Development of a New Design of the Semi-Mounted Sugar Beet Topping Machine and Theory of its Rotary Cutting Mechanism

Volodymyr Bulgakov[1], Prof. DrSc., akademician of the NAASU,
Valeriy Adamchuk[2], Prof. DrSc., akademician of the NAASU,
Hristo Beloev[3], Prof. DrSc. Eng, Boris Borisov[3], Prof., DrSc. Eng,
Ladislav Nozdrovicky[4], Prof., DrSc. Eng

[1]*National University of Life and Environmental Sciences of Ukraine*
[2]*National Scientific Centre "Institute for agricultural engineering and electrification", NAASU, Ukraine*
[3]*"Angel Kanchev" University of Ruse, Bulgaria*
[4]Slovak University of Agriculture in Nitra, Slovak Republic

The paper is focused on design of a new semi-mounted topper of the root crop harvester with a rotary cutter mechanism and passive supplementary cutter of heads of root crops. There is developed a advanced theory of the rotary cutter unit of the semi-mounted root crop harvester. In details there is considered the dynamic process of interaction between the arc-shaped knife cutting device with an array of root crop harvester topper and its separate beam which carry cutting without support and without sensing of the tops of sugar beet roots. Analytically there is defined the zone of cutting the tops, the amount of penetration of the knife into a basis of the tops, conditions of its full cut at single contact with the knife. There are defined the conditions of dynamic balancing of the rotary root crop topper mechanism. Obtained analytical dependences allows to calculate and design not only new design of the rotary cutting mechanism of root crop harvester, but also to use them for similar calculations for other mowers used for harvest of another crops.

Keywords: *beet, sugar beet tops, sugar beet harvesting machinery, rotor slice theory, differential equations, optimal parameters.*

Problem formulation. Harvest of the sugar beet (roots and tops) is one of the most time-consuming and energy-intensive operations in agricultural production. Taking into account the fact that sugar is one of the strategic food product, and as a whole beet production is an important bioenergy feedstock, it is necessary to produce sugar beet harvesters, which functional and performance indicators must be continuously improved.

Improving quality indicators of sugar beet harvester is a complex scientific and technical problem, the solution of which should be based on the search for new design solutions of the working mechanisms and layout diagrams of machines, deep theoretical justification of their design and technological parameters, experimental confirmation of theoretical studies with the ultimate goal of the analysis and synthesis optimal parametres.

One of the main operations in the process of sugar beet harvest is the removal of sugar beet tops from the heads of sugar beet roots. In recent years, the most spread there were sugar beet toppers with rotary cutting apparatus. However, there are many designs of these machines, which topping cutting blades can rotate in a vertical or horizontal planes. If the blades are rotating in the vertical plane, they can cut not only tufts of the tops, but also partly crushed them.

Publications review. The process of the crop stalks cutting (mowing) without support, or by so called innertial support, was at the beginning analytically [1], in relation to individual freely located stalks fixed in the soil. Subsequently this problem was studied by E.M. Gutlar [2], A. Ju. Ishlinski [3], and it was also the subject of basic research provided by I.F. Vasilenko [4], N.Ju.Reznik [5], E.S. Bosoj [6], and others.

As far as topping of the sugar beet concerns, for a long time (generally starting from the first development of the design of sugar beet toppers) there were used mechanisms cutting of the sugar beet tops, which were providing sliding cut by flat, curved horozontal (or obliquely disposed) knife. There were removed not only stalks or leaves of the crop but in most cases also the tops of the root crop, located close to the head of the root, as there was used individual sensing of the position of the heads.

Extensive research activities focused on topping of the sugar beet [7, 8 and others] were aimed on the research of the different types of the cutting mechanisms having different design, consisiting of sensing (with active or passive principle) and cutting working organs, as well as mechanisms for hanging and drive. Any way, in last years for the topping of the sugar beet roots, there is wide spread of rotary cutting mechanisms, which function do not provide individual cut of the top from each sugar beet root but there is performed a continuous free-flow cut of the sugar beet tops across all working width of the harvest machine.

The simplicity of design and high quality of the cutting process have caused a wide use of the above mentioned devices for different conditions of the sugar beet topping. Moreover, their widespread use is due to the fact that in most cases the sugar beet tops are not longer used as a feed for animals, and mostly very often they are crushed and desintegrated (with a large amount of soil contaminants) and spread on the on field surface.

Thus, the tops of sugar beet are cut with rotary knives having an arcuate shape, which rotate in a longitudinal-vertical plane and they are mounted on a higher cutting height (due to the different arrangement of heads of the root crop adjustment, both within itself row and in neighbouring/adjacent rows) . From a theoretical point of view, such devices are usually performing a cut of the stalk crops without support using just an inertial support, actually they are working on the principle of forage mower.

Obviously, for this reasons, the theory of the cut of sugar beet tops without support provided by the rotary cutting machine installed in the longitudinal vertical plane, untill now is not thoroughly developed, because it is believed that the classical theory of the cut without support fully reflects this process.

However, as clearly that in the development of a new theory of rotational topper mechanism, the classical theory of the cutting of forage crops without support can have a lot to do with it (in particular, in the part that deals with the physical nature of the cutting process), but as a result of differences between the physical and mechanical properties of the tops and the location of beet roots, individual design differences, it can have also a number of very different features.

Therefore, when creating a theory of the cutting unit of the topper machine, there can be used the main provisions of the classical theory of the cutting of the forage crops by using a rotary machine with a horizontal axis of rotation, which is the most extensively developed by E.S. Bosoj and presented in a current form in [6]. However, it should be noted immediately, that this theory is, unfortunately, not without some inaccuracies, especially because lately it is published without adequate verification in many textbooks and manuals.

As there is wide-spread of forage mower-conditioners in the area of agriculture, there are premises for using of design and technological specifications of mower-conditioners for the creation and development of a new design of the topping harvesters.

Therefore, considering the basic physical and mechanical properties of the tops and roots of the sugar beet, it is necessary to develop a design of the topping machine that would carry out technological process on the basis of a rotary mower. It is also necessary, as much as possible to use the existing theoretical work related to the cutting of plant matter, to develop the basic premise of the theory topping of the sugar beet without support and without sensing in order to develop the optimal parameters of the sugar beet topping machines .

The aim of research. The aim is to develop for the new topping harvester a revised theory of rotary cutting device and obtain analytical expressions that can be used for the design of similar devices for mowing machines and topping machines.

Object and methodology of the study. The object of the study is a rotary cutting unit performing the cutting of the sugar beet tops, grass or other plant matter without support and without sensing.

In the study of the process of cutting the tops, there was used by a number of provisions of analytical mechanics. In particular, to determine the zone of two adjacent cutting blades extending in one row there were composed equations of the trajectory of the knives by studying the geometry and kinematics of the movement.

To determine the depth of penetration of the knife blade into a sugar beet top there were compiled and integrated differential equations of motion for the reduced mass of the sugar beet top basis and the arc-shaped topper knife in their interaction. The difference between the movement of the knife blade of the topper is the depth of penetration of the knife blade in a basis of the top. This result makes it possible to determine the conditions of a complete cut-off of the sugar beet top the first collision of the actuate knife blade with it.

In the study of dynamic balancing of rotary topping mechanism there was analysed the process of a knife stroke along the basis of the sugar beet top on the basis of the theory of the impact of two bodies. The impulse response is defined by a hinged suspension of the knife during impact. From the condition of the equality to zero of the impulses, there were obtained necessary geometrical parameters of knives, in which a rotary cutting unit will be dynamically balanced.

Results of the study. There was developed a new universal sugar beet topping machine, performing technological process on the basis of forage mower-conditioner, which is front mounted on a wheel-type tractor. On the topping machine there is used a rotary topping mechanism, whose cutting shear blades are arc-shaped and rotates in a longitudinal-vertical plane [9-12]. Figure 1 shows the structural and technological scheme of the topping machine that cuts the sheaves and leaves of the sugar beet tops and plants that occures on the sugar beet field, and transports the cut matter to the load compartment of the transport vehicle, which is moving alongside.

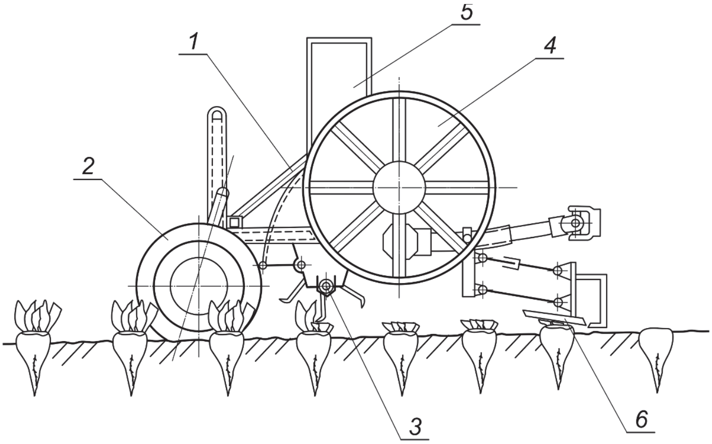

Figure 1. The structural and technological scheme of the new sugar beet topping machine equipped with rotary cutting mechanism and passive supplementary cutter of the sugar beet tops:
1 – basic frame; 2 – sensing wheel; 3 – rotary apparatus for cutting the sugar beet tops;
4 – mechanism for collecting and unloading of the sugar beet tops; 5 – conveying sleeve;
6 – supplementary cutter of the sugar beet tops

The technological process of harvesting the sugar beet topps is as follows. When driving a tractor on the rows of sugar beet roots, guide wheels 2 located at the front of the main frame 1 of the machine, there is set the rotor 3 with knives at the desired cutting height. The knives have an arcuate shape, and are pivotally mounted on the cylindrical generatrix along the length of the rotor 3, so that they provides the overlap of the entire working width.

Shear blades rotate at a high frequency, thus ensuring the whole cross-section cut of the whole matter of the top of root. The absolute velocity of the arcuate ends of the blades of knives for cutting the tops is from 20 to 25 m.s^{-1}, and for cutting of the other crops, in particular crops with larger diameter of the stalks is from 40 to 50 m.s^{-1} [11].

Tops of the sugar beet roots cutted by the arc-shaped knives are put to the top of the casing, where they fall on the auger conveyor that mix the mater cutted by every blade in the end of the transport unit, after which the mechanism for collecting and discharging 4 unloads it through the conveying sleeve 5 in the body of the vehicle moving alongside the topper harvest machine. The technological process of harvesting of the sugar beet tops finishes by circumcision of the heads of root crops from the root top residues by the rear mounted passive type supplementary cutter 6.

As an advantage of a new sugar beet topping machine equipped with rotary cutting mechanism, can be considerd the fact that the machine has only one working organ – rotor with cutting knives. Such machine performs total high quality cut of the basic part of the sugar beet tops and provides conveying them to the transport truck moving around the topper machine, or it is possible to spread the crushed crop material (sugar beet tops) on the surface of the harvested field. Sugar beet topping machine is a multipurpose machine, it has high working reliability and can be used as a rotary forage harvester (it can perform the high quality cut of the different grass crop stand up to the height of 1 m) [11]. As a disadvantage of the mentioned rotary type of a new sugar beet topping machine can be considered an excessive crushing of the sugar beet tops in case their loading to the load compartment of the transport vehicle body, which is moving alongside round, some pollution of the sugar beet tops by soil impurities (especially on dry soil), significant problems with of maintenance (particularly when removing the arcuate knives for sharpening, substitutions and the like).

In the next step we will provide a theoretical study of the rotational sugar beet tops cutting mechanism used on the above mentione sugar beet topping machine in order to determine its optimal structural and kinematic parameters. The subject of this study is to define the cutting area of the tops in the longitudinal-vertical plane, in relation to the kinematic and structural parameters of the rotary tops cutting mechanism, the condition of total cutting of the tops basis in single collision with an arc-shape knife blade, and analytical determination of other design parameters of the cutting machine. To do this, first of all, it must be done an equivalent circuit of the interaction of the blades of the rotary device with the tops basis.

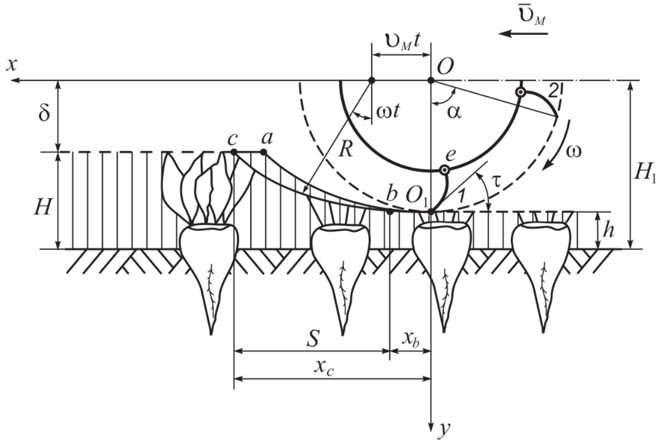

Figure 2. Equivalent scheme of the interaction of the knives of the rotary sugar beet tops cutting mechanism with the sugar beet tops matter

We will consider sugar beet tops cutting mechanism in a longitudinal-vertical plane and we will present it in the form of a rotor, on the periphery of which, there are pivotally mounted arcuate blades. The equivalent circuit is shown in Figure 2.

The rotor moves forward (direction of the forward velocity $\overline{\upsilon}_M$ is shown by the arrow) and simultaneously rotates (with angular velocity ω) in a direction similar to the direction of translational movement. The axis of the rotor (in the diagram there is the point *O*) is set at a height H_1 above the soil surface. The rotor moves along the row of sugar beet in which the height of sugar beet tops above the soil surface is denoted by *H*. The rotor performs a continuous cut of the tops at a set height *h* above the surface of the soil.

We will put through the center of the rotor (point *O*) rectangular flat Cartesian system *Oxy*, whose x-axis coincides with the direction of translational motion of the rotor, and the *y* axis is directed downward. We show in the equivalent circuit arcuate knife 1, which is mounted in the hinge *e* and is located at the lowest position of the rotor (point O_1), in which it actually starts the process of cutting the tops.

In the diagram, the trajectory of relative end of the knive 1 (as well as any other knives) is shown by a dotted line. In the lower part of the rotor blade 1 begins to interact with an matter of the sugar beet tops and in the accepted system of the coordinates *Oxy* of the equation of motion one end of the knife 1 (i.e. its blade edge) in parametric form have the form [6]:

$$\left.\begin{aligned} x_1 &= \upsilon_M t + R\sin\omega t, \\ y_1 &= R\cos\omega t, \end{aligned}\right\} \tag{1}$$

where: υ_M – forward movement speed of the sugar beet topper machine; *R* – the radius of the rotor (in this case, the distance from the axis of rotation of the rotor to the edge of the arcuate knife blade); *ω* – angular velocity of rotation of the rotor.

In the next part we will study the movement of the second knife. The adjacent knife 2, which is located on the rotor just beyond the knife 1 and is offset along the circumference of the rotor by the value of the central angle *α*, describe exactly the same curve, but shifted in the direction of an amount x_b (since knife 2 starts cutting the tops in the point *b*). In the same time, the center of the rotor (point *O*) is moved translationally by the amount $\upsilon_M t_b$. Thus, the value x_b equals:

$$x_b = \upsilon_M t_b = \upsilon_M \frac{\alpha}{\omega}, \tag{2}$$

where: α – central angle between two adjacent knives 1 and 2, but such that moving in one track; t_b – time during which point *b* shifts from the position O_1 when the forward movement of the rotor occures.

Taking into account that the translational and rotational motion of the rotor, the trajectory of the end of the blade 1 will be the curve O_1a.

The equations of motion of the end point of blade 2 with regard to (2), as it is seen from the scheme in Figure 2, in parametric form will have the form:

$$\left.\begin{aligned} x_2 &= \upsilon_M t + R\sin(\omega t - \alpha), \\ y_2 &= R\cos(\omega t - \alpha). \end{aligned}\right\} \tag{3}$$

As a trajectory of the end point of blade 2 will be the curve *bc.*

After determination of the trajectories O_1a and *bc* related to the movement of the two adjacent blades (1 и 2) of the rotor, there is possibility to determine their cutting zone *S* along the lenght of cutting. In the projection on the *x*-axis the cutting zone *S* is equal:

$$S = x_c - x_b, \tag{4}$$

where x_c – abscissa of the point *c*, that is the end point of the cutting zone.

Abscissa of the point x_c expressing the end of the cutting zone, can be determined as follows. If H – height of the basis of the sugar beet tops, H_1 – installation height of the rotor axiss above the soil surface, and δ - the value of which is equal to $\delta = H_1 - H$, and in such case, the ordinate y_c of the point c of the end cutting zone will be equal:

$$y_c = \delta = R\cos(\omega t_c - \alpha), \tag{5}$$

and from it follows::

$$cos(\omega t_c - \alpha) = \frac{\delta}{R}, \tag{6}$$

and finally from (6) it is possible to find the time t_c:

$$t_c = \frac{1}{\omega}\left[\alpha + arccos\left(\frac{\delta}{R}\right)\right]. \tag{7}$$

Now, for the time moment $t = t_c$, using the eqaution (3), it is possible to determine the abscissa x_c. It will be equall to:

$$x_c = \upsilon_M t_c + R\sin(\omega t_c - \alpha). \tag{8}$$

Further, by squaring both sides of equation (6), we obtain the following relation:

$$sin(\omega t_c - \alpha) = \sqrt{1 - cos^2(\omega t_c - \alpha)} = \sqrt{1 - \frac{\delta^2}{R^2}} = \frac{\sqrt{R^2 - \delta^2}}{R}. \tag{9}$$

Entering (7) and (9) in (8), we can obtain:

$$x_c = \frac{\upsilon_M}{\omega}\left[\alpha + arccos\left(\frac{\delta}{R}\right)\right] + \sqrt{R^2 - \delta^2}. \tag{10}$$

Entering (10) и (2) в (4), we finally determine the value of cutting zone lenght S:

$$\begin{aligned} S &= \frac{\upsilon_M}{\omega}\left[\alpha + arccos\left(\frac{\delta}{R}\right)\right] + \sqrt{R^2 - \delta^2} - \frac{\upsilon_M \alpha}{\omega} = \\ &= \frac{\upsilon_M}{\omega} arccos\left(\frac{\delta}{R}\right) + \sqrt{R^2 - \delta^2}. \end{aligned} \tag{11}$$

Further, we define the value of the penetration of the arcuate blade of the knife in the basis of sugar beet tops during their first contact. For this reason, it is necessary to consider the interaction between the individual basis of the top having conditional diameter d, disposed on the head of the root, and a separate arcuate blade which rotates with an angular velocity ω together with the rotor (Figure 3).

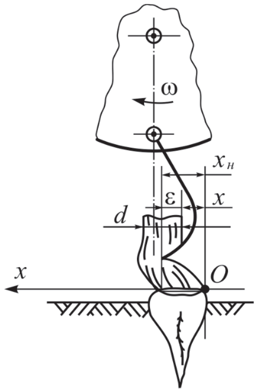

Figure 3. Scheme of the mutual interaction of the arcuate blade with the basis of the sugar beet top

In relation to the above mentioned, we will consider the motion of the basis of the beet tops having one degree of freedom and the reduced mass $m_{пр.}$, and the motion of the arcuate blade having the mass $M_{пр}$. We take such assumption, that the movement of the mass $m_{пр.}$. of the basis of the beet tops and the mass $M_{пр.}$ of the arcuate blade knife during the impact will be straight on the entire cutting area. In such case the basis of the beet tops deviate from its initial position to a distance *x*, and the end of the arcuate knife blade is moved to a distance $x_н$.

Thus, to determine the penetration of the knife blade into the basis of a beet tops it was necessary separately create the differential equations of motion for the reduced mass of the basis of the beet tops and the reduced mass of the arc-shaped knife, to determine their laws of motion, and then to consider the difference between these movements, which will be the size of the penetration *ε* knife into the basis of the beet tops.

The differential equation of linear motion of the basis of the beet top will have the following form:

$$m_{пр.}\ddot{x} = P(\varepsilon) - cx, \tag{12}$$

where:
$m_{пр.}$ − the mass of the basis of the sugar beet root top moved to the point of impact; *x* – linear movement of the given mass $m_{пр.}$; $P(\varepsilon)$ – the force exerted on the basis of the beet top from the side of the knife, which depends upon the value of *ε* knife penetration into the into the basis of the beet tops; *cx* – the force of resistance of the elastic bending of the basis of a beet tops.

As shown by previous studies [6], in the first approximation in order to determine the strength $P(\varepsilon)$ we can use the following expression:

$$P(\varepsilon) = P_{ср.} = \frac{A}{d}, \tag{13}$$

where: $P_{ср.}$ – average force of cutting; *A* – work required to cut the basis of a beet top; *d* – diameter of the basis of a beet top.

Entering (13) into (12), we obtain the following equation of motion of the basis of the beet top during the cutting by arcuate blade cutting knife.

$$m_{пр.}\ddot{x} + c\,x = P_{ср.}. \tag{14}$$

Here the initial conditions are as follows:

when $t = 0$: $x = 0$, $\dot{x} = 0$.

As a result, when using of the differential equation (14) we obtain an expression that describes the movement of the given mass of the basis of the beet tops at any time moment *t*:

$$x = \frac{P_{ср.}}{c}\left(1 - cos\sqrt{\frac{c}{m_{пр.}}}\,t\right). \tag{15}$$

To find the law of motion of the arc-shaped knife is necessary to make a differential equation of its rectilinear movement in the area of cutting. This differential equation will have the following form:

$$M_{пр.}\ddot{x}_н = -P_{ср.} + \mu(\upsilon_н t - x_н), \tag{16}$$

where: $M_{пр.}$ – applied weight of the knife (weight of the knife, applied to the point of impact of blade to the basis of the beet top); $x_н$ – movement of the applied weight of the knife; $\upsilon_н$ – critical speed of translational movement of the blade, in which the unsupported cut of the free-standing basis of the beet tops is possible; $\upsilon_н t$ – moving the blade edge of the knife at the moment *t* in the absence of collision with the basis of the beet tops, when the knife is in the radial position; $(\upsilon_н t - x_н)$ – deviation of the knife from its radial position as a result of a collision with a basis of the beet tops during the cutting process; μ – a proportionality factor (intensity of the loads acting on the knife during its deflection per unit length).

The second member of the right-hand side of equation (16) is the force that occurs due to the deviation of the knife from the radial position thanks to the acting of the centrifugal force.

The initial conditions for the given differential equation will be as follows:

for $t = 0$: $x_н = 0$, $\dot{x}_н = \upsilon_н$.

As a result of the using of the differential equation (16) there was obtained the law of the motion of the arc-shaped knife of a rotary beet topping apparatus in the following form:

$$x_н = \upsilon_н t - \frac{P_{ср.}}{\mu}\left(1 - cos\sqrt{\frac{\mu}{M_{пр.}}}\,t\right). \qquad (17)$$

Now, using a obtained equations (15) и (17), there is a possibility to determine the value of penetration ε of knife into the basis of a beet top:

$$\varepsilon = x_н - x,$$

or:

$$\varepsilon = \upsilon_н t - \frac{P_{ср.}}{\mu}\left(1 - cos\sqrt{\frac{\mu}{M_{пр.}}}\,t\right) - \frac{P_{ср.}}{\mu}\left(1 - cos\sqrt{\frac{c}{m_{пр.}}}\,t\right). \qquad (18)$$

The expression (18) makes it possible to determine the conditions of a complete cut-off of the basis of a beet tops having a diameter d in the first clash of the arcuate knife blade with a basis of a beet top.

It is clear, that in this case, it is necessary that $\varepsilon = d$, and therefore the expression (18) takes the form:

$$d = \upsilon_н t - \frac{P_{ср.}}{\mu}\left(1 - cos\sqrt{\frac{\mu}{M_{пр.}}}\,t\right) - \frac{P_{ср.}}{\mu}\left(1 - cos\sqrt{\frac{c}{m_{пр.}}}\,t\right). \qquad (19)$$

Thus, the expression (19) allows to input such structural and kinematic parameters of the rotary beet topping device in which a cut of basis of the beet top is performed in a process of the single impact collision of the basis of the beet top with a disposable blade arcuate knife. To cut the tops of the basis of the beet top the knife must penetrate the basis of the beet top on the value of its diameter d before the entire limb of the basis of beet top x exceeds a predetermined value $x_{кр.}$.

The character of the solution of equation (18) will depend largely on law of changing μ, as $\mu = f(\upsilon_н)$.

The actual circumferential speed of the rotor is determined from the condition that the linear velocity of the end of the knife blade must be greater than the critical speed necessary to cut free-standing basis of the beet tops:

$$\upsilon = \frac{\pi n R}{30} > \upsilon_н, \qquad (20)$$

and from there:

$$n > \frac{30\,\upsilon_н}{\pi R}, \qquad (21)$$

where: R − радиус, or distance from the axis of rotation of the rotor to the edge of the blade arc-shaped knife.

The radius of the rotor is selected based on the condition that the size of the cutting zone in the vertical must not exceed the value *R*, i.e. $R > H - h$. In practice the radius of the rotor varies within the range from 300 to 350 mm [9].

The width of the arc-shaped knife is determined by the maximum diameter d_{max} of the basis of beet top:

$$B = d_{max} + (30 \div 50), \quad \text{mm.} \tag{22}$$

The length of the working part of the blade O_1e (see Figure 2) is determined by the angle τ of the installation of a knife. With decreasing angle τ there worsens the movement of the cutted matter of tops from the surface of the knife, and when increasing - significantly increases the energy for the cutting and overcoming air resistance. Experimental studies [6] have shown that it is advisable to take the angle τ within the range from 30° to 40°.

Let us consider in more details the balancing of a rotary sugar beet topping mechanism and selection of the design parameters of the cutting knife. We will prepare the scheme of the pulses that act on arc-shaped knife belonging to a rotary sugar beet topping mechanism (Figure 4).

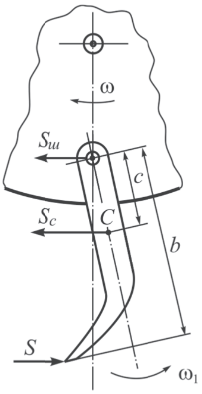

Figure 4. Scheme of the acting of the pulses on a arc-shaped knife in the moment of touch to basis of the sugar beet top

In the moment of touch to basis of the sugar beet top from the side on the knife, there will acts the pulse of the force *S*.

Knife leaning in the direction opposite the direction of rotation of the rotor, with a variable angular velocity ω_1, resists to shock pulses: to pulses in the center of knife weight S_c and also to pulses in the hinge $S_ш$. Then the differential equation of rotation of the blade with in relation to the hinge will have the following form:

$$J\frac{d\omega_1}{dt} = \sum_{i=1}^{n} M_i \, , \tag{23}$$

where: *J* − moment of inertia of the knife in relation to the hinge; ω_1 − the angular velocity of rotation of the knife in relation to the hinge; $\sum_{i=1}^{n} M_i$ – the sum of the moments related to the hinge of all external forces acting on the knife.

If we use a mean value of the average acceleration, the expression (23) can be written in following form:

$$J\frac{\Delta\omega_1}{\Delta t} = M \, , \tag{24}$$

where: $\Delta\omega_1 = \omega_1 - \omega_{10}$; ω_{10} – starting angular velocity of the turning of the knife in relation to the hinge; $M = \sum_{i=1}^{n} M_i$ – main moment of all external forces related to the hinge.

As far as:

$$\omega_{10} = 0, \tag{25}$$

and:

$$\Delta\omega_1 = \omega_1. \tag{26}$$

Then the expression (24) can be written as follows:

$$J\omega_1 = M\,\Delta t. \tag{27}$$

With a small error we can be assumed that the moment M is the product of force P, acting on the end of a knife during a knock of the knife along the basis of the beet top, on the shoulder of the force related to a hinge, that is the length of the knife:

$$M = P\,b. \tag{28}$$

Therefore, the expression (27) can be written as:

$$J\omega_1 = P\,b\,\Delta t = P\,\Delta t\,b = S\,b, \tag{29}$$

where: $S = P\Delta t$ – shock pulse of the force P.

Then the pulse $S_ш$ of the hinge reaction of an arc-shaped knife will be equal:

$$S_ш = S - S_c\,, \tag{30}$$

where: S_c – force pulse oriented to the weight centre of the arc-shaped knife.

Since, considering (29)

$$S = \frac{J\omega_1}{b}, \tag{31}$$

a pulse S_c of the force, oriented to the weight centre of the arc-shaped knife, will be equal to the extent of the movement:

$$S_c = m\upsilon_C = m\,\omega_1\,c\,, \tag{32}$$

where: m – weight of the knife; υ_C – linear velocity of the weight centre of the arc-shaped knife,

it is possible to obtain:

$$S_ш = \frac{J\omega_1}{b} - m\,\omega_1\,c\,. \tag{33}$$

The rotor will be dynamically balanced when the impulse response of the hinge blade will be equal to zero ($S_ш = 0$), it means that:

$$\left(\frac{J}{b} - mc\right)\omega_1 = 0\,, \tag{34}$$

or

$$\frac{J}{b} - m\,c = 0\,. \tag{35}$$

As far as $J = m\,\rho^2$, it is possible to write

$$\frac{m\rho^2}{b} - mc = 0\,, \tag{36}$$

and from there

$$\rho^2 = b\,c. \tag{37}$$

where: ρ – radius of inertia of the arc-shaped knife.

Hence, the rotor with arc-shaped knives of the rotary sugar beet topping mechanism will be dynamically balanced, if the size and weight of the blade will be selected so that the square radius ρ of inertia of a knife is equal to the value of the length of the knife at a distance from its center of mass to the hinge suspension.

Conclusions. There was created a new front mounted sugar beet topping machine with rotary cutting mechanism and and passive supplementary cutter of heads from the residues of root tops. The advanced theory of the rotary cutting mechanism of sugar beet topping machine was developed. Using a basic principles of the classic theory of support-free cutting of crop materials, developed by E. S. Bosoj (1967), there were formulated a new theoretic assumptions for the calculations of the rotary cutting mechanism of the sugar beet topping machine. By using an analytical tools there were found the zone of the cutting of the sugar beet tops, the value of penetration of the blade of arc-shaped knife into the basis of sugar beet top, as well as the conditions of the full cut of the basis of sugar beet top during a single collision with a knife, and other conditions, which provide a total cut of the matter of the top of sugar beet root.

There was also determind the conditions of the dynamic balancing of a rotary sugar beet topping mechanism. By using of the obtained analytical functions there is possibility to calculate and project not only new design of the rotary mechanisms of the sugar beet topping machines, but also to use them for designing of the mowers for the grass and other field crops.

References:

[1] Gorjachkin V.P. Sobranije sochinenij. Tom 3. Izd. 2-e. – Moscow: Кolos, 1968. – 384 pp. (In Russian language)

[2] Gutljar E.M. К teoriji srezanija steblej. – Zhurnal “Selkhozmashina”, 1931, №7. – p.12-13. (In Russian language)

[3] Ishlinskij A.Ju. Zadacha o skorosti kosby zlakov. Zhurnal “Selkhozmashina”, 1937, № 5-6. – p. 8-12. (In Russian language)

[4] Vasilenko I.F. Teorija rezhushchih apparatov zhatvennyh mashin. Trudy VISHOM. – Moscow: 1937, №5. – p.7-14. (In Russian language)

[5] Reznik N.E. Teorija rezanija lezvijem i osnovy raschota rezhushchih apparatov. – Moscow: Mashinostroenie, 1975. – 311 pp. (In Russian language)

[6] Bosoj E.S. Rezhushchie apparaty uborochnih mashin. Teorija i raschet. – Moscow: Mashinostroenie, 1967. – 167 pp. (In Russian language)

[7] Tatjanko N.V. Raschet rabochih organov dlja obrezky botvy saharnoj. Zhurnal “Traktory i selskohozjajstvennye mashiny”. – 1962, №11. – p. 18-21. (In Russian language)

[8] Hvostov V.A., Reingart E.S. Mashiny dlja uborky korneplodov i luka (teoria, konsrukcija, raschet). – Moscow: VISHOM, 1995. – 391 pp. (In Russian language)

[9] Bulgakov V.M., Siplyvec A.A. i dr. Razrabotka konstrukciji novoj universalnoj botvouborochnoj mashiny. – Sbornik nauchih trudov Nacionalnogo agrarnogo universiteta. Tom III, “Mehanizacija celskohozjajstvennogo proizvodstva”, Кiev, 1997. – С. 76–77. (In Ukrainien language).

[10] Bulgakov V.M. i dr. Sozdanie novogo universalnogo kompleksa sveklouborichnih mashin dlja fermerskih hozjajstv. – In a book: Problemy konstruirovanija, proizvodstva i eksploataciji selskohozjajstvennoj tehniky. Sbornik nauchnih trudov. Kirovograd: KISM, 1997. – p. 14–19. (In Ukrainien language)

[11] Bulgakov V.M. Sovershenstvovanie tehnologichekogo processa dlja uborky korneplodov svekly. Avtoreferat disserataciji – doctor tehn, nauk. Moscow: VISHOM, 1993. – 61 pp. (In Russian language)

[12] Bulgakov V.M. Sveklouborochnije mashiny. – Kiev: Agrarnja nauka, 2011. – 352 pp. (In Russian language)

Kontact:

Prof. Volodymyr Bulgakov, DrSc., akademician of the NAASU, National University of Life and Environmental Sciences of Ukraine, e:mail: vbulgakov@meta.ua.