https://doi.org/10.17221/104/2017-RAE

Theoretical studies of interaction of the drum cleaner with the sugar beet head

Volodymyr Bulgakov[1*], Semjons Ivanovs[2], Valerii Adamchuk[3], Stanislav Smolinskyi[1]

[1]*Department of Mechanics, Faculty construction and design, National University of Life and Environmental Sciences of Ukraine, Kiev, Ukraine*
[2]*Ulbroka Research Centre, Faculty of Engineering, Latvia University of Agriculture, Jelgava, Latvia*
[3]*National Scientific Centre "Institute for Agricultural Engineering and Electrification", Hlevakha, Ukraine*

**Corresponding author: semjons@apollo.lv*

Abstract

Bulgakov V., Ivanovs S., Adamchuk V., Smolinskyi S. (2018): Theoretical studies of interaction of the drum cleaner with the sugar beet head. Res. Agr. Eng., 64: 143–150.

Basic provisions have been worked out for a theory of interaction of the drum cleaner from the remaining tops with the sugar beet heads after the basic mass has been cut off without extracting the roots from the soil, wherein the head of the root stays motionless in the soil at a certain height of protrusion. The drum cleaner, working forward and simultaneously rotating, starts a contact with the protruding head of the rootcrop and, moving around it, brushes away efficiently the remaining tops. On the basis of the obtained differential equations of the movement of the drum there are proposed mathematical dependencies substantiating the optimal parameters of the drum cleaner of the rootcrop heads from the remaining tops.

Keywords: tops; equivalent scheme; optimal parameters

Sugar beet harvesting is carried out by successive execution of a number of technological operations the first of which being complete removal of the basic green mass of the haulm without a tracer, its gathering, transportation, and further utilisation for biogas extraction (Lammers et al. 2010). However, on the sugar beet heads there are still residues which are to be removed by individual tracing of each rootcrop head on condition that the rootcrops are not knocked out of the soil and high quality of cleaning is provided. Although the existing technical solutions of the sugar beet harvesting are constantly improving, ideal quality of the work is not yet achieved (Pogaorelyj, Tatjanko 2004). Issues concerning the operation of the sugar beet cleaners have been considered by many scientists (Smith 1991; Ivančan et al. 2002; Lilleboe 2014; Linnik 2014), however, generally they touched only a little upon the work of the drum cleaners which, according to (Martynenko 2000) have good prospects for their applications in the designs of top removers. The cleaning process of the rootcrop heads from the remaining tops without extracting the roots from the soil by a drum cleaner is carried out as a result of a contact of the drum surface with the rootcrop head in which, due to forced rotation of the drum around the horizontal axis and its forward movement around the head, its cleaning takes place. The wire-mesh surface of the drum, which brushes up the residues, is made by cross-placement of metal bars of a definite diameter performing this technological process.

The aim of the present work is to develop a system of differential equations for the drum movement at

The article was presented at the 10th International Scientific Conference of Central and Eastern European Institutes of Agricultural Engineering (CEE AgEng) took place on September 14 - 15, 2017 in the premises of Research Institute of Agricultural Engineering p.r.i., Prague, Czech Republic.

https://doi.org/10.17221/104/2017-RAE

its any contact point with the rootcrop head, considering all the forces acting upon the drum and finding specified conditions for a continuous contact of the drum with the rootcrop head, as well as mathematical dependencies to determine the main parameters of the drum cleaner.

MATERIAL AND METHODS

Let us discuss in detail a methodology of the construction of a mathematical model for the movement of a rootcrop drum cleaner interacting with the rootcrop head. For this purpose at first we will make an equivalent scheme of the movement of the drum cleaner along the surface of the rootcrop head (Bulgakov et al. 2016). We will consider that during the movement (the forward movement "from the right to left" at a speed $\bar{V}_n$ and rotating with an angular speed ω) the cleaner drum with a radius R runs onto the head of the rootcrop placed (in fact, rigidly fixed) in the soil (Fig.1). In this case the rootcrop head is approximated to the semicircle with radius r, which protrudes above the surface of the soil to the height h. The centre of the semicircle of the head is marked by point O, the axis of the drum O_1. In order to construct differential equations of the movement of the drum, a fixed coordinate system xAy is adopted which is connected with the surface of the soil. Its origin is in point A, i.e. in the contact point of the drum with the surface of the soil at the moment it runs onto the rootcrop head (the moment when the contact of the drum with the rootcrop head starts in point K_1). The surface of the soil is assumed to be even and undeformable. Besides axis Ax is directed horizontally towards the forward movement of the cleaner, axis Ay is directed vertically upwards.

In any moment of time the movable coordinate system $\bar{\tau}K\bar{n}$ will have its origin in the movable point K_i of the contact of the drum with the rootcrop head. In any discussed position of the drum axis $K_i\bar{\tau}$ will be directed along the tangent to the surface of the rootcrop head, axis $K_i\bar{n}$ – along the normal to this surface. During the contact of the drum with the rootcrop head at its arbitrary point the following forces will be applied: $\bar{G}$ – the weight of the drum, $\bar{P}$ – the pressing force of the spring, $\bar{T}$ – the traction force, $\bar{F}_B$ – the centrifugal force of inertia, $\bar{F}_{mp}$ – the slidig friction force, $\bar{S}$ – the circumferential force on the drum, $\bar{N}$ – the reaction force from the soil side, $\bar{N}_K$ – the rootcrop reaction force directed along the normal towards the head surface. It is obvious that before the initial contact of the drum with the rootcrop head, which takes place in the contact point K_1 , forces $\bar{G}$ and $\bar{P}$ are balanced by the reaction force $\bar{N}$ from the side of the soil sur-

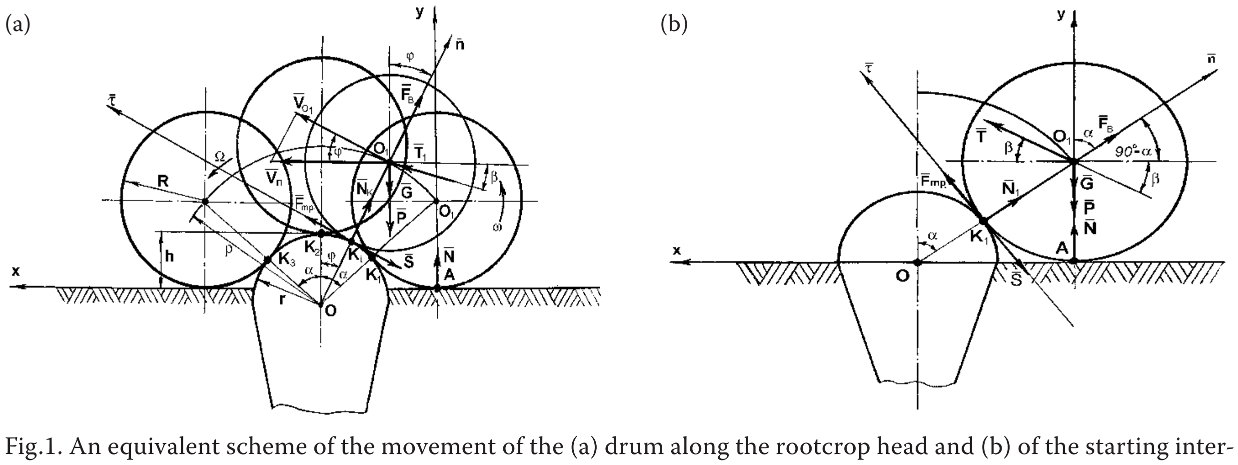
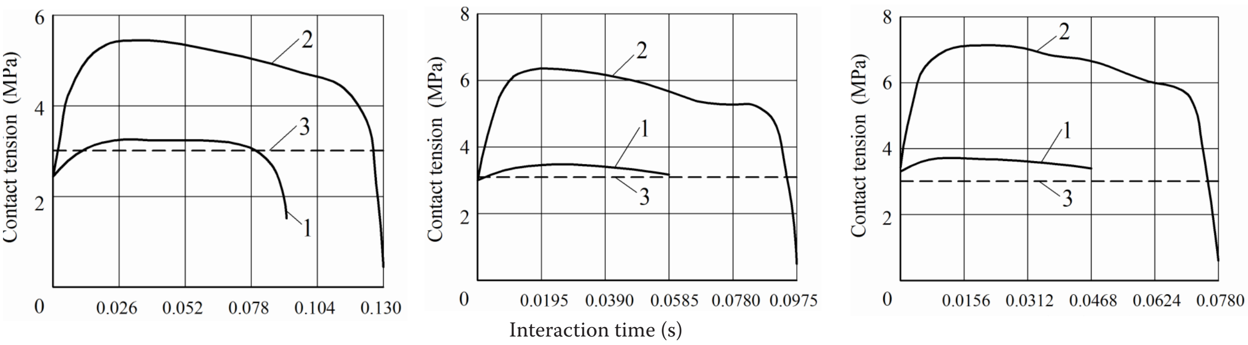


Fig.1. An equivalent scheme of the movement of the (a) drum along the rootcrop head and (b) of the starting interaction of the drum with the rootcrop head

$\bar{G}$– weight of the drum (N); $\bar{P}$ – pressing force of the spring (N); $\bar{T}$ – the traction force (N); $\bar{F}_B$ – the centrifugal force of inertia (N); $\bar{F}_{tr}$ – the slidig friction force (N); $\bar{S}$ – the circumferential force on the drum (N); $\bar{N}$ – the reaction force from the soil side (N); $\bar{N}_K$ – the rootcrop reaction force directed along the normal towards the head surface (N); N_1–the rootcrop reaction force directed along the normal towards the head surface; N (in the starting interaction); K – contact points; $\bar{V}_{O1}$ –velocity vector of axis O_1 of drum (m·s^{-1}); $\bar{V}_n$ – velocity vector of cleaner forward movement (m·s^{-1}); φ – angle between vectors $\bar{V}_n$ and $\bar{V}_{O1}$ (deg); r – rootcrop head radiu (m); R–drum radius (m); ρ – movement path of drum axis O_1 from point K_1 to point K_3 (m); α –angle whose nature is clear from figure (deg); ω – drum angular speed (rad·s^{-1}); h –rootcrop head height above soil surface (m); O centre of semicircle of rootcrop head; O_1 – axis of drum (deg); Ω – angular velocity of drum rolling around centre O of axis O_1 (rad·s^{-1}); β – angle between traction force and horizontal (deg)

https://doi.org/10.17221/104/2017-RAE



(1) P = 76.6 N; (2) P = 1,050.0 N; (3) allowable contact stress $[\sigma_{CT}]$ = 3.0 MPa

(1) P = 108.0 N; (2) P = 1,849.0 N; (3) allowable contact stress $[\sigma_{CT}]$ = 3.0 MPa

(1) P = 150.0 N; (2) P = 2,876.0 N; (3) allowable contact stress $[\sigma_{CT}]$ = 3.0 MPa

Fig. 2. Contact stresses σ on the surface of the sugar beet root at various values of the pressing force P and velocity V_n of the forward movement of the cleaner: (a) V_n = 1.5 m·s^{-1}; (b) V_n = 2.0 m·s^{-1}; (c) V_n = 2.5 m·s^{-1}

face. Besides, before the contact point K_1 the velocity vector $\bar{V}_{O_1}$ of axis O_1 of the drum coincides with the velocity vector $\bar{V}_n$ of the forward movement of the cleaner, i.e. $\bar{V}_{O_1} = \bar{V}_n$. In point K_1 vector $\bar{V}_{O_1}$ instantly changes its direction and value; besides: $V_{O_1} = V_n\cos\alpha$. At an arbitrary contact point K_i of the drum with the rootcrop head vector $\bar{V}_{O_1}$ will be equal to $V_{O_1} = V_n\cos\varphi$, where φ is an angle between vectors $\bar{V}_n$ and $\bar{V}_{O1}$. If the drum is moving from point K_1 to point K_2 angle φ changes from α to zero, but if from point K_2 to point K_3 – from zero to – α ("minus" α). Just instantly after the last contact point K_3 velocity $\bar{V}_{O_1} = \bar{V}_n$. The path of the movement of the drum axis O_1 from point K_1 to point K_3 is the arc of the circle of radius ρ; besides: ρ = $r + R$.

where: $r = OK_1$ – radius of the rootcrop head; $R = K_1O_1$ – radius of the drum $\bar{V}_N$

The path of the movement of the drum axis O_1 before and after the contact with the rootcrop head will be a straight line.

At an arbitrary contact point K_2 the centrifugal force of inertia $\bar{F}_B$ will be equal to:

$$F_B = \frac{mV_{O_1}^2}{\rho} = \frac{mV_n^2\cos^2\varphi}{\rho} \tag{1}$$

where: m – drum mass (kg); $\bar{V}_{O_1}$ – velocity vector of axis O_1 of drum (m·s^{-1}); $\bar{V}_n$ – velocity vector of cleaner forward movement (m·s^{-1}); φ – angle between vectors $\bar{V}_n$ and $\bar{V}_{O_1}$(deg); ρ – movement path of drum axis O_1 from point K_1 to point K_3 (m)

Correspondingly at points K_1 and K_3 its value will be determined by such an expression:

$$F_B = \frac{mV_n^2\cos^2\alpha}{\rho} \tag{2}$$

where: α – angle whose nature is clear from Fig. 1 (deg)

At point K_2 the value of this force will be equal to:

$$F_B = F_{B\max.} = \frac{mV_n^2}{\rho} \tag{3}$$

Let us consider in detail the start of interaction of the drum with the rootcrop head. For this purpose we will make a separate scheme of forces presented in Fig. 2. Since at the contact point K_1 there will be such equality $\bar{G} + \bar{P} + \bar{N} = 0$, the condition of collision of a drum with the rootcrop head at this point in the projection onto the normal $\bar{n}$ will have the following form:

$N_1 = [\sigma_d]$, $A_k = T\sin(\alpha - \beta) - F_B$, or, considering (2):

$$N_1 = [\sigma_d]\ A_K = T\sin(\alpha - \beta) - \frac{mV_n^2 \times \cos^2\alpha}{\rho} \tag{4}$$

where: $[\sigma_d]$ – the allowable dynamic stress for the rootcrops; A_k – the contact patch area of the surfaces of the drum and the rootcrop during their interaction.

RESULTS AND DISCUSSION

To ensure the process of brushing the residues from the rootcrop head, it is necessary to choose the required contact force $\bar{N}_K \neq 0$ in any contact point K_i of the drum with the head. Obviously, this condition will be met by such an analytical expression:

$$N_k = G\cos\varphi + P\cos\varphi - F_B + T\sin(\varphi - \beta) \neq 0 \tag{5}$$

or $N_k - G\cos\varphi - P\cos\varphi + F_B - T\sin(\varphi - \beta) = 0$ (6)

https://doi.org/10.17221/104/2017-RAE

Eq. (6) is the sum of projections of all the forces applied to the drum, the normal $\bar{n}$, drawn through the contact point K_i. At a given weight $\bar{G}$ and radius R of the drum, as well as the velocity $\bar{V}_n$ of its forward movement, the necessary value $\bar{N}_K$ can ensure only the pressing force $\bar{P}$ of the spring. Guaranteed condition for a constant contact is the condition which is ensured just by Eq. (5). However, the condition of a continuous contact actually does not yet provide the required quality of the technological process performed by the drum cleaner. At the expense of the clamping force $\bar{P}$ of the spring it is necessary to choose the required $\bar{N}_K$, and such its value to meet the following condition:

$$N_k = [\sigma_{CT}]A_k \tag{7}$$

where: [σCT] – the allowable static stress for the rootcrops

It is necessary to take into account the fact that on condition $N_k > [\sigma_{CT}]A_k$, there will occur damage to the rootcrops. Considering Eq. (6), the technological process of the work of the drum cleaner (qualitative brushing of the remaining haulm) is possible on condition:

$$[\sigma_{CT}]\, A_k - G\cos\varphi - P\cos\varphi + F_B - T\sin(\varphi - \beta) = 0 \tag{8}$$

Considering that $G = mg$ and Eq. (1) for the centrifugal force of inertia $\bar{F}_B$, we find from (8):

$$\left[\sigma_{CT}\right] A_K + \left(\frac{V_n^2 \cos\varphi}{\rho} - g\right) m \times \cos\varphi - \\ -P\cos\varphi - T\sin\left(\varphi - \beta\right) = 0 \tag{9}$$

where: g – acceleration of gravity (m·s^{-2})

For any point of contact K_i between the drum and the rootcrop head.

The highest contact point K_2 (φ = 0) of the drum with the rootcrop head we find from Eq. (9):

$$\left[\sigma_{CT}\right] A_K + \left(\frac{V_n^2}{\rho} - g\right) m - P + T\sin\beta = 0 \tag{10}$$

Since the drum, due to its forward movement, in section K_1K_2 runs onto the rootcrop head, the condition of a continuous contact of the drum in section K_1K_2 will be guaranteed. In section K_2K_3, on the contrary, the drum runs down the rootcrop head, therefore its separation from the head is possible. To avoid separation of the drum from the rootcrop head in section K_2K_3, it is necessary to choose a value of the spring pressing force $\bar{P}$ which would ensure a contact of the drum with the rootcrop head over the entire section K_2K_3. It is absolutely obvious that, in case this contact is ensured in point K_3, it will be ensured over the entire section K_2K_3. With this end in view it is necessary to construct a differential equation of the movement of the drum (its axis O_1) when the root crop head is fully rolled over. Considering all the forces acting upon the drum in any point K_i of its contact with the rootcrop head, this differential equation in a vector form will have such an appearance:

$$m\bar{a} = \bar{N}_K + \bar{F}_B + \bar{P} + \bar{G} + \bar{F} + \bar{S} + \bar{T} \tag{11}$$

where: $\bar{F}_{tr}$ – the sliding friction force (N); $\bar{S}$ – the circumferential force on the drum (N); m – the mass of the drum (kg;) $\bar{a}$ – acceleration of the drum (m·s^{-2})

If we project this differential equation onto axes x and y of the selected fixed coordinate system, we will obtain a system of differential equations describing in a general way the movement of the cleaner drum along the surface of the rootcrop head:

$$\left.\begin{aligned} \ddot{x} &= \frac{1}{m}\left(-N_K\sin\varphi - F_B\sin\varphi + F_{mp}\cos\varphi - S\cos\varphi + T\cos\beta\right) \\ \ddot{y} &= \frac{1}{m}\left(N_K\cos\varphi + F_B\cos\varphi - P - mg + F_{mp}\sin\varphi - S\sin\varphi + T\sin\beta\right) \end{aligned}\right\} \tag{12}$$

Next, we express angle φ as a function of time t. The time of the movement of the drum along the rootcrop head from point K_1 to point K_3 will be equal to:

$$t_1 = \frac{2\rho \times \sin\alpha}{V_n} \tag{13}$$

Then, the angular velocity Ω of the drum rolling around the centre O of its axis O_1 will be:

$$\Omega = \frac{2\alpha}{t_1} \tag{14}$$

or, considering Eq.(13),

$$\Omega = \frac{V_n \times \alpha}{\rho\sin\alpha} \tag{15}$$

Since $\varphi = \alpha - \Omega t$, then from (15) we will obtain the value of angle φ:

$$\varphi = \alpha - \frac{V_n \times \alpha}{\rho \times \sin\alpha} t \tag{16}$$

https://doi.org/10.17221/104/2017-RAE

Taking into account that $F_{mp} = fN_K$, where f is the coefficient of sliding friction of the drum surface along the surface of the rootcrop head, as well as Eq. (1), the system of differential equations (12) can be presented in the following way:

$$\left.\begin{aligned}\ddot{x} &= \frac{1}{m}\left[\begin{aligned}&-N_K\sin(\alpha-\Omega\times t)-\frac{mV_n^2\times\cos^2(\alpha-\Omega\times t)}{\rho}\sin(\alpha-\Omega\times t)+\\&+fN_K\cos(\alpha-\Omega\times t)-S\cos(\alpha-\Omega\times t)+T\cos\beta\end{aligned}\right]\\ \ddot{y} &= \frac{1}{m}\left[\begin{aligned}&N_K\cos(\alpha-\Omega\times t)+\frac{mV_n^2\times\cos^3(\alpha-\Omega\times t)}{\rho}-P-mg\\&+N_K\sin(\alpha-\Omega\times t)-S\sin(\alpha-\Omega\times t)+T\sin\beta\end{aligned}\right]\end{aligned}\right\} \quad (17)$$

where: Ω – angular velocity of the drum rolling around the rootcrop head, which is determined according to Eq. (15)

The initial conditions for the system of Eq. (17) will be such:

At $t = 0$:

$$\left.\begin{aligned}&\varphi=\alpha\\&x=0\\&\dot{x}=V_{O_1}(0)\times\cos\alpha=V_n\cos^2\alpha\\&y=R+r-h=\rho-h\\&\dot{y}=V_{O_1}(0)\times\sin\alpha=V_n\cos\alpha\times\sin\alpha\end{aligned}\right\} \quad (18)$$

where: h – the height of the position of the rootcrop head above the surface of the soil

The system of Eqs (17) is integrated in quadratures (Dreizler, Ludde 2010). After integration we will have following solutions:

$$\dot{x}=\frac{1}{m}\left[-\frac{N_K}{\Omega}\cos(\alpha-\Omega\times t)-\frac{mV_n^2}{3\rho\Omega}\cos^3(\alpha-\Omega\times t)+\left(\frac{S}{\Omega}-\frac{fN_K}{\Omega}\right)\sin(\alpha-\Omega\times t)+T\cos\beta\times t\right]+C_1 \quad (19)$$

$$x=\frac{1}{m}\left[\left(\frac{N_K}{\Omega^2}+\frac{mV_n^2}{3\rho\Omega^2}\right)\sin(\alpha-\Omega\times t)-\frac{mV_n^2}{9\rho\Omega^2}\sin^3(\alpha-\Omega t)+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}\right)\cos(\alpha-\Omega\times t)+T\cos\beta\cdot\frac{t^2}{2}\right]+C_1t+C_2 \quad (20)$$

$$\dot{y}=\frac{1}{m}\left[-\left(\frac{N_K}{\Omega}+\frac{mV_n^2}{\rho\Omega}\right)\sin(\alpha-\Omega\times t)+\frac{mV_n^2}{3\rho\Omega}\sin^3(\alpha-\Omega\times t)-(P+mg)t+\left(\frac{fN_K}{\Omega}-\frac{S}{\Omega}\right)\cos(\alpha-\Omega\times t)+T\sin\beta\times t\right]+L_1 \quad (21)$$

$$y=\frac{1}{m}\left[-\left(\frac{N_K}{\Omega^2}+\frac{2mV_n^2}{3\rho\Omega^2}\right)\cos(\alpha-\Omega\times t)-\frac{mV_n^2}{9\rho\Omega^2}\cos^3(\alpha-\Omega\times t)-(P+mg)\frac{t^2}{2}+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}\right)\sin(\alpha-\Omega\times t)+T\sin\beta\times\frac{t^2}{2}\right]+L_1t+L_2 \quad (22)$$

where: C_1, C_2, L_1 and L_2 – arbitrary constants (from the initial conditions we find):

$$C_1=V_n\cos^2\alpha-\frac{1}{m}\left[-\frac{N_K}{\Omega}\cos\alpha-\frac{mV_n^2}{3\rho\Omega}\cos^3\alpha+\left(\frac{S}{\Omega}-\frac{fN_K}{\Omega}\right)\sin\alpha\right]$$

$$C_2=-\frac{1}{m}\left[\left(\frac{N_K}{\Omega^2}+\frac{mV_n^2}{3\rho\Omega^2}\right)\sin\alpha-\frac{mV_n^2}{9\rho\Omega^2}\sin^3\alpha+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}\right)\cos\alpha\right]$$

$$L_1=V_n\cos\alpha\times\sin\alpha-\frac{1}{m}\left[-\left(\frac{N_K}{\Omega}+\frac{mV_n^2}{\rho\Omega}\right)\sin\alpha+\frac{mV_n^2}{3\rho\Omega}\sin^3\alpha+\left(\frac{fN_K}{\Omega}-\frac{S}{\Omega}\right)\cos\alpha\right]$$

$$L_2=\rho-h-\frac{1}{m}\left[-\left(\frac{N_K}{\Omega^2}+\frac{2mV_n^2}{3\rho\Omega^2}\right)\cos\alpha-\frac{mV_n^2}{9\rho\Omega^2}\cos^3\alpha+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}\right)\sin\alpha\right]$$

Now, if we substitute the values of arbitrary constants C_1, C_2 and L_1, L_2 respectively into Eqs (20) and (22), then we will obtain the motion law of axis O_1 of the drum rolling around the rootcrop head:

$$\begin{aligned}x=&\frac{1}{m}\left[\left(\frac{N_K}{\Omega^2}+\frac{mV_n^2}{3\rho\Omega^2}\right)\sin(\alpha-\Omega\times t)-\frac{mV_n^2}{9\rho\Omega^2}\sin^3(\alpha-\Omega\times t)+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}\right)\cos(\alpha-\Omega\times t)+T\cos\beta\times\frac{t^2}{2}\right]+\\&+\left\{V_n\cos^2\alpha-\frac{1}{m}\left[\left(\frac{S}{\Omega}-\frac{fN_K}{\Omega}\right)\sin\alpha-\frac{N_K}{\Omega}\cos\alpha-\frac{mV_n^2}{3\rho\Omega}\cos^3\alpha\right]\right\}t-\frac{1}{m}\left[\left(\frac{N_K}{\Omega^2}+\frac{mV_n^2}{3\rho\Omega^2}\right)\sin\alpha-\frac{mV_n^2}{9\rho\Omega^2}\sin^3\alpha+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}\right)\cos\alpha\right]\end{aligned} \quad (23)$$

$$\begin{aligned}y=&\frac{1}{m}\left[-\left(\frac{N_K}{\Omega^2}+\frac{2mV_n^2}{3\rho\Omega^2}\right)\cos(\alpha-\Omega t)-\frac{mV_n^2}{9\rho\Omega^2}\cos^3(\alpha-\Omega\times t)-(P+mg)\frac{t^2}{2}+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}-\right)\sin(\alpha-\Omega\times t)+T\sin\beta\times\frac{t^2}{2}\right]+V_n\cos\alpha\times\sin\alpha\times t-\\&-\frac{1}{m}\left[-\left(\frac{N_K}{\Omega}+\frac{mV_n^2}{\rho\Omega}\right)\sin\alpha+\frac{mV_n^2}{3\rho\Omega}\sin^3\alpha+\left(\frac{fN_K}{\Omega}-\frac{S}{\Omega}\right)\cos\alpha\right]t+\rho-h-\frac{1}{m}\left[-\left(\frac{N_K}{\Omega^2}+\frac{2mV_n^2}{3\rho\Omega^2}\right)\cos\alpha-\frac{mV_n^2}{9\rho\Omega^2}\cos^3\alpha+\left(\frac{S}{\Omega^2}-\frac{fN_K}{\Omega^2}-\right)\sin\alpha\right]\end{aligned} \quad (24)$$

https://doi.org/10.17221/104/2017-RAE

We will find the condition of a continuous contact of the drum at point K_2 from Eq. (24) in case $t=\frac{t_1}{2}=\frac{\rho\sin\alpha}{V_n}$, $y = \rho$, $\Omega=\frac{V_n\times\alpha}{\rho\sin\alpha}$:

$$\frac{1}{m}\times\frac{N_K\times\rho^2\sin^2\alpha}{V_n^2\times\alpha^2}\times(\cos\alpha-1)+\frac{2\rho\sin^2\alpha}{3\alpha^2}(\cos\alpha-1)+\frac{\rho\sin^2\alpha}{9\alpha^2}(\cos^3\alpha-1)-\frac{(P+mg)\rho^2\sin^2\alpha}{2mV_n^2}+\frac{T\rho^2\sin\beta\times\sin^2\alpha}{2mV_n^2}+$$
$$+\rho\cos\alpha\times\sin^2\alpha+\frac{1}{m}\times\frac{N_K\times\rho^2\sin^3\alpha}{V_n^2\times\alpha}++\frac{\rho\sin^2\alpha}{\alpha}-\frac{\rho\sin^5\alpha}{3\alpha}-\frac{1}{m}\left(\frac{fN_K\rho^2\sin^2\alpha\times\cos\alpha-S\times\rho^2\sin^2\alpha\times\cos\alpha}{V_n^2\cdot\alpha}\right)- \tag{25}$$
$$-h-\frac{1}{m}\times\frac{\left(S\times\rho^2\sin^3\alpha-fN_K\times\rho^2\sin^3\alpha\right)}{V_n^2\times\alpha^2}=0$$

We will find out the conditions of a constant contact of the drum in point K_3, and, consequently, in the entire section K_2K_3, from Eq. (24) at $t=\frac{t_1}{2}=\frac{\rho\sin\alpha}{V_n}$, $y = \rho - h$

$$-\frac{1}{m}(P+mg)\frac{\rho^2\sin^2\alpha}{V_n^2}-\frac{1}{m}\times\frac{(S-fN_K)\rho^2\sin^3\alpha}{V_n^2\times\alpha^2}+\frac{1}{m}\times\frac{T\sin\beta\times\rho^2\sin^2\alpha}{V_n^2}+\rho\cos\alpha\times\sin^2\alpha+$$
$$+\frac{1}{m}\times\frac{N_K\times\rho^2\sin^3\alpha}{V_n^2\times\alpha}+\frac{\rho\times\sin^3\alpha}{\alpha}-\frac{\rho\times\sin^5\alpha}{3\alpha}-\frac{1}{m}\times\frac{(fN_K-S)\rho^2\times\sin^2\alpha\times\cos\alpha}{V_n^2\times\alpha}=0 \tag{26}$$

The obtained conditions for a continuous contact Eq. (25) and (26) are more exact than the conditions determined by Eq. (9) and (10). Besides, from conditions Eq. (25), (26) and (4) it is possible to determine the mass of the drum which ensures the particular condition of the continuous contact. This could not be done using condition (9) or (10) because in them the mass of the drum, vice versa, has to be indicated. In order to determine the unknown values – the contact patch area AK, the mass of the drum m and the pressing force $\bar{P}$ of the spring, we will discuss a system of Eq. (4), (25) and (26). Thus, from Eq. (4) we find the area of the contact patch of the drum with the rootcrop head. It is:

$$A_K=\frac{T\times\rho\times\sin(\alpha-\beta)-mV_n^2\times\cos^2\alpha}{[\sigma_d]\rho} \tag{27}$$

Further, taking into account (7), we obtain the reaction force $\bar{N}_K$, which will be equal to:

$$N_K=\frac{[\sigma_{CT}]\times\left[T\ \rho\sin(\alpha-\beta)-mV_n^2\times\cos^2\alpha\right]}{[\sigma_d]\rho} \tag{28}$$

Substituting (28) into Eq. (25) and (26), after a number of transformations we obtain an expression for the determination of the mass m of the drum, which will ensure unseparated movement of the drum along the rootcrop head:

$$m=\frac{\left\{\frac{[\sigma_{CT}]T\sin(\alpha-\beta)}{[\sigma_d]}\times\left[\frac{\rho^2\sin^2\alpha}{V_n^2\times\alpha^2}(\cos\alpha-1)+\frac{\rho^2\sin^3\alpha}{V_n^2\times\alpha}-\frac{f\rho^2\sin^2\alpha\times\cos\alpha}{2V_n^2\times\alpha}+\right.\right.}{\left\{\frac{[\sigma_{CT}]\cos^2\alpha}{[\sigma_d]}\times\left[\frac{\rho\sin^2\alpha}{\alpha^2}(\cos\alpha-1)+\frac{\rho\sin^3\alpha}{2\alpha}-\frac{f\rho\sin^2\alpha\times\cos\alpha}{2\alpha}+\frac{f\rho\sin^3\alpha}{2\alpha^2}\right]-\right.}\times$$
$$\times\frac{\left.\left.+\frac{f\rho^2\sin^3\alpha}{2V_n^2\times\alpha^2}\right]+\frac{S\rho^2\sin^2\alpha\times\cos\alpha}{2V_n^2\times\alpha}-\frac{S\rho^2\sin^3\alpha}{2V_n^2\times\alpha}\right\}}{\left.-\frac{2\rho\sin^2\alpha}{3\alpha^2}(\cos\alpha-1)-\frac{\rho\sin^2\alpha}{9\alpha^2}(\cos^3\alpha-1)-\frac{\rho\cos\alpha\times\sin^2\alpha}{2}-\frac{\rho\sin^2\alpha}{\alpha}+\frac{\rho\sin^5\alpha}{6\alpha}+h+\frac{\rho\sin^3\alpha}{2\alpha}\right\}} \tag{29}$$

https://doi.org/10.17221/104/2017-RAE

The pressing force $\bar{P}$ of the spring will also be found from the condition for a continuous contact of the drum with the rootcrop head in point K_3, i.e., from Eq. (26).

Solving this equation with respect to $\bar{P}$, considering Eq. (28), this force will be equal to:

$$P = m\left[-g - \frac{[\sigma_{CT}]V_n^2\cos^2\alpha}{[\sigma_d]\rho}\left(\frac{f\sin\alpha}{\alpha^2} + \frac{\sin\alpha}{\alpha} - \frac{f\cos\alpha}{\alpha}\right) + \frac{V_n^2\cos\alpha}{\rho} + \frac{V_n^2\sin\alpha}{\alpha\rho} - \frac{V_n^2\sin^3\alpha}{3\alpha\rho}\right] - \\ -\frac{S\sin\alpha}{\alpha^2} + \frac{[\sigma_{CT}]T\sin(\alpha-\beta)}{[\sigma_d]}\left(\frac{f\sin\alpha}{\alpha^2} + \frac{\sin\alpha}{\alpha} - \frac{f\cos\alpha}{\alpha}\right) + T\sin\beta + \frac{S\cos\alpha}{\alpha} \tag{30}$$

where: m – the mass of the drum which is determined according to Eq. (29)

Since the force $\bar{P}$ is determined considering Eq. (28), then this is just the maximum allowable force of pressing the drum to the rootcrop head which will ensure efficient brushing of the residues from the rootcrop head without its damage. On the basis of the obtained theoretical investigations numerical calculations were performed by a compiled program on the PC to determine contact stresses σ on the head of the rootcrop depending on time t for the speeds of the forward movement of the drum cleaner: V_n = 1.5; 2.0; 2.5 m·s^{-1}. The parameters of the suspension of the drum cleaner were accepted as follows: h = 0.29 m; l = 0.565 m; I = 2.689 kg·m^2; c_n = 4,200 N/m; Q = 17.66 N; q = 6.57 N. The parameters of the drum cleaner: R = 0.1 m; G = 53.56 N; E = 86 N; ν = 0.3; E = 2.10^5 MPa. The parameters of the sugar beet root: r = 0.04 m; ν = 0.48; E = 19 MPa; [σ_{CT}] = 3.0 MPa. The other parameters: f = 0.8; [σ] = 0.007 m. Among the indicated characteristics, in particular ν, there are Poisson's ratio, E – modulus of elasticity. The results of the calculations are presented in Fig. 3a for V_n = 1.5 m·s^{-1}; Fig. 3b for V_n = 2.0 m·s^{-1}; Fig. 3c for V_n = 2.5 m·s^{-1}.

As it is evident from the presented graphs, it is necessary to create the following pressing forces of the spring: P = 1,050.0 N for V_n = 1.5 m·s^{-1}; P = 1,849 N for V_n = 2.0 m·s^{-1}; P = 2,876 N for V_n = 2.5 m·s^{-1}. None of the indicated values is acceptable since the condition that the sugar beet heads should not be damaged is not fulfilled. Only the value of the contact stress σ can be considered acceptable when P = 76.6 N for V_n = 1.5 m·s^{-1} because in this case insignificant and partial excess of allowable contact stresses [σ_{CT}] is observed. The results of the conducted experimental field investigations showed that certain spring-back of the drum from the sugar beet root during their collision is possible. Obviously, for qualitative removal of the remaining haulm from the rootcrop head, the following condition must be fulfilled:

$$\delta \le [\delta]$$

where: [δ] – the allowable spring-back value of the drum from the surface of the rootcrop head after the collision

Accepting that δ = [δ], it is necessary to create the following pressing stresses:

P = 50.0 N for V_n = 1.5 m·s^{-1}; P = 81.5 N for V_n = 2.0 m·s^{-1}; P = 122.5 N for V_n = 2.5 m·s^{-1}. In such a case, at V_n > 2 m·s^{-1} and more, the rootcrop drum cleaner operates under conditions of increasing galloping, which significantly degrades its quality work.

Consequently, the boundary for productive and qualitative cleaning of the sugar beet heads from the remaining haulm by the drum cleaner is the velocity of the forward movement of the aggregate, which does not exceed 2 m·s^{-1}.

CONCLUSION

A system of differential equations has been developed for the drum movement at its any contact point with the rootcrop head, considering all the forces acting upon the drum and specified conditions for a continuous contact of the drum with the rootcrop head.

The obtained dependencies make it possible to calculate the optimal parameters of a drum cleaner of the rootcrop heads.

References

Bulgakov V., Ivanovs S., Golovach I., Ruzhylo Z. (2016): Theoretical investigations in cleaning sugar beet heads from remnants of leaves by cleaning blade. In: Proceedings from 15th International Scientific Conference Engineering for Rural Development, Jelgava, May 25–27, 2016, Jelgava: 1090–1097.

https://doi.org/10.17221/104/2017-RAE

Dreizler, R.M., Ludde C.S. (2010): Theoretical Mechanics. Springer.

Ivančan S., Sito S., Fabijanić G. (2002): Factors of the quality of performance of sugar beet combine harvesters. Bodenkultur, 53: 161–166.

Lammers S., Olaf P., Olaf R. (2010): Defoliation of sugar beets – assessment of quality and gain in delivered beet mass. Landtechnik, 3: 464–467.

Lilleboe D. (2014): Optimizing defoliator & harvester performance. The sugar beet grower. July 2014, 53: 6–13.

Linnik A. (2014): Determination of dynamic parameters of a rigid cleaner interacting with a root crop. Scientific works of the Ternopol National Technical University, 73: 165–171.

Martynenko V. (2000): Mechanic and technological foundations for increasing the efficiency of the working tools of the haulm removing machines. Ternopol.

Pogorelyj L., Tatjanko N. (2014): Machines for Harvesting Sugar Beet. Fenix, Kyiv.

Smith L. (1991): The effect of defoliator flail configuration, speed and crown removal on sugar beet yield, quality and profitability. Sugar Beet Research and Extension Reports, 22: 222–227.

Received for publication October 20, 2017
Accepted after corrections June 11, 2018