5 acts (moves) not only in the normal but also in the tangential directions, we will take into account its displacement only in the normal direction by an value of the $\delta - \delta_O$, as such its displacement (approaching the body of the head of the sugar beet root, containing the sacchariferous mass) will determine the quality of the technological process of cutting the remains of the tops from the heads of the sugar beet root.

Since taking into account the crumpled layer of the residues of the tops to its minimum value in this direction, direct contact is excluded, and therefore the root itself is injured. The deformation of the tops in the other direction (for example, in the longitudinal direction) will not significantly affect the indicated quality of damage to the sugar beet roots.

With the regard to the resulting scheme of the forces (Figure 3), on the basis of the fundamental law of dynamics of a material point, we write the differential equation of motion of flat sensing organ on the head of sugar beet root in the vector form:

$$m\bar{a} = \bar{F}_{st} + \bar{F}_{sr} + \bar{F}_{sp} + \bar{F}_{c} + \bar{F}_{\mu} + \bar{F}_{tp} + \bar{G} \tag{4}$$

where $\bar{a}$ - acceleration of the motion of the flat sensing organ on the head of a sugar beet root; m - weight of the flat sensing organ.

The movement of the sensing organ we will consider in absolute fixed Cartesian coordinate system xOy where the horizontal axis Ox is directed in the direction of motion of the copier, and the axis Oy is directed vertically upward, the centre of the coordinate system (point O) is located in the centre of the circle, the upper part of which simulates the shape of the surface of the head of the sugar beet root.

We determine the values of all the forces appearing in the vetor Equation (4). The forces of elasticity $\bar{F}_c$ and the viscous resistance (damping) $\bar{F}_\mu$ will be considered as arising from the strain γ and strain rate $\dot{y}$ of elastic residues (roots) tops and acting in the direction normal n to the surface of the head of sugar beet root.

Moreover, the deformation of the elastic residues of the sugar beet root tops largely depends on the arrangement of rootlets on the head of the sugar beet root before beginning contact with the surface of the sensing organ. Thus, at the beginning of the contact, some roots can undergo compression deformations, some - bending, some - compression and bending simultaneously.

However, once the some parts of the roots are pressed against the head of the root by the flat surface of the sensing organ, it can be assumed that this bundle of bent rootlets will subsequently undergo deformation of compression, down to partial collapse. Therefore, just this bundle of compressed roots of the residues of the leaves will create an elastic-viscous resistance to the direct contact of the flat sensing organ with the spherical surface of the sugar beet root, preventing it from damage. Obviously, in the general case, the magnitude of deformation γ and the speed of this deformation $\dot{y}$ can depend on the coordinates x, y of the position of the sensing organ, speed $\dot{x}$, $\dot{y}$ of the movement of the sensing organ over the head of the sugar beet root, and the time of this displacement.

Moreover, the elastic deformation of the leaves residues depends on the location of the of rootlets on the head of root crops before contact with the surface of the sensing organ. Thus, at the beginning of contact may undergo some rootlets can be effected by compression deformation, some of them by bending, and also by simultaneous bending and compression.

However, once the rootlets are pressed against the flat surface of the sensing organ to the head of sugar beet root, it can be assumed that the bunch of bent rootlets will continue to be subjected to compressive strain, until the partial collapse.

Therefore, this bunch of compressed of residues of rootlets tops will create an elastic-viscous resistance of the direct contact of flat sensing organ with the spherical surface of the head of sugar beet root, preventing it from being damaged.

Obviously, that in general, the quantity of strain γ and strain rate $\dot{y}$ may depend on the coordinates x, y of positions of the sensing organ, the sensing organ moving speed V on the head of the sugar beet root and the time t of this displacement. To determine this dependence theoretically is quite difficult.

Therefore, the values of these forces can usefully be determined according to the following expressions (in the beginning in general form):

$$F_c = c \cdot \gamma(x, y, t), \quad F_\mu = \mu \cdot \dot{\gamma}(x, y, \dot{x}, \dot{y}, t) \tag{5}$$

where $\gamma(x,y,t)$, $\dot{y}(x,y,\dot{x},\dot{y},t)$- respectively, the magnitude of deformation and speed of deformation of the bases of leaves, while in contact with the surface of the sensing organ; c - coefficient of elastic deformation of the bases of the leaves residues on the roots, $N.m^{-1}$; μ - viscous drag coefficient (damping) of the bases of leaves on the roots, $N.s \cdot m^{-1}$.

We express the value of the strain γ and deformation rate $\dot{y}$ of the short remains of the tops through the coordinates of the position of the sensing organ as it moves along the head of the sugar beet root at an arbitrary time.

Let in the beginning of the contact, when all the roots of the bundle of the residues of the tops that have fallen into the contact area are pressed against the head of the root by the flat surface of the sensing organ, the thickness of the formed layer from the residues of the leaves will be equal to δ_O.

With further movement of the sensing organ over the head of the root, the indicated layer of the residues of the leaves begins to contract. Let at any time the thickness of the layer of compressed residues of the leaves be equal δ. Then the deformation γ of this layer at this instant of time will be equal to:

$$\gamma = \delta = \delta_0 \tag{6}$$

Since the sensing organ moves on the head of the root without interruption, at any time when the sensing organ is at a point $A(x,y)$, the distance from the point A to the origin of the coordinates (point O) will be equal to $\sqrt{x^2 + y^2}$ and, therefore, the thickness of the layer δ expressed in terms of the coordinates of the point A (the point of contact position of the sensing organ) will be equal to (Figure 4):

$$\delta = \sqrt{x^2 + y^2} - R \tag{7}$$

where R - radius of the head of a sugar beet root.

Taking into account expression (6), the deformation of the layer of remains of the tops at an arbitrary point A will be determined by the following expression:

$$\gamma = \sqrt{x^2 + y^2} - R - \delta_o \quad (8)$$

Differentiating the expression (8) over time *t*, we get the value of a speed of said strain at any given time moment. We have:

$$\dot{\gamma} = \frac{x\dot{x} + y\dot{y}}{\sqrt{x^2 + y^2}} \quad (9)$$

Taking into account the Equation (5), and also the Equations (8) and (9), we get the value of the elastic force of the compressed sugar beet root tops residue deformation in the following form:

$$F_c = c\left(\sqrt{x^2 + y^2} - R - \delta_o\right) \quad (10)$$

and the force of viscous resistance (damping):

$$F_\mu = \mu\left(\frac{x\dot{x} + y\dot{y}}{\sqrt{x^2 + y^2}}\right) \quad (11)$$

As it can be seen from the main scheme (Figure 3), the magnitude of the frictional force will be equal to:

$$F_{tp} = f\left[F_{sp} + F_{sr} - F_c - F_\mu - F_{st}\cdot\cos\left(\widehat{x,\bar{n}}\right) + G\cdot\cos\left(\widehat{y,\bar{n}}\right)\right] \quad (12)$$

where *f* - coefficient of the friction of the surface of residues of leaves on the surface of the flat passive sensing organ.

In projection on the axes O_x and O_y the vector Equation (4) can be written as a system of differential equations of the following form:

$$\left.\begin{aligned} m\ddot{x} &= F_{st} - F_{sr}\cos\left(\widehat{x,\bar{n}}\right) - F_{sp}\cos\left(\widehat{x,\bar{n}}\right) + \\ &\quad + F_c\cos\left(\widehat{x,\bar{n}}\right) + F_\mu\cos\left(\widehat{x,\bar{n}}\right) - F_{tp}\cos\left(\widehat{\dot{x},\bar{V}}\right), \\ m\ddot{y} &= -F_{sr}\cos\left(\widehat{y,\bar{n}}\right) - F_{sp}\cos\left(\widehat{y,\bar{n}}\right) + F_c\cos\left(\widehat{y,\bar{n}}\right) + \\ &\quad + \bar{F}_\mu\cos\left(\widehat{y,\bar{n}}\right) - \bar{F}_{tp}\cos\left(\widehat{\dot{y},\bar{V}}\right) - G, \end{aligned}\right\} \quad (13)$$

where $\cos\left(\widehat{x,\bar{n}}\right)$, $\cos\left(\widehat{y,\bar{n}}\right)$ – the direction cosines of the vector of the normal $\bar{n}$ to the axis O_x and O_y respectively; $\cos\left(\widehat{\dot{x},\bar{V}}\right)$, $\cos\left(\widehat{\dot{y},\bar{V}}\right)$ - the direction cosines of the vector of the forward speed $\bar{V}$ to the axis O_x and O_y respectively; $\dot{x}$, $\dot{y}$ - projection of the vector of the forward speed $\bar{V}$ to the axis O_x and O_y respectively.

According to Vasilenko (1996) the mentioned direction cosines will be equal to:

$$\cos\left(\widehat{x,\bar{n}}\right) = \frac{df}{dx}\cdot\frac{1}{\Delta f}, \quad \cos\left(\widehat{y,\bar{n}}\right) = \frac{df}{dy}\cdot\frac{1}{\Delta f} \quad (14)$$

$$\cos\left(\widehat{\dot{x},\bar{V}}\right) = \frac{\dot{x}}{V}, \quad \cos\left(\widehat{\dot{y},\bar{V}}\right) = \frac{\dot{y}}{V} \quad (15)$$

where *f(x,y)* - the equation of the connection (surface, on which a material point moves); Δf - module of the function gradient *f(x,y)*; *V* - module of the vector of point forward speed.

Since it was initially assumed that the head of sugar beet root has a spherical shape, in the two-dimensional case the constraint equation has the following form:

$$f(x,y) = x^2 + y^2 - R^2 = 0 \quad (16)$$

where *R* - radius of the head of the sugar beet root.

The above equation is related to the circle with the radius *R* having the centre *O* in the centre of the coordinates.

According Vasilenko (1996) the module of the gradient function and module of the forward speed points, respectively, will be equal to:

$$\Delta f = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \quad (17)$$

$$V = \sqrt{\dot{x}^2 + \dot{y}^2} \quad (18)$$

With regard to Equation (16), we have obtained:

$$V = \sqrt{\dot{x}^2 + \dot{y}^2} \quad (19)$$

Then, according to (17), we obtain:

$$\Delta f = \sqrt{(2x)^2 + (2y)^2} = 2R \quad (20)$$

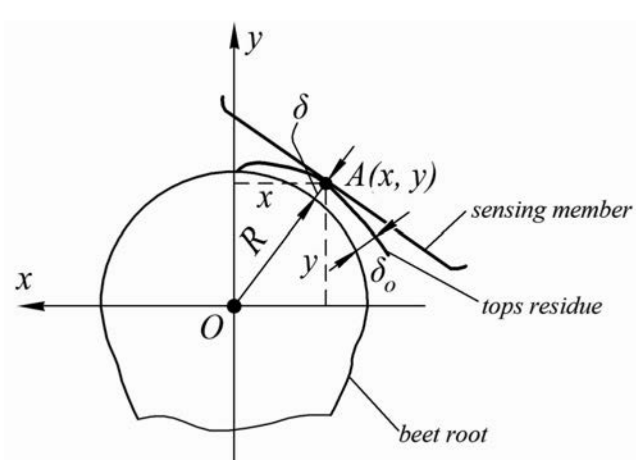

Figure 4. Scheme for determining the deformation of leaves residues on the head of sugar beet root head during contact with a flat sensing organ.

With regard to Equations (14), (19) and (20) we have found:

$$\cos\left(x,\hat{\bar{n}}\right)=\frac{x}{R},\quad \cos\left(y,\hat{\bar{n}}\right)=\frac{y}{R} \tag{21}$$

Taking into account (10), (11) and (21), the Equation (12) for the determination of the friction force F_{tp} will be as follows:

$$F_{tp}=f\left[F_{sp}+F_{sr}-c\left(\sqrt{x^2+y^2}-R-\delta_o\right)-\right.$$
$$\left.-\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-\frac{x}{R}F_{st}+\frac{y}{R}G\right]. \tag{22}$$

Substituting in (13) the Equations (10), (11), (15), (21) and (22) we obtain the following system of differential equations:

$$\left.\begin{array}{l}
m\ddot{x}=F_{st}-\frac{x}{R}F_{sr}-\frac{x}{R}F_{sp}+\frac{x}{R}\cdot c\left(\sqrt{x^2+y^2}-R-\delta_o\right)+\\
+\frac{x}{R}\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-\frac{\dot{x}f}{\sqrt{\dot{x}^2+\dot{y}^2}}\left[F_{sp}+F_{sr}-\right.\\
\left.-c\left(\sqrt{x^2+y^2}-R-\delta_o\right)-\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-\frac{x}{R}F_{st}+\frac{y}{R}G\right],\\
m\ddot{y}=\frac{y}{R}F_{sr}-\frac{y}{R}F_{sp}+\frac{y}{R}\cdot c\left(\sqrt{x^2+y^2}-R-\delta_o\right)+\\
+\frac{y}{R}\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-\frac{\dot{y}f}{\sqrt{\dot{x}^2+\dot{y}^2}}\left[F_{sp}+F_{sr}-c\left(\sqrt{x^2+y^2}-R-\delta_o\right)-\right.\\
\left.-\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-\frac{x}{R}F_{st}+\frac{y}{R}G\right]-G.
\end{array}\right\} \tag{23}$$

For the purpose of calculation, the systems of differential Equations (23) can be presented in more convenient form:

$$\left.\begin{array}{l}
\ddot{x}=\frac{F_{st}}{m}-\frac{x}{mR}\left[c\left(\sqrt{x^2+y^2}-R-\delta_o\right)+\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-F_{sr}-F_{sp}\right]-\\
-\frac{\dot{x}f}{\sqrt{\dot{x}^2+\dot{y}^2}}\left[F_{sr}+F_{sp}-c\left(\sqrt{x^2+y^2}-R-\delta_o\right)-\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-\right.\\
\left.-\frac{x}{R}F_{st}+\frac{y}{R}G\right],\\
\ddot{y}=-\frac{y}{mR}\left[c\left(\sqrt{x^2+y^2}-R-\delta_o\right)+\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-F_{sr}-F_{sp}\right]-\\
-\frac{\dot{y}f}{\sqrt{\dot{x}^2+\dot{y}^2}}\left[F_{sr}+F_{sp}-c\left(\sqrt{x^2+y^2}-R-\delta_o\right)-\mu\left(\frac{x\dot{x}+y\dot{y}}{\sqrt{x^2+y^2}}\right)-\right.\\
\left.-\frac{x}{R}F_{st}+\frac{y}{R}G\right]-g,
\end{array}\right\} \tag{24}$$

where g - free fall acceleration, m.s^{-2}.

Obtained system of a differential Equations (24) can be accepted as a calculation mathematical model of the movement of the flat sensing organ having a permanent contact with the head of the sugar beet root. For the contact point it is very probable the occurrence of a hard impact which can always cause the damage of upper part of a sugar beet root or knocking-out of whole sugar beet root from the soil. Mentioned mathematical model in general and complex form allows to model the process of a work functioning of the passive sensing organ of a sugar beet topper with the regard of all forces, acting on a given case based on their physical character. Original mathematical model takes into account *elastic-damping* properties of a residues of sugar beet leaves, which undoubtedly belong to sensing system, which is used for sugar beet leaves harvest.

Besides this the obtained system of Equations (24) can be considered as a system of differential equations of a second-order, it is non-linear, and it can be solved only by numerical methods with the use of existing computer programs.

This system of differential Equations (24) can be solved by numerical methods using a personal computer, and for the particular case, also, for example, when the forces acting during operation of the dynamic system are having constant and maximum values.

Such particular case also provides an opportunity for successful determining the optimal design and kinematic parameters of the sensing organ mechanism for the topping of sugar beet roots standing in a soil to ensure the quality of its work in a wide range of operating conditions of sugar beet harvest and sugar beet field status.

The following conditions can be considered as a starting conditions in the process of solving the system of differential Equations (24):

for $t = 0$:

$$x=x_o,\ \ y=y_o,\ \ \dot{x}=V_p,\ \ \dot{y}=0 \tag{25}$$

During solution, for example, the system (24) of differential equations for some range of elastic-damping properties of residues of the sugar beet leaves tops we can get a different values of the speed of sensing organ after the initial contact with the head of the sugar beet root. The smaller is the change speed of a sensing organ after contact with a side bud of sugar beet leaves roots, there will be less impact load, the smoother and softer will be impact of a flat sensing organ on a sugar beet root. This substantially reduces the probability of knocking of the sugar beet roots from the soil and their damage, which in itself is very important for high-quality running of the technological process under consideration.

Investigating the obtained system (24) of differential equations, the similar calculations can be provided for some intervals of changing of the driving horizontal force F_{st} and the spring force F_{sp} in order to evaluate the smoothness of hitting the sensing organ to the head of sugar beet root.

It is necessary to mention that the most substantial parts of the sugar beet leaves after the flat sensing-less cut they are concentrated especially on the side part of a sugar beet root heads. In a upper part of a heads of sugar beet roots mentioned residues of a leaves are less substantial, and many times they do not occur in this part. It is necessary to mention also that in the beginning of a contact they accept the basic impact between the sensing organ and sugar beet root head, which is reducing of this impact. Due to this fact, in the beginning of contact of sensing organ with the sugar beet root head the side buds of leaves are deformed in a large scale, creating in the same time the maximal strength and deforming forces $F_{c\,max}$ and $F_{\mu\,max}$, reducing an impact load, which is changed into the form of more soft interaction.

Considering the above observations, we will study the movement of a sensing organ over the head of sugar beet root in the first moment of its contact with the sugar beet root and in such starting moment the system of differential Equations (24) is significantly simplified.

Namely, in the first approximation, we can assume that the angle between the normal and the axis O_y remains constant and equal α, and between the tangent and the axis O_y is equal to (90° – α), when the contact time of the sensing organ with the side part of the head of sugar beet root is very small. Then the system of differential Equations (24) obtains the following form:

$$\left.\begin{aligned} \ddot{x} &= \frac{F_{st}}{m} + \left(F_{sr} + F_{sp} - F_{c\max} - F_{\mu\max}\right)\frac{\sin\alpha}{m} - \\ &- \frac{f}{m}\cos\alpha\left(F_{sp} + F_{sr} - F_{c\max} - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right), \\ \ddot{y} &= \left(F_{c\max} + F_{\mu\max} - F_{sr} - F_{sp}\right)\cdot\frac{\cos\alpha}{m} - \frac{f}{m}\sin\alpha\left(F_{sp} + F_{sr} - \right. \\ &\left. - F_{c\max} - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right) - g. \end{aligned}\right\} \quad (26)$$

Thus, there was obtained a system of linear differential equations, each of which can be easily integrated in quadratures. After the first integration of the system of Equations (26) we get:

$$\left.\begin{aligned} \dot{x} &= \frac{F_{st}}{m}t + \left(F_{sr} + F_{sp} - F_{c\max} - F_{\mu\max}\right)\frac{\sin\alpha}{m}t - \\ &-\left(F_{sp} + F_{sr} - F_{c\max} - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\cos\alpha}{m}t + C_1, \\ \dot{y} &= \left(F_{c\max} + F_{\mu\max} - F_{sr} - F_{sp}\right)\frac{\cos\alpha}{m}t - \left(F_{sp} + F_{sr} - F_{c\max} - F_{\mu\max} + \right. \\ &\left. + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\sin\alpha}{m}t - gt + L_1, \end{aligned}\right\} \quad (27)$$

where C_1, L_1 - the arbitrary constants.

After the second integration of the system of a Equation (26) we obtain:

$$\left.\begin{aligned} x &= \frac{F_{st}}{2m}t^2 + \left(F_{sr} + F_{sp} - F_{c\max} - F_{\mu\max}\right)\frac{\sin\alpha}{2m}t^2 - \left(F_{sp} + F_{sr} - \right. \\ &\left. - F_{c\max} - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\cos\alpha}{2m}t^2 + C_1 t + C_2, \\ y &= \left(F_{c\max} + F_{\mu\max} - F_{sr} - F_{sp}\right)\frac{\cos\alpha}{2m}t^2 - \left(F_{sp} + F_{sr} - F_{c\max} - \right. \\ &\left. - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\sin\alpha}{2m}t^2 - \frac{gt^2}{2} + L_1 t + L_2, \end{aligned}\right\} \quad (28)$$

where C_2, L_2 - the arbitrary constants.

From the initial conditions (25) we obtain the values of a arbitrary constants: $C_1 = V_p$, $L_1 = 0$, $C_2 = x_0$, $L_2 = y_0$.

Thus, we finally obtain:

i) the law of changes of the move of sensing organ on the head of sugar beet root at the beginning of the contact:

$$\left.\begin{aligned} x &= \frac{F_{st}}{2m}t^2 + \left(F_{sr} + F_{sp} - F_{c\max} - F_{\mu\max}\right)\frac{\sin\alpha}{2m}t^2 - \left(F_{sp} + F_{sr} - \right. \\ &\left. - F_{c\max} - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\cos\alpha}{2m}t^2 + C_1 t + C_2, \\ y &= \left(F_{c\max} + F_{\mu\max} - F_{sr} - F_{sp}\right)\frac{\cos\alpha}{2m}t^2 - \left(F_{sp} + F_{sr} - F_{c\max} - \right. \\ &\left. - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\sin\alpha}{2m}t^2 - \frac{gt^2}{2} + L_1 t + L_2, \end{aligned}\right\} \quad (29)$$

ii) the law of movement of a sensing organ on the head of sugar beet root at the beginning of the contact:

$$\left.\begin{aligned} x &= \frac{F_{st}}{2m}t^2 + \left(F_{sr} + F_{sp} - F_{c\max} - F_{\mu\max}\right)\frac{\sin\alpha}{2m}t^2 - \left(F_{sp} + F_{sr} - \right. \\ &\left. - F_{c\max} - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\cos\alpha}{2m}t^2 + V_p t + x_0, \\ y &= \left(F_{c\max} + F_{\mu\max} - F_{sr} - F_{sp}\right)\frac{\cos\alpha}{2m}t^2 - \left(F_{sp} + F_{sr} - F_{c\max} - \right. \\ &\left. - F_{\mu\max} + F_{st}\sin\alpha + G\cos\alpha\right)\frac{f\sin\alpha}{2m}t^2 - \frac{gt^2}{2} + y_0. \end{aligned}\right\} \quad (30)$$

By varying the values of forces appearing in the expression (29), it is possible to minimise the change in speed of the sensing organ by its initial contact with the head of the sugar beet root.

For practical use of the expressions (23) and (24) we need to find a contact time τ of the sensing organ with the head of the sugar beet root. This can be done, taking into account the working speed V_p of the topper.

We assume that on one linear meter of the sugar beet row there is not more than 6 sugar beet roots that can respond to high sugar beet yields. Next, we consider that if sugar beet head topper moves at a forward speed V_p ($m\cdot s^{-1}$), during the time interval 1 s, the sugar beet topper will make contact with the $6V_p$ sugar beet roots. Therefore, the contact time τ of the sensing organ with one sugar beet root will be:

$$\tau = \frac{1}{6V_p} \quad (31)$$

In order not to knock out the sugar beet root of the soil during the impact of a flat passive sensing organ on the head of the sugar beet root, it is necessary to ensure the condition under which the maximum value of the horizontal component of the force $P_{g.max}$, which acts from the side of the sensing organ at the head of the sugar beet root and its allowed value $[P_g]$ will be determined by the following relationship:

$$P_{g.max} < [P_g] \quad (32)$$

We find the horizontal component of the forces acting on the head of the sugar beet root during the interaction with the sensing organ. As you can see from the scheme (Figure 3), this force will be equal to:

$$P_g = F_{st} + (F_{sr} + F_{sp} - F_{c\,max} - F_{\mu\,max})\sin\alpha - F_{tp}\cos\alpha \quad (33)$$

On the bases of (32) and (33) we can write the condition of not knocking out the sugar beet root from the soil:

$$F_{st} + (F_{sr} + F_{sp} - F_{c\,max} - F_{\mu\,max}) \sin\alpha - \quad (34)$$
$$- f\,(F_{sr} + F_{sp} - F_{c\,max} - F_{\mu\,max} + (F_{st} \sin\alpha + G\cos\alpha)\cos\alpha < [P_g]$$

Inequality (34) can be used for testing of any set of forces incorporated in its left-hand side.

Based on results of experimental research, published in Pogorelij (1964), it can be stated that varies within the range 98 – 1.15.10^3 N. At value $[P_g]$ = 98 N of soft soil (hardness of 0.5 –1.0 MPa) on an average more than 45% of the sugar beet roots are knocked out. These data can be used later in the numerical calculations with the using of personal computer.

Our experimental studies (Bulgakov, 2011; Bulgakov *et al*., 2016) have established such values of the following coefficients: coefficient of the elasticity of the tops (short, green stems) the of sugar beet $c = 1.5 \cdot 103$ N^3.m^{-1}; coefficients of the damping of the leaves (short, green stems) $\mu = 18.5$ N.s.m^{-1}; coefficient of the friction of the tops on steel $f = 0.4$. The values of these coefficients have fairly stable maximum values for the sugar beet tops at the time of harvest, so during numerical simulation on a PC actually it is not necessary to vary their values to study the behaviour of a given dynamic system.

Thus, to estimate the vibration intensity of a sensing organ upon impact on the head of a sugar beet root with various design parameters of the sensing organ, it is necessary to know its speed V, depending on the time of contact with the beetroot root, which will be equal to:

$$V = \sqrt{\dot{x}^2 + \dot{y}^2} \quad (35)$$

where x and y are the coordinates of the centre of the sensing organ or the law of its movement along the root of the root, determined by the expression (30).

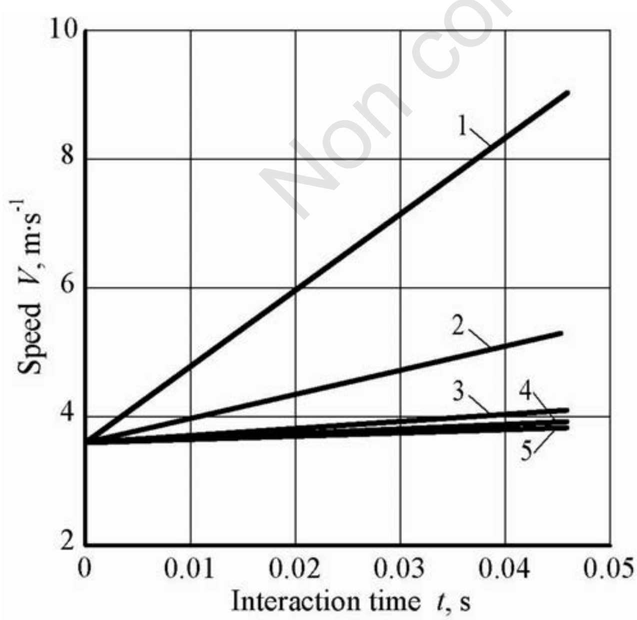

Figure 5. Dependences of the speed V of the sensing organ on the contact time t at an angle of inclination α = 5° for a different mass of the sensing organ: 1 - *m* = 1 kg; 2 - *m* = 3 kg; 3 - *m* = 10 kg; 4 - *m* = 15 kg; 5 - *m* = 20 kg.

The results of the numerical simulation of the obtained system of equations on a PC for determining the kinematic and design parameters of the sensing organ when it moves along the head of the root crop at the translational speed V_p=1 m.s^{-1} of the entire topper are presented in Figures 5-7.

From the obtained graphical dependences, presented in Figures 5-7 it can be seen that the preference should be given to curves 3, 4 and 5 (which is close to linear dependence), which ensure minimum oscillations of the sensing organ itself in the vertical plane due to the vertical component of its speed, which plays an important role in changing the speed of the sensing organ at the beginning of its contact with the head of the sugar beet root.

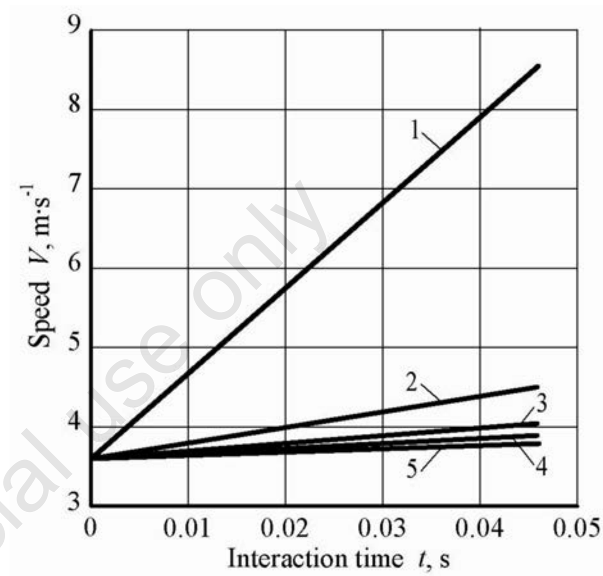

Figure 6. Dependences of the speed V of the sensing organ on the contact time t at an angle of inclination α = 15° for a different mass of the sensing organ: 1 - m = 1 kg; 2 - *m* = 3 kg; 3 - *m* = 10 kg; 4 - *m* = 15 kg; 5 - *m* = 20 kg.

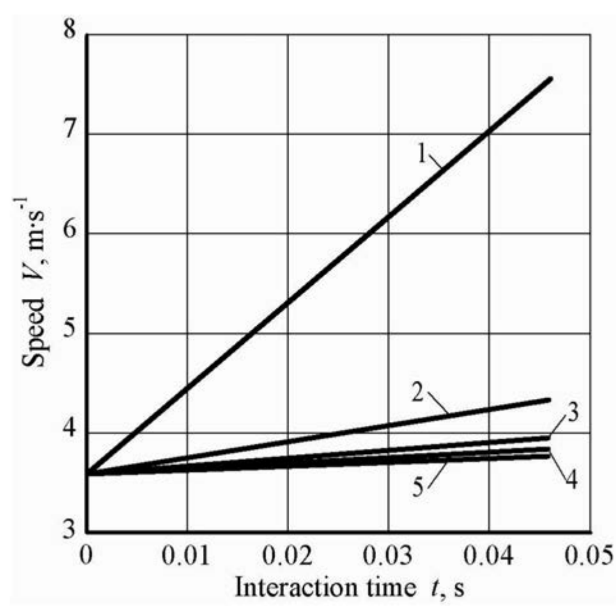

Figure 7. Dependences of the speed V of the sensing organ on the contact time t at an angle of inclination α = 35° for a different mass of the sensing organ: 1 - *m* = 1 kg; 2 - *m* = 3 kg; 3 - *m* = 10 kg; 4 - *m* = 15 kg; 5 - *m* = 20 kg.

Since all these three curves (3, 4 and 5) are approximately on all the graphs close to each other, then, nevertheless, it is preferable to give curves 3, which correspond to the minimum value of the sensing organ mass, equal to m = 10 kg. One could take the mass m of the sensing organ even larger, according to curves 4 and 5 (corresponding to a larger mass of the sensing organ: 4 - m = 15 kg; 5 - m = 20 kg), but there is no reason to intentionally increase the mass of the sensing organ, due to reasons of unnecessary increase in the metal capacity of the sensing device and the topper in general.

In addition, giving preference to curve 3, we get the minimum shock load during the initial contact of the sensing organ with the head of the sugar beet root during its after-trimming. This follows from the theorem on the change in the momentum for an impact of this type (Butenin *et al*., 1985):

$$m\left(\bar{V} - \bar{V}_p\right) = \bar{S} \quad (36)$$

where $\bar{S}$ - impact impulse; $\bar{V}_p$ - speed of the sensing organ before the impact; $\bar{V}$ - speed of the sensing organ after the impact.

Since on all presented graphs (Figures 5-7) for curves 3, 4 and 5, the speed differences $\bar{V} - \bar{V}_p$ are approximately the same (these curves are close enough to each other), then for masses m = 10 kg, m = 15 kg and m = 20 kg, we get on the basis of expression (36), an obvious inequality of the following kind:

$$S_{\min} = 10\left(\bar{V} - \bar{V}_p\right) < 15\left(\bar{V} - \bar{V}_p\right) < 20\left(\bar{V} - \bar{V}_p\right) \quad (37)$$

Thus, the minimum shock pulse for curves 3 will be much smaller than for curves 4 and 5. The use of curves 3 for further calculations will ensure that the sugar beet roots are unobstructed from the soil, when interacting with the sensing organ and excludes damage to their upper parts of the heads.

Similarly it affects the oscillations of the sensing organ and an increase in its angle of inclination relative to the direction of motion. In this case, preference should be given to large values of the angle α, *i.e.* α > 15°, as the values of the speed for the same moments of time, as seen from Figures 5 and 6, are smaller at α > 15°.

Conclusions

- There was developed a new design of the topper for topping the heads of the sugar beet roots standing in the soil. The experimental research and production tests have shown positive results, confirming its efficient work and high quality of the topping the heads of the sugar beet roots.

- There was developed also a new theory of the interaction of passive sensing organ with the head of the sugar beet root. For this purpose there was designed a force scheme of the interaction of a passive sensing organ and the spherical surface of the head of the sugar beet root. During this contact residues there are accounted the elastic-damping properties of the residues of the tops of the head of a sugar beet root, which are presented as model with elastic and viscous properties. At the points of contact on these schemes there are applied at the same time all the existing forces. The coordinate axes, appropriately arranged, are selected.

- By using the basic law of dynamics there was made up a new system of differential equations that describes the motion of a plane passive sensing organ on the spherical surface of the head of the sugar beet root, which contains the remains of the tops. After double integration there were obtained laws of a changes the speed of movement of the moving flat passive sensing organ on the head of sugar beet root at the beginning of the contact. There was taking into account the condition of not knocking the bodies of the sugar beet root from the soil.

- Using of a obtained new analytical dependences and the results of specific numerical calculations on the PC in the development and design of sugar beet harvesters having a modern technical level it is necessary to use the weight m of the sensing organ up to 10 kg and the angle of its initial inclination α > 15, and it will provide a significant improvement in the quality of sugar beet tops and roots during their mechanised harvesting.

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