# THEORETICAL DETERMINATION OF CUTTING FORCE OF THE SUGAR BEET TOPS FROM ROOT CROP HEAD

## ТЕОРЕТИЧЕСКОЕ ОПРЕДЕЛЕНИЕ СИЛЫ СЧЕСЫВАНИЯ БОТВЫ САХАРНОЙ СВЁКЛЫ С ГОЛОВКИ КОРНЕПЛОДА


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**Abstract:** *Beet tops harvesting is a complex task of the sugar beet growing industry which forms the qualitative indicators of root crops during their further digging out from the soil and determines the loss of tops and sugar-bearing mass. In the development of theoretical foundations of the optimal tops cutting from heads of sugar beet root by different types of topping working bodies should take into account forces which act at the same time and the rational cutting height. Theoretical researches having been carried out hitherto concerned only the detailed analytical description of the functioning of the new designs of topping working bodies and practically did not concern the general provisions of the separation tops from the head of root crop. The aim of this study is the theoretical determination of the forces that occur at the contact point of cutting working body of topper machines with root crops head of sugar beet root crop. When carrying out theoretical studies are used the methods of mathematics, theoretical mechanics, strength of materials, methods of programming and numerical calculations on PC. As a result, of the theoretical research new analytical dependencies of force describing the processes of crumpling and subsequently cutting of sugar beet heads by topping working body, depending on the size and shape of root crops heads and design parameters of topper have been obtained. As a result, of numerical calculations on PC critical level value of penetration of the cutting element of topping working body into root crops head of sugar beet and maximum value of cutting force at which ejection of root vegetables from the soil doesn't take place, was defined. The obtained theoretical dependencies and values of normal reaction and cutting forces are the basis for the further working out of a mathematical model of dynamic interaction system of cutting working bodies with the heads of sugar beet.*



***KEYWORDS**: ROOT CROP, BEET TOPS, HEAD OF ROOT, WORKING BODY, THEORY, CONTACT AREA, CUTTING FORCE*


### *1. Introduction*

Sugar beet is one of the strategic industrial crops in the world. Sugar, beet pulp and green mass of foliage are useful products for humans and animals as well as feedstock for biogas production. The most difficult process in the production of sugar beet is its harvesting. First operation of this of technological process is cutting of beet tops from root crops heads on a root. The quality of the beet tops cutting from root crops heads is directly affect other harvesting indicators – even a small amount of tops residues on the root crops heads during digging up significantly reduces quality indicators of sugar beet. Having been conducted earlier researches showed that a low-quality tops cutting can reduce the quality of sugar beet roots per 10 ... 15%. Therefore, cutting the tops from root crops heads of sugar beet is a relevant scientific and technical task for beet industry.

### *2. Preconditions and means for resolving the problem*

*2.1. Analysis of recent research and publications*

Such researchers as P.M. Vasilenko, L.V. Pogorelyiy, V.M. Bulgakov, P.V. Savich, N.V. Tatyanko et al. [1, 2, 3, 4] dedicated many works to the issues of theoretical and experimental research of beet tops separation from root crops heads.

*2.2. Purpose of the study*

Theoretical definition of the forces taking place at the point of contact of cutting working body of topper machines with a root crops head of sugar beet.

*2.3 Materials and Methods*

When carrying out theoretical studies methods of mathematics, theoretical mechanics, strength of materials, as well as methods of programming and numerical calculations on the PC was used.

#### *3. Results and discussion*

The equivalent scheme of interaction tops-cutting working body and head of sugar beet for carrying out theoretical studies was developed. Consider one of the most typical cases of such interaction when cutting working body penetrates by its front cutting edge into the upper part of the head of sugar beet. Let us represent sugar beet root as motionless object placed in the soil (Fig. 1). Upper part of root crops - the head is represented as a sphere of radius $r$, with a center in point $O$. Flat Cartesian coordinate system $xOy$ has been drawn across the point $O$ in where the axis $Oy$ is directed vertically upward and the axis $Ox$ is directed to the right. Sugar beet head starts interaction with cutting working body, represented as rectangular cross section, which moves translationally and penetrates into the body of the head of root crop. The front lower point of blade is denoted by $C$. Penetrated in the body of root crops head the cutting working body of rectangular shape has coordinates of its points $C$ in the above mentioned coordinate system, denoted by $x_c$ and $y_c$. Other dimensions characterizing interaction of sugar beet head and cutting working body are being denoted by $r_x$ and $r_y$.

According to the results of preliminary experimental studies it was found that during the interaction with the head of root crop, when topping leaves bunch, cutting working body moves at a relatively small value. Preliminary studies of the kinematics interaction of cutting working body with sugar beet have shown that blade of working body have slight displacement distance and its absolute velocity is also changes slightly. And therefore this curvilinear arcuate trajectory with a sufficient degree of accuracy, is possible to replace with a straight-line trajectory.

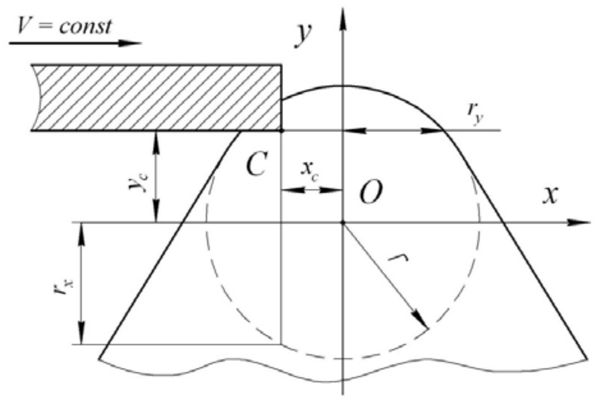


***Fig. 1.*** *The equivalent scheme of cutting working body interaction with head of sugar beet when tops cutting*

Taking into account these circumstances, the assumption has been made that cutting working body interacting with the head of root sugar beet moves in a straight line at a constant forward speed $V$ (Fig. 1) [6, 11, 12].

If at the initial moment of time, in this interaction, deformation of the upper layer of the head of root beet takes place then occurs crumpling. The increase of contact area of the front edge of the cutting working body with the root crop head after that takes place tension grows at a certain value of working body penetration into the root crop head body the final cut is carried out. Theoretically, this will happen when crumpling force exceeds cutting force of the rest of sugar beet root crop head, i.e. in compliance with such inequality:

$$P_s \geq P_c, \tag{1}$$

where: $P_s$ – crumpling force of the root crop head; $P_c$ – cutting force of the root crop head.

After that, let us determine the critical value of penetration of cutting working body in the root beet head and define its relationship with the values $P_s$ and $P_c$.

Crumpling force will be determined by the current contact area $F_s$ and permissible contact stresses of crumpling $[\sigma_s]$. For determine the crumpling force $P_s$ well known dependency was used [7]:

$$P_s = [\sigma_s] F_s. \tag{2}$$

The contact area is determined by the area of the segment formed by a circle of radius $r_x$ and the chord, which passes at a distance $y_c$ from the axis $Ox$ (Fig. 1):

$$F_s = \frac{r_x^2}{2}\left(\beta - \sin\beta\right). \tag{3}$$

where: $\beta$ – sector angle formed by the segment with $F_s$ area; $r_x$ – radius of the circle, which has been obtained by the intersection of the sphere of the head of root with plane, which passes through the contact edge of the working element.

Angle sector $\beta$ of crumpling area and circle radius $r_x$ in the crumpling plane is determined from equation [5, 8]:

$$\beta = 2\arccos\left(\frac{y_c}{r_x}\right), \tag{4}$$

and

$$r_x = \sqrt{r^2 - x_c^2}, \tag{5}$$

where: $r$ – sphere radius of the head of root beet.

Taking into account the value determined by (2 – 4), and on the basis of conducted algebraic transformations the dependence has been finally obtained for crumpling force $P_s$ on the penetration value $x_c$ of cutting working body into the body of the head and is represented in the following equation:

$$P_s = [\sigma_s]\left\{-\left(\frac{r^2}{2} - \frac{x_c^{\,2}}{2}\right)\left[\sin\left(2\arccos\left(\frac{y_c}{\sqrt{r^2 - x_c^2}}\right)\right)\right] - 2\arccos\left(\frac{y_c}{\sqrt{r^2 - x_c^2}}\right)\right\}. \tag{6}$$

Cutting force $P_c$ of root crops head is determined by the cuts area $F_c$ and permissible cutting force $[\tau]$ root beet head and it is equal to [7]:

$$P_c = [\tau] F_c. \tag{7}$$

Area cut $F_c$ of root crops head is defined as the difference area of the circles formed by the intersection of the sphere by the cut plane and area of segment formed by radius $r_y$ and chord, which passes at a distance $x_c$ from the axis $Oy$ (Fig. 1). We have:

$$F_c = \pi r_y^2 - \frac{r_y^2}{2}\left(\gamma - \sin\gamma\right), \tag{8}$$

where: $\gamma$ – sector angle formed by a segment of area $F_c$.

The angle $\gamma$ and radius $r_y$ are defined by following equation (4) and (5):

$$\gamma = 2\arccos\left(\frac{x_c}{r_y}\right), \tag{9}$$

and

$$r_y = \sqrt{r^2 - y_c^2}, \tag{10}$$

Taking into account the value determined by (8 – 10), and on the basis of conducted algebraic transformations the dependence of crumpling force $P_s$ on the penetration value $x_c$ of cutting working body into the body of the head of sugar beet has been finally obtained (Fig. 1).:

$$P_{ç\eth} = [\tau]\left\{-\left(\frac{r^2}{2} - \frac{y_c^{\,2}}{2}\right)\left[\sin\left(2\arccos\left(\frac{x_c}{\sqrt{r^2 - y_c^2}}\right)\right) - 2\arccos\left(\frac{x_c}{\sqrt{r^2 - y_c^2}}\right)\right] + \pi\left(r^2 - y^2\right)\right\}. \tag{11}$$

Substituting the value of expressions (6) and (7) in the inequality (2) it is possible to determine the critical penetration value $x_c$ under root crops head cutting.

Thanks to the developed program for the PC the numerical calculations have been carried out and the graphics solutions of inequality obtained (2), taking into account the equation (6) and (11) are shown in Fig. 2 and Fig. 3.

The following values of initial parameters in the calculations were adopted: $[\tau]$ = 1.14 MPa [10], $[\sigma_s]$ = 3.0 MPa [9, 14, 15], $r$ = 0.025 m, $y_c$ = 0.015…0.025 m.

As can be seen from the obtained graphical dependences (Fig. 2) maximum cutting force $P_c$ will be determined by the maximum value of crumpling force $P_s$ of root crops head. The cutting force $P_c$ will be equal to crumpling force $P_s$ at the cutting height of root crops head being equal to 10 mm. At the same time cutting force equals to 820 N that is much higher than the permissible stability force of root sugar beet in the soil (Fig. 2). Obviously, the height difference $\Delta h$ of contiguous working elements of cutting working body should not exceed 4 mm. The parameter value of kinematic coupling between the cutting working bodies $\Delta\varphi = 2°$ is being determined on this condition basis. Thus, for further calculations is possible to accept the maximum cutting force $Q$ = 200 N.

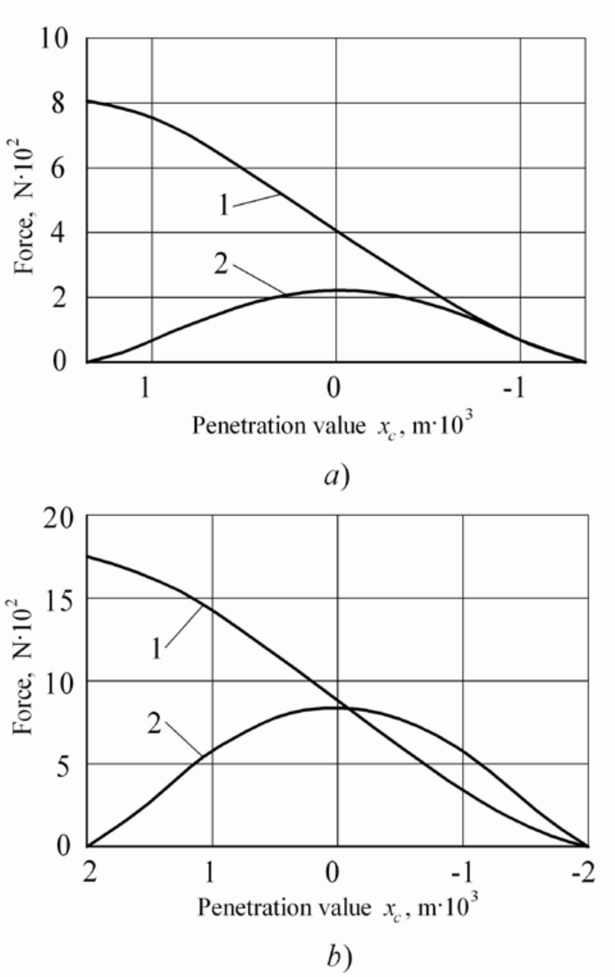


Fig. 2. Dependencies: 1 – cutting force $P_c$ and 2 – crumpling force $P_s$ from
height of cut $\Delta h$ and the value of penetration $x_c$ into the root crop head body:
*a*) $\Delta h$ = 0,004 m; *b*) $\Delta h$ = 0,01 m

Using the obtained dependencies (Fig. 2) the graphs of the total maximum crumpling force $P_s$ of sugar beet head from the cutting height $\Delta h$ have been worked out (Fig. 3). Thus in Fig. 3 the permissible crumpling force $P_s$ is shown.

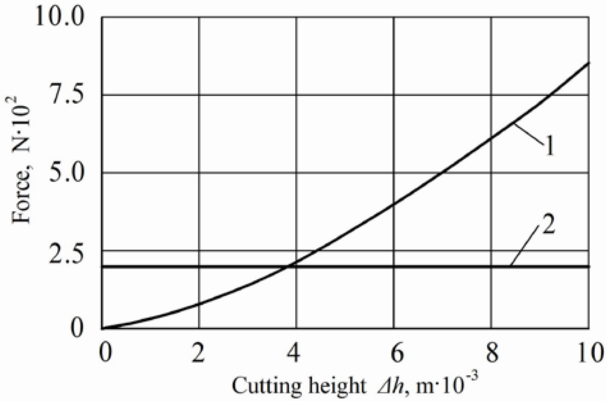


Fig. 3. Dependence of the total maximum force from the cutting height $\Delta h$:
1 – root crop head crumpling $P_s$; 2 – tops detachment from the root crop head

Analysis of the graphical dependencies (Fig. 3) shows that the maximum crumpling force $P_s$ can be reached on the height of cut not more than 4 mm.

## 4. Conclusion

1. New analytical equations that describe the processes of crumpling and the subsequent cut of root crops head of sugar beets then separating the tops were defined.
2. Critical value of the penetration of the cutting part of topping working body in the root head, when there is no ejection of sugar beet out of the soil was found. Numerical calculations carried out on a PC enabled to determine its value $\Delta h$ = 4 mm.
3. Maximum value of the cutting force Q equal to 200 N, was determined.
4. The obtained theoretical dependencies and values of normal reaction and cutting force *Q* are the basis for the further working out mathematical model of dynamic interaction system of cutting working bodies with sugar beet heads.

## 5. Literature


1. Bulgakov V.M. Teoriya sveklouborochnyih mashin. Monografiya / V.M. Bulgakov. – Kiev: Izdatelskiy tsentr NAU, 2005. – 245 s.
2. Vasilenko P.M. Osnovyi nauchnyih issledovaniy (Mehanizatsiya selskohozyaystvennogo proizvodstva) / P.M. Vasilenko, L.V Pogorelyiy. – Kiev: Vyisshaya shkola, 1984. – 266 s.
3. Vasilenko A.A. Kompleksnaya mehanizatsiya proizvodstva saharnoy sveklyi / A.A. Vasilenko, P.T. Babiy, P.V. Savich i dr. – Kiev: Selhozobrazovanie, 1962. – 243 s.
4. Pogorelyiy L.V. Svekloborochnyie mashinyi: istoriya, konstruktsiya, teoriya, prognoz / L.V. Pogorelyiy, N. V. Tatyanko. – K.: Feniks, 2004. – 232 s.
5. Filchakov P.F. Spravochnik po vyisshey matematike / P.F. Filchakov. – Kiev: Nauchnaya myisl, 1974. – 743 s.
6. Targ S.M. Kratkiy kurs teoreticheskoy mehaniki: uchebnik dlya vyisshih tehnicheskih zavedennyiy / S.M. Targ. – Moskva: Vyisshaya shkola, 1986. – 416 s.
7. Pisarenko G.S. Spravochnik po soprotivleniyu materialov / G.S. Pisarenko, A.P. Yakovlev, V.V. Matveev. – Kiev: Nauchnaya myisl, 1975. – 704 s.
8. Vodnev V.T. Osnovnyie matematicheskie formulyi / V.T. Vodnev, A.F. Naumovich, N.F. Naumovich. – Minsk: Vyisshaya shkola, 1988. – 255 c.
9. Helemendik N.M. Povyishenie mehaniko-tehnologicheskoy effektivnosti trudoemkih protsessov v sveklovodstve: avtoref. dis. na poluchenie nauch. stepeni dokt. tehn. nauk.: spets. 05.20.01 / N.M. Helemendik. – Ternopol: TPI, 1996. – 48 s.
10. Helemendik N.M. Issledovanie tehnologicheskogo protsessa i rabochih organov dlya uborki saharnoy sveklyi v usloviyah Zapadnoy Stepi USSR: Diss. kand. tehn. nauk: 05.410 / N.M. Helemendik. – Voronezh: SHI, 1968. – 31 s.
11. Bat M.I. Teoreticheskaya mehanika v primerah i zadachah: uchebnoe posobie / M.I. Bat, G.Yu. Dzhanilidze, A.S. Kelzon. – Moskva: Nauka, 1973. – 488 s.
12. Butenin N.V. Kurs teoreticheskoy mehaniki. Tom 2 / N.V. Butenin , Ya.L. Lunts , D.R. Merkin. – Moskva: Nauka, 1985. – 496 s.
13. VISHOM. Fiziko-mehanicheskie svoystva rasteniy, pochv i udobreniy: metodyi issledovaniya, priboryi, harakteristiki. – Moskva: Kolos, 1970. – 417 s.
14. Vovk P.F. Agrofizicheskie svoystva korney saharnoy sveklyi v svyazi s mehanizatsiey uborki / P.F. Vovk // V sbornike: Teoriya, konstruktsiya i proizvodstvo selskohozyaystvennyih mashin. Tom 2. – Leningrad: Selhozizdatelstvo, 1936. – S. 269-284.
15. Tsarenko O.M. Mehaniko-tehnologicheskie svoystva selskohozyaystvennyih materialov: praktikum / O.M. Tsarenko, S.S. Yatsun i dr. – K.: Agrarnoe obrazovanie, 2000. – 93 s.
16. Lammers P.-S. Harvest quality of six-row sugar beet tanker harvesters / P.-S. Lammers, M. Rose // Landtechnik. – 2005. – №60., H. 5. – P. 252-253.
17. Huijbregts T. Long-term storage of sugar beet in North-West Europe / T. Huijbregts, G. Legrand et al. // COBRI report. – 2013. – №1. – 54 p.
18. Przybył J. Method of external assessment of the quality of sugar beet roots / J. Przybył et al. // Agricultural engineering. – 2013. – Z. 4., T. 2. – P. 113-125.