; \quad (15)$$

$$R_m = -S_m b_m \dot{Z}; \quad (16)$$

$$R_{zt} = \Delta R_z(t); \quad (17)$$

$$R_{xt} = -\Delta R_x(t); \quad (18)$$

$$Q_n = Q_0 + C_n\left[4\left(l^2+d^2\right)\sin^2\frac{1}{2}(\alpha-\alpha_0)+\left(\frac{Z}{\cos\varepsilon}\right)^2 - \right.$$

$$\left. -4\sqrt{l^2+d^2}\,\frac{Z}{\cos\varepsilon}\sin\frac{1}{2}(\alpha-\alpha_0)\cos\left(\frac{\alpha_0+\alpha}{2}-\varepsilon\right)\right]^{\frac{1}{2}}; \qquad (19)$$

$$Q_{nm} = \left\{Q_0 + C_n\left[4(l^2+d^2)\sin^2\frac{1}{2}(\alpha-\alpha_0)+\left(\frac{Z}{\cos\varepsilon}\right)^2 - \right.\right.$$

$$\left.\left. -4\sqrt{l^2+d^2}\,\frac{Z}{\cos\varepsilon}\sin\frac{1}{2}(\alpha-\alpha_0)\cos\left(\frac{\alpha_0+\alpha}{2}-\varepsilon\right)\right]^{\frac{1}{2}}\right\}\sin\alpha; \qquad (20)$$

$$Q_{nб} = \left\{Q_0 + C_n\left[4(l^2+d^2)\sin^2\frac{1}{2}(\alpha-\alpha_0)+\left(\frac{Z}{\cos\varepsilon}\right)^2 - \right.\right.$$

$$\left.\left. -4\sqrt{l^2+d^2}\,\frac{Z}{\cos\varepsilon}\sin\frac{1}{2}(\alpha-\alpha_0)\cos\left(\frac{\alpha_0+\alpha}{2}-\varepsilon\right)\right]^{\frac{1}{2}}\right\}\cos\alpha \qquad (21)$$

or if we take $\alpha=\alpha_0$

$$Q_n = Q_0 + C_n\frac{Z}{\cos\varepsilon}; \qquad (22)$$

$$Q_{nm} = (Q_0 + C_n\frac{Z}{\cos\varepsilon})\sin\alpha_0 \qquad (23)$$

and

$$Q_{nб} = (Q_0 + C_n\frac{Z}{\cos\varepsilon})\cos\alpha_0. \qquad (24)$$

Taking these and expressions (15)-(18) into account, equation (7) will have the following form

$$m\frac{d^2Z}{dt^2} = -mg - (Q_0 + C_n\frac{Z}{\cos\varepsilon})\sin\alpha_0 + (\Delta_{cm} - Z)S_mC_m - S_mb_m\dot{Z} +$$

$$+\Delta R_z(t) - \left[R_x^{ў} - \Delta R_x(t) - (Q_0 + C_n\frac{Z}{\cos\varepsilon})\cos\alpha_0\right]tg\varepsilon. \qquad (25)$$

where C_n – is the stiffness coefficient of the pressure spring of parallelogram mechanisms, N/m;

b_m – is the coefficient of resistance of the soil to a unit surface of the plane of the leveler, Nc/m^3;

$\Delta R_z(t)$, $\Delta R_x(t)$ – driving forces, N.

In the equilibrium state of the rectifier

$$-mg - Q_0 \sin\alpha_0 + \Delta_{cm} S_n C_m - R_x^{\check{y}} tg\varepsilon + Q_0 \cos\alpha_0 tg\varepsilon = 0. \qquad (26)$$

Taking this into account, we write equation (25) in the following form

$$m\frac{d^2Z}{dt^2} = -C_n Z \frac{\sin\alpha_0}{\cos\varepsilon} - S_m C_m Z - S_m b_m \dot{Z} + \Delta R_Z(t) +$$

$$+\Delta R_X(t) tg\varepsilon + C_n Z \frac{\cos\alpha_0}{\cos\varepsilon} tg\varepsilon \qquad (27)$$

or

$$m\frac{d^2Z}{dt^2} + S_m b_m \frac{dZ}{dt} + (C_n \frac{\sin\alpha_0}{\cos\varepsilon} + S_m C_m -$$

$$-C_n \frac{\cos\alpha_0}{\cos\varepsilon} tg\varepsilon) Z = \Delta R_Z(t) + \Delta R_x(t) tg\varepsilon. \qquad (27, a)$$

$\sin\alpha_0 = d / \sqrt{l^2 + d^2}$ and $\cos\alpha_0 = \sqrt{1 - \sin^2\alpha_0}$ taking into account that this last expression will have the following form

$$m\frac{d^2Z}{dt^2} + S_m b_m \frac{dZ}{dt} + \left(C_n \frac{d}{\sqrt{l^2 + d^2}\cos\varepsilon} + S_m C_m - \right.$$

$$\left. -C_n \frac{l tg\varepsilon}{\sqrt{l^2 + d^2}\cos\varepsilon} \right) Z = \Delta R_Z(t) + R_x(t) tg\varepsilon. \qquad (28)$$

To solve this equation, we assume that the excitation forces on its right-hand side vary according to the harmonic law, i.e.

$$\Delta R_Z(t) + \Delta R_x(t) tg\varepsilon = \sum_{n-1}^{n_1} (\Delta R_z^n + \Delta R_x^n tg\varepsilon) \cos n\omega t, \qquad (29)$$

where $\Delta R_z^n, \Delta R_x^n$ – the amplitude of harmonics of excitation and power, respectively, N;

n=1, 2, ..., n_1 – number of harmonics;

ω – rotation frequency of alternating forces, s^{-1};

t – time, s.

Taking (29) into account, equation (28) has the following form

$$m\frac{d^2Z}{dt^2}+S_m b_m\frac{dZ}{dt}+\left(C_n\frac{d}{\sqrt{l^2+d^2}\cos\varepsilon}+S_m C_m-\right.$$

$$\left.C_n\frac{ltg\varepsilon}{\sqrt{l^2+d^2}\cos\varepsilon}\right)Z=\sum_{n=1}^{n_1}(\Delta R_z^n+\Delta R_x^n tg\varepsilon)\cos n\omega t. \qquad (30)$$

The solution of this equation representing the forced vibrations of the leveler under the influence of the excitation forces, and its amplitude will have the following form [13].

$$Z(t)=\frac{1}{m}\sum_{n=1}^{n_1}\left\{(\Delta R_z^n+\Delta R_x^n tg\varepsilon)\cos(n\omega t-\delta_n):\left\{\left[\frac{1}{m}\left(\frac{C_n d}{\sqrt{l^2+d^2}\cos\varepsilon}+\right.\right.\right.\right.$$

$$\left.\left.\left.\left.+S_m C_m-\frac{C_n ltg\varepsilon}{\sqrt{l^2+d^2}\cos\varepsilon}\right)-(n\omega)^2\right]^2+\left(\frac{S_m b_m}{m}\right)^2(n\omega)^2\right\}^{\frac{1}{2}}\right\} \qquad (31)$$

and

$$A_T=\frac{1}{m}\sum_{n=1}^{n_1}\left\{(\Delta R_z^n+\Delta R_x^n tg\varepsilon):\left\{\left[\frac{1}{m}\left(\frac{C_n d}{\sqrt{l^2+d^2}\cos\varepsilon}+\right.\right.\right.\right.$$

$$\left.\left.\left.\left.+S_m C_m-\frac{C_n ltg\varepsilon}{\sqrt{l^2+d^2}\cos\varepsilon}\right)-(n\omega)^2\right]^2+\left(\frac{S_m b_m}{m}\right)^2(n\omega)^2\right\}^{\frac{1}{2}}\right\}, \qquad (32)$$

where $\delta_n=arctg\dfrac{S_m b_m(n\omega)}{\left(\dfrac{C_n l}{\sqrt{l^2+d^2}\cos\varepsilon}+S_m C_m-\dfrac{C_n ltg\varepsilon}{\sqrt{l^2+d^2}\cos\varepsilon}\right)-m(n\omega)^2}$.

When $\varepsilon=0$, expressions (31) and (32) have the following form.

$$Z(t)=\frac{1}{m}\sum_{n=1}^{n_1}\frac{\Delta R_z^n\cos(n\omega t)}{\sqrt{\left[\frac{1}{m}\left(\frac{C_n d}{\sqrt{l^2+d^2}}+S_m C_m\right)-(n\omega)^2\right]+\left(\frac{S_m b_m}{m}\right)^2(n\omega)^2}} \qquad (33)$$

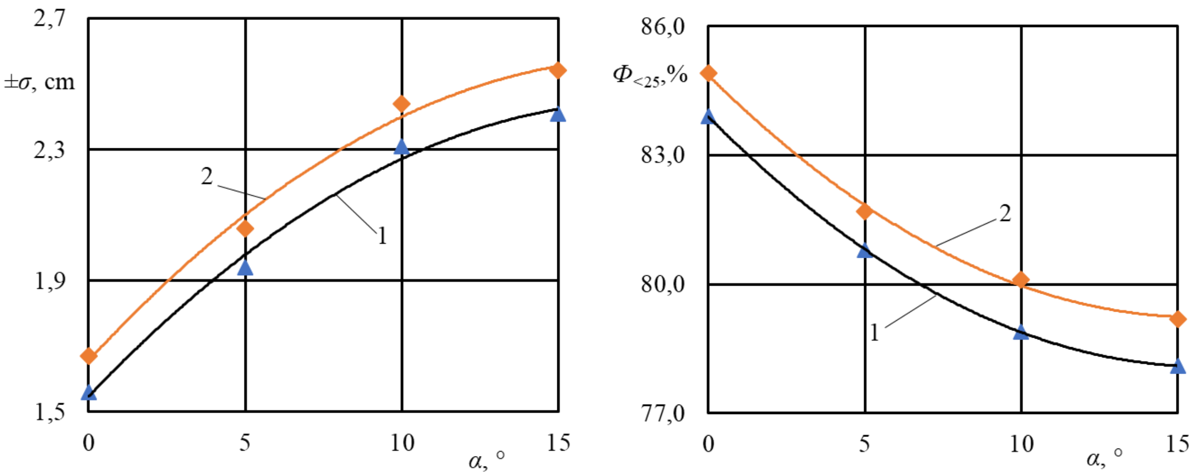
and

$$A_T=\frac{1}{m}\sum_{n=1}^{n_1}\frac{\Delta R_z^{n1}}{\sqrt{\left[\frac{1}{m}\left(\frac{C_n d}{\sqrt{l^2+d^2}}+S_m C_m\right)-(n\omega)^2\right]+\left(\frac{S_m b_m}{m}\right)^2(n\omega)^2}} \qquad (34)$$

Comparing expressions (31) and (32) with expressions (33) and (34), we agree that $\varepsilon = 0$, i.e., during the operation, when the longitudinal pulls of the parallelogram mechanisms of the leveler are in a horizontal or close position, due to the elimination of the effect of the driving force $\Delta R_x(t)$, the leveler the amplitude of forced vibrations will have a minimum value, and therefore, a high-quality leveling of the field surface and good soil compaction will be achieved.

In order to verify the results of the conducted theoretical researches, experimental researches were present. In it, the influence of the angle of deviation of the parallelogram mechanisms with a combined machine leveler to the horizon, the mean square deviation (±σ) of the heights of irregularities on the field surface, and the level of soil compaction ($\Phi_{<25}$), i.e., the amount of soil fractions smaller than 25 mm, was studied.

In this case, the angle of deviation of the parallelogram mechanisms' longitudinal pulls relative to the horizon was ensured by changing the height of their connection points with the machine frame relative to the field surface. The results obtained in the experiments are presented in Figure 4. Their analysis shows that the mean square deviation of the height of irregularities on the field surface increased with the increase of the angle of deviation of the parallelogram mechanisms with a combined machine leveler to the horizon (Fig. 4, a), that is, the degree of leveling of the field surface decreased. The degree of soil compaction worsened (Fig. 4, b), that is, the amount of fractions smaller than 25 mm in size decreased. This can be explained by the fact that according to the expressions (31) and (32), the increase in the angle of deviation of the parallelogram mechanisms with respect to the horizon causes the forces acting on



1 and 2 when aggregate speed is 6 and 8 km/h, respectively

Figure 4. The influence of the angle of deviation of the parallelogram mechanisms with respect to the horizon on its performance

the leveler and the variability of the physical-mechanical properties of the soil to increase its vertical vibrations. As a result of the reduction of the influence of the forces and physical-mechanical properties of the soil on the vertical vibrations of the leveler when the longitudinal pullers of the parallelogram mechanisms work in a horizontal or close position, the mean square deviation of the unevenness on the field surface is minimal, and the level of soil compaction has a maximum value.

Conclusion. According to the results of the conducted research, it should be ensured that the longitudinal pulls of the parallelogram mechanisms with the combined machine leveler are in a horizontal position or close to it during the work process. In this case, a high quality of work is achieved due to the reduction and elimination of the influence of the impact forces and the variability of the physico-mechanical properties of the soil on vertical forced vibrations of the leveler.

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