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Study of the Oscillational Movement of Tandem Roller in the Longitudinal-Vertical Plane

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Abstract. The article presents the results of theoretical studies on the study of the oscillatory motion of a tandem roller in the longitudinal-vertical plane, while to ensure the high quality of the tandem roller, the amplitude of its forced oscillations should have a minimum value, and it is emphasized that in practice this is mainly ensured by the correct choice of the longitudinal distance from the center of rotation of the slatted and tubular roller to the "O" hinge, as well as the number of slats and tubes installed on the rollers.

Keywords: tandem roller, slatted roller, tubular roller, oscillatory motion in the longitudinal-vertical plane, angular oscillation, amplitude of forced oscillations, physical and mechanical properties of the soil.

Introduction

Currently, in the composition of combined machines, plate, toothed plate, segmented, tubular, flat surface, toothed and ring-toothed rollers are widely used [1]. But these types of coils have several technical and technological shortcomings that affect their performance. In order to overcome these shortcomings, the existing coils at the Scientific-research institute of agricultural mechanization were improved in order to increase their performance, and on this basis, a two-row (tandem) coil was developed, and scientific and innovative studies are being carried out to justify its parameters [2].

The tandem reel consists of an *N*-shaped frame 1, slatted 2 and tubular 3 reels, and pulleys 4, which are mounted back to back on it (Figure.1). Ties 4 connect frame 1 to the machine.

The reels are mounted on the frame using bearings, the drawbars are hinged to both the frame and the machine, allowing the reels to adapt to the field terrain.

In the process of work, the plate roller installed in the first row softens the top layer of the soil, grinds lumps and partially compacts it, and the tube roller installed in the second row additionally grinds lumps and compacts the soil to the required level.

This article presents the results of theoretical studies conducted on the study of the vibration behavior of a tandem roller in the longitudinal-vertical plane.

Materials and research methods

During the movement of the aggregate, due to the unevenness of the field surface and the variation of the physical-mechanical properties of the soil, the reaction forces exerted by the soil on the rollers are constantly changing during the work process. This leads to the imbalance of the rollers in the longitudinal plane and the oscillating movement around the "*O*" joint. This, in turn, has a negative effect on the uniform compaction and compaction of the soil throughout the soil. In order to reduce and eliminate this effect, we create and solve the differential equation of the oscillations of the coils around the "*O*" hinge. We accept the

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following restrictions [3]:

- during work, the unit moves at a constant speed;
- Frictional forces in the "*O*" joint are low and do not affect the vibrations of the rollers;
- vibrations of the machine frame are small and do not affect the vibrations of the rollers;
- the equilibrium position of the pulleys connecting the coils is horizontal, and their deviation from this position is a small angle.

Study findings and their discussion

Taking into account these limitations and the calculation schemes presented in Figure. 2, the differential equation of the oscillations of the coils around the "*O*" hinge will have the following form:

$$J_y \frac{d^2\psi}{dt^2} = \left(-N_{TZ} + m_T g\right) l_2 \cos\psi - N_{TX} l_2 \sin\psi + \\ +(N_{\Pi Z} - m_\Pi g) l_1 \cos\psi + N_{\Pi X} l_1 \sin\psi, \qquad (1)$$

where J_y – is the total moment of inertia of the rollers relative to the "*O*" joint (including traction), kg/m^2; ψ – deviation angle of the pulleys connecting the coils,^{o}; N_{TZ}, N_{TX} – vertical and horizontal components of the reaction force acting on the tube coil by the soil, respectively, N; m_T – is the mass of the tube roller, kg; g – acceleration of free fall, m/s l_1, l_2 – longitudinal distances from the center of rotation of the plate and tube coils to the "*O*" hinge, respectively; $N_{\Pi Z}$, $N_{\Pi X}$ – vertical and horizontal components of the reaction force acting on the coils by the soil, respectively, N; m_Π – is the mass of the plate roller, kg;

Since the angle of deviation of the coils from the equilibrium (horizontal) position is small, we consider that $\sin\psi=\psi$, $\cos\psi=1$, and write (1) in the following form

$$J_y \frac{d^2\psi}{dt^2} = \left(m_T g - N_{TZ}\right) l_2 - N_{TX} l_2 \psi + (N_{\Pi Z} - m_\Pi g) l_1 + N_{\Pi X} l_1 \psi. \qquad (2)$$

The reaction forces N_{TZ} and $N_{\Pi Z}$ in this expression are linearly dependent on the amount and rate of soil deformation under the influence of rollers N_d and N_T and we consider that it consists of N_t driving forces arising from the unevenness of the field surface and the variability of physical and mechanical properties of the soil [4],

$$N_{\Pi Z} = N_{\Pi \partial} + N_{\Pi T} + N_{\Pi t} \qquad (3)$$

and

$$N_{TZ} = N_{T\partial} + N_{TT} + N_{Tt}. \qquad (4)$$

Taking these into account, expression (2) will have the following form

$$J_y \frac{d^2\psi}{dt^2} = \left(m_T g - N_{T\partial} - N_{TT} - N_{Tt}\right) l_2 - N_{TX} l_2 \psi + \\ +(N_{\Pi \partial} + N_{\Pi T} + N_{\Pi Z} - m_\Pi g) l_1 + N_{\Pi X} l_1 \psi. \qquad (5)$$

In the state of static equilibrium, i.e., in the state where the tension of the coils is horizontal (Figure. 2, a) [4]

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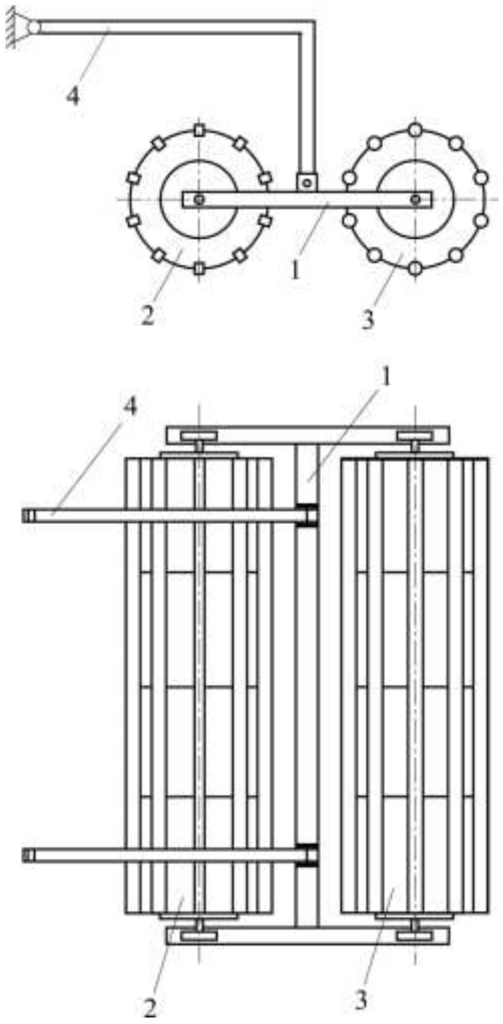

1 – frame; 2 – plate roller;

3 – tube roller; 4 - pull

Figure 1. Scheme of the tandem winding

$$N_{T\partial} = h_{T\partial} C_T B_T; \qquad (6)$$

$$N_{\Pi d} = h_{\Pi\partial} C_\Pi B_\Pi; \qquad (7)$$

$$N_{TT} = 0; \ N_{\Pi T} = 0; \ N_{Tt} = 0; \ N_{\Pi t} = 0, \qquad (8)$$

where $h_{\Pi\partial}$, $h_{T\partial}$ – are the depth of immersion of slatted and tubular coils into the soil, m; S_T - soil compaction brought to a unit coverage width of sheet and tube rollers, H/m^2; B_Π, B_T - are the covering width of the plate and tube coils, respectively , m.

ψ under the influence of the forces acting on them (Figure. 2, b)

$$N_{T\partial} = \left(h_{T\partial} + l_2\psi\right) C_T B_T; \qquad (9)$$

$$N_{\Pi\partial} = \left(h_{\Pi\partial} - l_1\psi\right) C_T B_\Pi; \qquad (10)$$

$$N_{TT} = b_T B_T l_2 \frac{d\psi}{dt}; \qquad (11)$$

$$N_{\Pi T} = -b_T B_\Pi l_1 \frac{d\psi}{dt}; \qquad (12)$$

$$N_{Tt} = \Delta R_{ZT}\left(t\right); \qquad (13)$$

$$N_{\Pi T} = \Delta R_{Z\Pi}\left(t\right), \qquad (14)$$

where b_T – is the coefficient of resistance of the soil with flat and tubular coils per unit coverage width of the coil, H·s/m ^{2} . We put the values of H·c/m^2. $N_{T\partial}$, $N_{\Pi\partial}$, N_{TT}, $N_{\Pi T}$, N_{Tt} and $N_{\Pi t}$ according to expressions (8)-(13) in (5)

$$J_y \frac{d^2\psi}{dt^2} = \left[m_T g - (h_{T\partial} + l_2\psi) C_T B_T - b_T B_T l_2 \frac{d\psi}{dt} - \Delta R_{ZT}\left(t\right) \right] l_2 - N_{TX} l_2 \psi +$$

$$+\left[(h_{\Pi\partial} + l_1\psi) C_T B_\Pi - b_T B_\Pi l_1 \frac{d\psi}{dt} - \Delta R_{Z\Pi}\left(t\right) - m_\Pi g \right] l_1 + N_{\Pi X} l_1 \psi. \qquad (15)$$

In the state of static equilibrium of the coils

$$\left(m_T g - h_{T\partial} C_T B_T\right) l_2 + \left(h_{\Pi\partial} C_T B_\Pi - m_\Pi g\right) l_1 = 0. \qquad (16)$$

Taking this into account, equation (15) will have the following form

$$J_y \frac{d^2\psi}{dt^2} = -\left[C_T l_2 B_T \psi + b_T B_T l_2 \frac{d\psi}{dt} + \Delta R_{ZT}\left(t\right) \right] l_2 - N_{TX} l_2 \psi -$$

$$+\left[C_T l_1 B_\Pi \psi - b_T B_\Pi l_1 \frac{d\psi}{dt} - \Delta R_{Z\Pi}\left(t\right) \right] l_1 + N_{\Pi X} l_1 \psi. \qquad (17)$$

Let us reduce this equation to the following form

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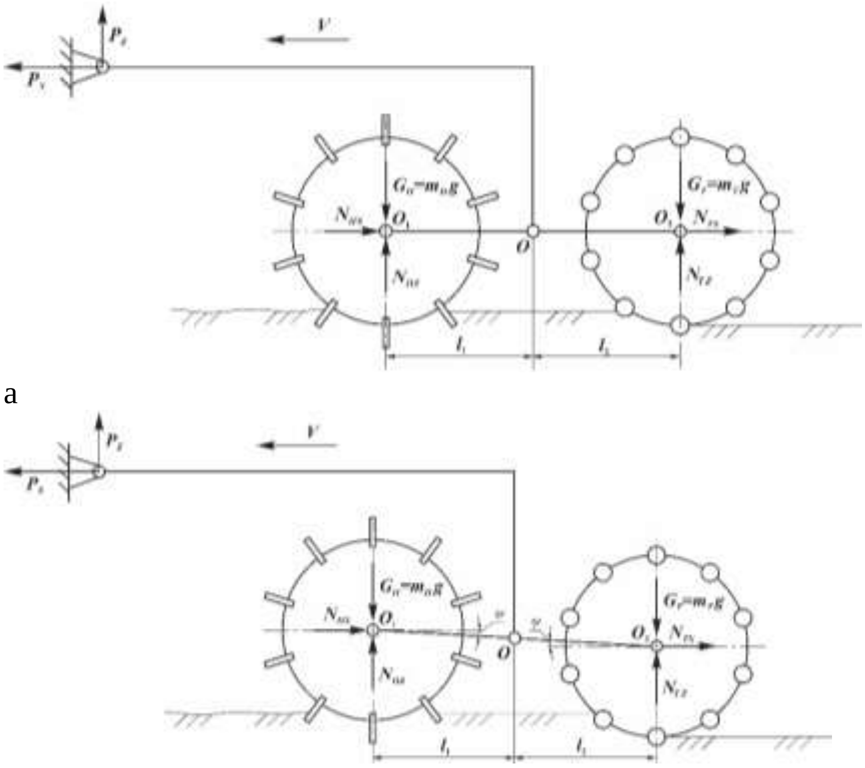
$$J_y \frac{d^2\psi}{dt^2} + b_T\left(B_{\Pi} l_1^2 + B_T l_2^2\right)\frac{d\psi}{dt} + \left[C_T\left(B_{\Pi} l_1^2 + B_T l_2^2\right) + N_{TX} l_2 - N_{\Pi X} l_1\right]\psi =$$
$$= \Delta R_{Z\Pi}(t) l_1 - \Delta R_{ZT}(t) l_2. \qquad (18)$$

This equation is N_{TX} and $N_{\Pi X}$ is a second-order non-differential equation with variable coefficients because the forces are variable [5] and represents parametric fluctuations [6]. But due to the large damping property of the soil, parametric oscillations of the coils relative to the "*O*" hinge are not observed, and in practice they are $\Delta R_{Z\Pi}(t)$ and $\Delta R_{ZT}(t)$ Forced vibration acts under the influence of forces.

Based on this, considering the forces N_{TX} and $N_{\Pi X}$ in equation (18) as constant and equal to their average value [3], we make it look like this



a

b

Figure 2. Scheme for determining the angular oscillations of the rollers around the O-joint

$$J_y \frac{d^2\psi}{dt^2} + b_T\left(B_{\Pi} l_1^2 + B_T l_2^2\right)\frac{d\psi}{dt} + \left[C_T\left(B_{\Pi} l_1^2 + B_T l_2^2\right) + N_{TX}^{\breve{y}p} l_2 - N_{\Pi X}^{\breve{y}p} l_1\right]\psi =$$
$$= \Delta R_{Z\Pi}(t) l_1 - \Delta R_{ZT}(t) l_2, \qquad (19)$$

where $N_{TX}^{\breve{y}p}$, $N_{\Pi X}^{\breve{y}p}$ –are the average values of forces N_{TX} ва $N_{\Pi X}$ respectively, *N*.

(18) is the variable on the right-hand side of $\Delta R_{Z\Pi}(t)$ ва $\Delta R_{ZT}(t)$ we consider that the forces change according to the harmonic law,

$$\Delta R_{Z\Pi}(t) l_1 - \Delta R_{ZT}(t) l_2 = \sum_{n=1}^{n_i}\left(\Delta R_{Z\Pi}^n l_1 - \Delta R_{ZT}^n l_2\right)\cos n\omega t, \qquad (20)$$

in $\Delta R_{Z\Pi}^n$, ΔR_{ZT}^n –correspondingly variable $\Delta R_{Z\Pi}(t)$ ва $\Delta R_{ZT}(t)$ amplitude of harmonics of forces, N; n=1, 2, … , n_i – number of harmonics; ω – is the rotation frequency of variable forces, S^{-1}, t – is time, S

Taking into account the expression (20), the solution of the equation (19) representing the forced oscillations of the windings has the following form [7]

$$\psi(t)=\frac{1}{J_y}\sum_{n=1}^{n_i}\left[\left(\Delta R_{Z\Pi}^{n}l_1-\Delta R_{ZT}^{n}l_2\right)\cos\left(n\omega t-\delta_n\right)\right]:$$

$$:\sqrt{\left[\frac{C_T\left(B_\Pi l_1^2+B_T l_2^2\right)+N_{TX}^{\check{y}p}l_2-N_{\Pi X}^{\check{y}p}l_1}{J_y}-\left(n\omega\right)^2\right]^2+\left(\frac{b_T\left(B_\Pi l_1^2+B_T l_2^2\right)}{J_y}\right)^2(n\omega)^2}, \quad (21)$$

in this

$$\delta_n=arctg\,\frac{2m(n\omega)}{k^2-\left(n\omega\right)^2}=arctg\left\{\left[\frac{b_T\left(B_\Pi l_1^2+B_T l_2^2\right)}{J_y}\right]\left(n\omega\right):\right.$$

$$\left.:\left[\frac{C_T\left(B_\Pi l_1^2+B_T l_2^2\right)+N_{TX}^{\check{y}p}l_2-N_{\Pi X}^{\check{y}p}l_1}{J_y}-\left(n\omega\right)^2\right]\right\}. \quad (22)$$

According to (21), the amplitude of the forced oscillations of the coils is equal to the following

$$A_z=\frac{1}{J_y}\sum_{n=1}^{n_i}\left(\Delta R_{Z\Pi}^{n}l_1-\Delta R_{ZT}^{n}l_2\right)\div\left\{\left[\frac{C_T\left(B_\Pi l_1+B_T l_2\right)^2+N_{TX}^{\check{y}p}l_2-N_{\Pi X}^{\check{y}p}l_1}{J_y}+\right.\right.$$

$$\left.+\left(n\omega\right)^2\right]^2+\left[\frac{b_T\left(B_\Pi l_1^2+B_T l_2^2\right)}{J_y}\right]^2\left(n\omega\right)^2\Big\}^{\frac{1}{2}}. \quad (23)$$

Usually $B_\Pi = B_T$. Taking this into account, the expression (26) becomes:

$$A_z=\frac{1}{J_y}\sum_{n=1}^{n_i}\left(\Delta R_{Z\Pi}^{n}l_1-\Delta R_{ZT}^{n}l_2\right)\div\left\{\left[\frac{C_T B\left(l_1+l_2\right)^2+N_{TX}^{\check{y}p}l_2-N_{\Pi X}^{\check{y}p}l_1}{J_y}+\right.\right.$$

$$\left.+\left(n\omega\right)^2\right]^2+\left[\frac{b_T B\left(l_1^2+l_2^2\right)}{J_y}\right]^2\left(n\omega\right)^2\Big\}^{\frac{1}{2}}, \quad (24)$$

where B – is the coverage width of the coils, m.

Conclusion

A_z should have a minimum value to ensure high performance of the windings . From the analysis of the expression (24), in practice, this is ensured mainly due to the correct selection of l_1 and l_2 and the number of plates and tubes installed on the coils with plates and tubes. If the reaction is provided due to the change of these factors, the $\sum_{n=1}^{n_i}\left(\Delta R_{Z\Pi}^{n}l_1+\Delta R_{ZT}^{n}l_2\right)=0$ coils will improve the amplitude of forced vibrations is equal to zero and very close to it, and the highest results are achieved in terms of the quality of soil compaction and the level of compaction.

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