RESEARCH THE FORCE PARAMETERS OF FORMING THE SCREW CLEANING ELEMENTS
/
ДОСЛІДЖЕННЯ СИЛОВИХ ПАРАМЕТРІВ ФОРМОУТВОРЕННЯ ГВИНТОВИХ ОЧИСНИХ ЕЛЕМЕНТІВ

Prof. Ph.D. Eng. Hevko Iv.B., Lect. Ph.D. Eng. Dychun A.Y., Prof. Ph.D. Eng. Lyashuk O.L., Ph.D. Eng. Martsenko, Eng.Gypka A.B.
Ternopil Ivan Pul'uj National Technical University, Ruska Str., 56, Ternopil, Ukraine
E-mail: gypkab@gmail.com

Keywords: *digger's disk, auger cleaner, Г-shaped, cleaning.*

ABSTRACT
In this article the results of theoretical research of power parameters while forming the deflected outer contour of acrew workpiece are analysed in this article. The design of disk digger for cleaning the disks' working surfaces isworked out. The advances of Г-shaped auger cleanersare substantiated. The power and kinematic computationof the suggested auger cleaners of disk digger of rootcrops is carried out.

РЕЗЮМЕ
У даній роботі викладенно результати теоретичних досліджень силових параметрів при формоутворенні відігнутого зовнішнього контура на гвинтовій заготовці. Розроблено конструкцію дискового копача із можливістю очищення робочих поверхонь дисків. Проаналізовано й обґрунтовано вибір Г–подібних шнекових очисників. Проведено силовий і кінематичний розрахунок запропонованих шнекових очисників дискових копачів коренеплодів.

INTRODUCTION
Г-shaped augers' spirals can be widely used in transport and technological systems in the future. Nowadays such spirals are used to supply dry, wet, sticky, lumpy, fibrous products in agriculture, and food, building, chemical and other industries, etc. However, they possess additional qualities that, depending on the inclination of the spiral, can manifest themselves as the functions of increasing the resistance of transporting the materials to the surface of displacement, or vice versa - reducing the friction of transported material to the surface of displacement. In the first case, this phenomenon can be widely used in wiping or shredding different materials, and in the second - in separating and pruning various materials from the surface displacement.

Grigoriev A.M. Preobrejenskiy P.A., 1967, Hevko B.M.,1986, Loveikin V., 2012, and others investigated the procces of creating and operating the screw mechanisms; their works are dedicated to the issue of efficiency of auger conveyors. *Pylypets M.I., 2002*, *Hevko R.B., 2013,* and others researched the process of separating the root chaff. *Rohatynskiy R.M., 1997* and other scientists researched the process of profiling screw spirals as well as the process of transportation by means of *Г*-shaped augers.

MATERIAL AND METHOD
The objective of this research is the designing of auger cleaner for efficient cleaning the disk diggers of root crops from contamination. The usage of such cleaner will reduce power consumption during the mechanism's operation and improve the quality of cleaning root crops.

The process of digging the roots is accompanied by significant soil and chaff sticking to the surfaces of disk diggers. The digging devices are equipped with Г-shaped spiral augers, which allow to clean them efficiently. The process of cleaning is accompanied by removing the chaff by the spiral from the working surface of the disk digger. Under such conditions the angle of inclination μ of screw spiral in its cross section influences much the force, which is necessary to overcome the resistance of material transportation (Fig. 1). Terefore, the usage of the spiral with inclined outer contour in direction of transportation is the most efficient one, because the vector of normal force between the coil and casing $\bar{N}_1$, acting on the product from the side of the coil, is directed from the tangent to the casing at an angle *γ1*.

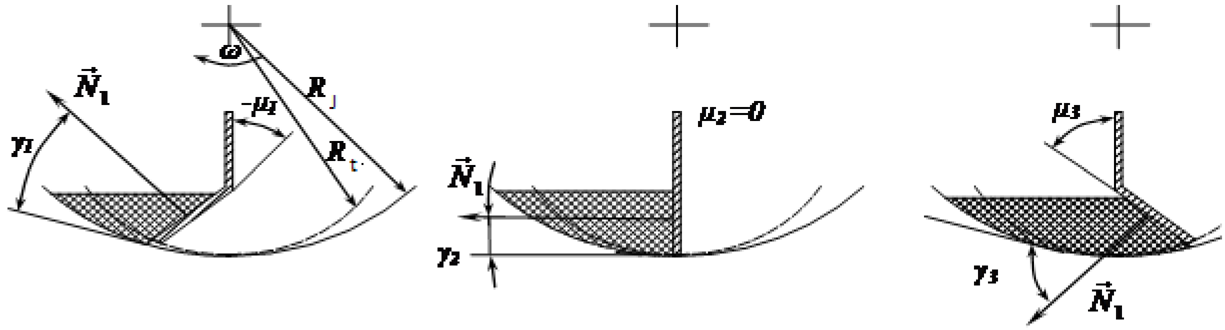

Fig.1 - Estimated circuit for determining the effect of slope angle helical tape in cross-section of the process jamming material
a) spiral slope in the direction of transportation; b) radial spiral; c) the slope of the spiral in the opposite direction to the direction of transport

Investigating the force parameters of forming the screw purifying elements
The process of manufacturing the screw purifying elements is as follows:
1. Bending the shelf on a tape using the rollers.
2. Coiling the given tape with a shelf around a collet.

The process of coiling such a tape around the collet is shown in Fig.2.

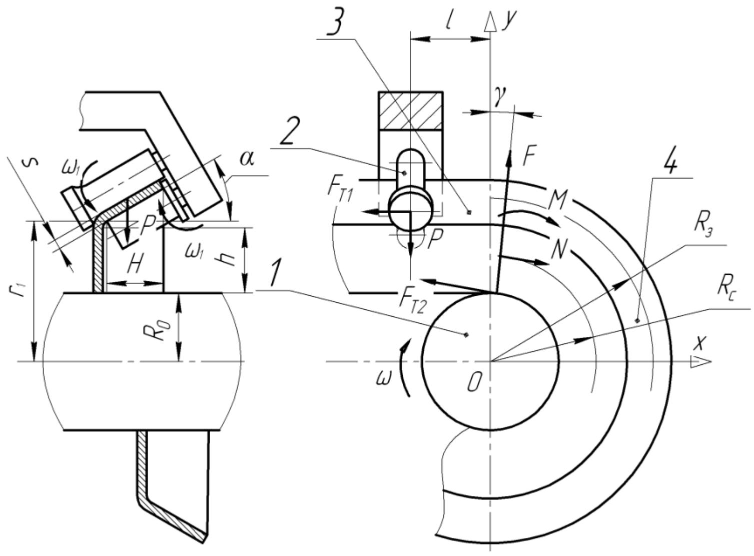

Fig.2 - Computational model of coiling the tape around the collet
1 – collet; 2 – clamp roller; 3 – tape; 4 – screw element

While coiling, the compression of tape fibers along the inner diameter occurs, as well as the tension of tape fibers along the outer diameter of the screw-purifying element (*Pylypets M.I., 2002*) . That is, in the shelf's zone, only the strain deformations occur, as well as in the workpiece's vertical part − the compressive deformations (*Hewko B. M., 1989, Rohatynskyi P.M., and others 2014).* Having considered the process of deformation in the hot state, the moment of tape bending in these zones can be defined.

As it is known, the radial stresses, occurring in the tape shelf, are determined by the formula *(Zubtsov M.E. 1980):*

$$\sigma_{\rho 1} = -\beta\sigma_s \cdot \ln\frac{R}{\rho} \tag{1}$$

Where:

β – the coefficient, which depends on the impact of the mean primary stress, equals 1.15;

σ_s – the liquid limit of screw clamping element material, MPa;

R – the outer bending radius, mm;

ρ – the polar coordinate of bending radius, mm.

Similarly, the radial stresses in the compression zone can be determined *(Rohatynskyi P.M., and others 2014, Aleksey Popov, 2010):*

$$\sigma_{\rho 2} = -\beta\sigma_s \cdot \ln\frac{\rho}{r}, \tag{2}$$

where r – the inner bending radius, mm.

Tangential stresses in the tension zone:

$$\sigma_{\theta 1} = \beta\sigma_s \cdot \left(1 - \ln\frac{R}{\rho}\right) \tag{3}$$

Tangential stresses in the compression zone:

$$\sigma_{\theta 2} = -\beta\sigma_s \cdot \left(1 + \ln\frac{\rho}{r}\right) \tag{4}$$

According to the computational model in Fig.1, the radius of bending the workpiece's shelf changes from r_1 to $r(x)$, where

$$r(x) = r_1 + x \cdot \mathrm{tg}\,\alpha \tag{5}$$

where

r_1 – the smallest inner radius of bending the shelf, mm;

α - the inclination angle of the shelf, grade.

The outer radius of bending the workpiece:

$$R(x) = r_1 + \frac{s}{\cos\alpha} + x \cdot tg\alpha, \tag{6}$$

where s – the tape thickness, mm.

The value of bending moment while coiling with heating is considered as the integral sum from tangential stresses along the height of elementary elements' workpiece.

$$M = \int_0^H \int_{r(x)}^{R(x)} \sigma_{\theta 1}\rho d\rho dx + s\int_{R_0}^{R_0+h} \sigma_{\theta 2}\rho d\rho, \tag{7}$$

where:

ρ_H - the radius of neutral surface of stresses, mm;

h – the height of the workpiece's vertical part, mm;

H – the height of the screw element's shelf, mm.

Using formulas (3) – (6) in the equation (7) we obtain:

$$M = \int_0^H \int_{r_1 + x\cdot tg\alpha}^{r_1 + \frac{s}{\cos\alpha} + x\cdot tg\alpha} \beta\sigma_s \cdot \left(1 - \ln\frac{r_1 + \frac{s}{\cos\alpha} + x\cdot tg\alpha}{\rho}\right) \cdot \rho d\rho dx + s\int_{R_0}^{R_0+h} -\beta\sigma_s \cdot \left(1 + \ln\frac{\rho}{R_0}\right)\rho d\rho \tag{8}$$

where R_0 - the collet radius, mm.

Having transformed the equation (8), we obtain:

$$M = \frac{1}{2}\cdot\beta\cdot\sigma_s([bH\left(r_1 + \frac{1}{2}b + Htg\alpha\right) + \frac{H}{3}(H\cdot tg\alpha\cdot\left(-r_1 D + tg\alpha KH + \frac{1}{2}b + 3r_1 K - Dtg\alpha H\right) +$$
$$+3r_1^2(K-D) - b(b+r_1)) + \frac{r_1^3(K - D - C + \ln r_1) + b^3(K-C) + r_1 b^2}{tg\alpha}] + s(-\frac{1}{2}((R_0+h)^2 - R_0^2) - (R_0+h)^2\ln\left(\frac{R_0+h}{R_0}\right))), \tag{9}$$

where the following marks are used:

$$b = \frac{s}{\cos\alpha};\ K = \ln(r_1 + b + Htg\alpha);\ C = \ln(r_1 + b);\ D = \ln(r_1 + Htg\alpha)$$

According to the computational model in fig.1, the equilibrium equation of a tape part under deformation can be written as follows:

$$\left.\begin{array}{r}\text{axis x: } -F_{T1}-F_{T2}\cdot\cos\gamma+N\cdot\cos\gamma+F\cdot\sin\gamma=0;\\ \text{axis y: } -P+F_{T2}\cdot\sin\gamma-N\cdot\sin\gamma+F\cdot\cos\gamma=0;\\ \text{sum of points: } P\cdot l+F_{T1}\cdot R_з+F_{T2}\cdot R_0-N\cdot R_c-M=0,\end{array}\right\} \quad (10)$$

Where:

F_{T1}- friction force between the tape and the roller,

N; F_{T2} - friction force between the tape and the collet,

N; γ - collet's turning angle, grd.; N - direct force, N;

F- resultant force of the tape normal contact stresses, N;

P-the bending force by the clamp roller, N;

l -distance between the collet centre and the clamp roller centre, mm;

R_3- mean radius of screw element's interaction, mm;

R_c- mean radius of screw element, mm.

The friction forces can be developed from the dependences:

$$F_{T1}=\mu_1\cdot P; \quad (11)$$

$$F_{T2}=\mu_2\cdot F, \quad (12)$$

Where:

μ_1 - the coefficient of friction between the clamp roller and the tape;

μ_2 - the coefficient of friction between the collet and the crew element.

The resultant force of normal contact stresses is determined by the formula:

$$F=\sigma_r\cdot s\cdot L, \quad (13)$$

Where:

σ_r - the contact normal stresses along the screw workpiece's inner radius, MPa;

S - the tape thickness, mm; L - length of contact along the inner diameter, mm.

Provided the bending moment M is known, all forces, which occur while coiling, can be found after solving the equation system (7). In the given case:

$$F=\frac{-P\cdot\left(\mu_1\cdot tg\gamma-1\right)}{\mu_2\cdot\sin\gamma+tg\gamma\cdot\left(-\mu_2\cdot\cos\gamma+\sin\gamma\right)+\cos\gamma} \quad (14)$$

$$N=\frac{\mu_1\cdot P+F\cdot\left(\mu_2\cdot\cos\gamma+\sin\gamma\right)}{\cos\gamma} \quad (15)$$

According to the results of experimental research, the maximum bending force P by clamp roller occurs at the beginning stage of deformation, that is, when the angle γ equals zero. Therefore, to simplify calculations, the solution of equations system (10) will be as follows:

$$P=F \quad (16)$$

$$N=\left(\mu_1+\mu_2\right)\cdot P; \quad (17)$$

$$P=\frac{M}{l+\mu_1\cdot(R_з-1)+\mu_2\cdot\left(R_0-1\right)} \quad (18)$$

It should be noted that the friction coefficient μ_1 between the clamp roller and the profiled tape is the given value and does not correlate directly with the value of contacting materials' friction coefficient. The moment applied to coining the collet depends on collets' structural peculiarities, and is generally defined as it is shown in Fig. 1., accordingly to the dependences:

$$M_O=k_M\cdot P\cdot\left(l+\mu_1\cdot R_з\right) \quad (19)$$

where k_M – the coefficient, which depends on the structural manufacture of the collet.

Based on the proposed above formulas, the required technological equipment can be designed. Thus, to reduce the torque of collet, and consequently to reduce the required power of coiling the screw workpiece, it is necessary to minimize friction coefficient μ_1, for example, using the lubricants.

The coiling of a screw element being executed in the cold state, the workpiece material is being strengthened consequently, the bending moment increases, which can be determined by the formula:

$$M=\int_{0}^{H}\int_{r_1+x\cdot tg\alpha}^{r_1+\frac{s}{\cos\alpha}+x\cdot tg\alpha}\beta\left[\begin{array}{l}\sigma_{TO}\cdot\left(1-\ln\dfrac{r_1+\dfrac{s}{\cos\alpha}+x\cdot tg\alpha}{\rho}\right)+\\ +\dfrac{\Pi}{2}\cdot\left(2\ln\dfrac{\rho}{R_c}-\ln\dfrac{\rho\left(r_1+\dfrac{s}{\cos\alpha}+x\cdot tg\alpha\right)}{R_c^2}\ln\dfrac{\left(r_1+\dfrac{s}{\cos\alpha}+x\cdot tg\alpha\right)}{\rho}\right)\end{array}\right]\cdot\rho d\rho dx+s\beta\int_{R_0}^{R_0+h}\left[\sigma_{TO}\left(1+\ln\frac{\rho}{R_0}\right)+\frac{\Pi}{2}\left(2\ln\frac{R_0+h}{\rho}+\ln\frac{(R_0+h)^2}{\rho R_0}\ln\frac{\rho}{R_0}\right)\right]\rho d\rho, \quad (20)$$

where

$\sigma_{T.O}$ - extrapolated liquid limit, MPa;

Π - strengthening linear module, MPa.

RESULTS

The analytical method of solving the equation (20) is rather cumbersome, that is why the specific numerical value of bending moment should be defined by the numerical method, using appropriate software. Such method significantly reduces the calculation time.

An example of such calculation is shown in the graph in Fig. 3.

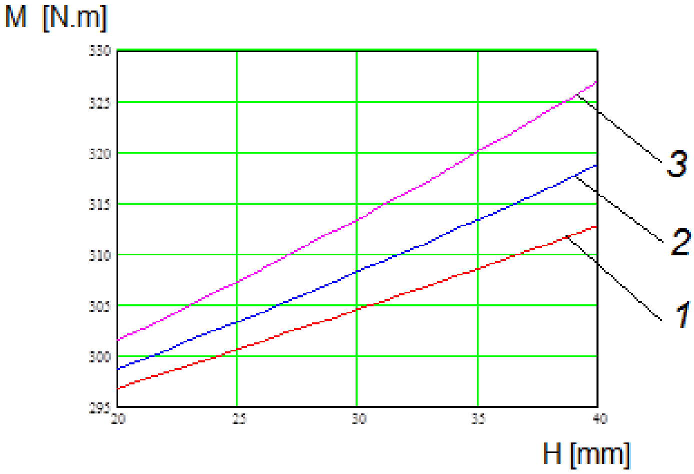

Fig.3 - Graph of dependence of tape bending moment on height shelf (steel 08kP)

s=1,5 mm, R_0=30 mm: 1 - $\alpha=10^0$, 2 - $\alpha=20^0$; 3 - $\alpha=30^0$

Analyzing the graph in Fig.2 we conclude: the shelf height and its inclination angle increases, the moment of bending the screw element increases as well.

Based on the graph in Fig.3 and formula (18), the graphs of dependence of the tape bending force on the shelf height can be drawn (Fig.3).

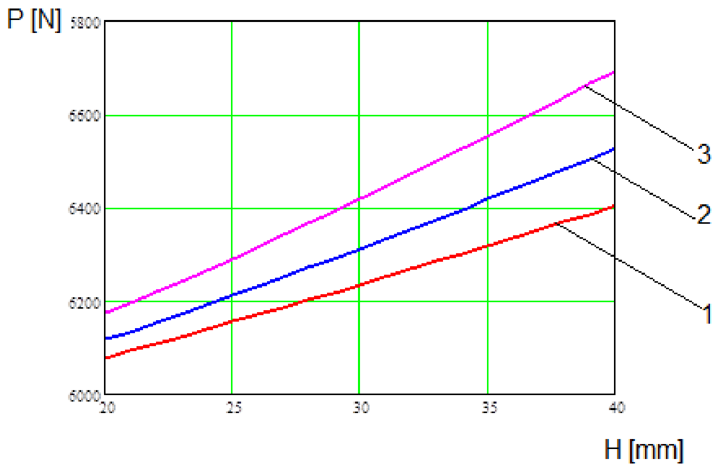

Fig.4 - Graph of dependence of the tape bending force on the shelf height (steel 08kp)

s=1,5 mm, R_0=30 mm: 1 - $\alpha=10^0$, 2 - $\alpha=20^0$; 3 - $\alpha=30^0$.

According to the results theoretical research and having analyzed the graphs in figures 2 and 3, we conclude that mainly the vertical part of the workpiece deforms; and while increasing the shelf height and the inclination angle of the screw element, the bending force increases as well. As the main working surface of a screw-purifying element is a shelf, the cuts on the vertical part of the tape must be performed to reduce the bending moment of such tape.

CONCLUSIONS

Based on the analysis of the patent search screw constructions and working bodies of the literature from the definition mode of operation of the proposed new design screw with curved outer contour

As a result of investigations proved the practical feasibility of the proposed mechanism for clearing L-shaped spirals screw drives root crop working surfaces

The proposed treatment technology manufacturing screw elements by bending the tape on shelves using clips and coiling the resulting tape with a shelf to be set.

The results can be used for designing different types of screw working bodies with curved working surfaces based on the rheological of properties of such screws when transporting bulk materials.

REFERENCES

[1] Aleksey Popov, (2010), The new theory of elastic contact strength of compressed bodies (Новая теория контактной прочности упруго сжатых тел), MOTROL, *Commission of Motorization and Power Industry in Agriculture Polish Academy of Sciences* Branch of Lublin Ropczyce School of Engineering and Management, Vol. 12A, pp. 223-232, Lublin;

[2] Grigoriev A.M., Preobrejenskiy P.A., (1967), *Complex mechanization and automation of cargo handling and transport operations in engineering and instrument (Комплексна механізація і автоматизація вантажорозвантажувальних і транспортних робіт в машинобудуванні і приладобудуванні)*, Naukova Dumka, p.116;Hevko B.M., (1986), *Manufacturing technology spiral auger (Технология изготовления спиралей шнеков)*, High school, p.128, Lviv;

[3] Hewko B. M., (1989), – Screw falling mechanisms of agricultural machinery (Винтовые подающие механизмы сельскохозяйственных машин), Higher school, p. 176, Lviv;

[4] Hevko R.B., Klendiy O.M. (2013), Methodology of investigation of a screw conveyer with a safety device (Методика проведення досліджень шнекового транспортера із запобіжним пристроєм.) *Agricultural Machinery: Scientific works*, No.24, Edition of Lutsk NTU, pp. 67-75., Lutsk;

[5] Loveikin V., Chovniuk Yu., Kulyk V. (2012), Optimizatsiia rezhimov kolebanii zernovykh smesei pri nalichii sukhogo treniia. Motrol – *Motoryzacja I energetyka rolnictva,* Vol. 14, v3, 140-149, Lublin;

[6] Pylypets M.I., (2002), *Scientifically and technological bases of production coiling machine parts billet*: Author. PhD.Thesis Engineering Sciences specials (Науково-технологічні основи виробництва навивних заготовок деталей машин : автореф. дис. на здобуття наук. ступеня доктора техн. наук), p.35, Lviv;

[7] Rohatynskyi P.M., and others (2014), *Scientific and applied backgrounds of creating the screw transport and technological mechanisms (Науково-прикладні основи створення гвинтових транспортно-технологічних механізмів)*, TNTU, p. 278, Ternopil;

[8] Rohatynskyi R. M., (1997), *Mechanical and technological backgrounds of interaction of screw working bodies with agricultural raw materials*, Thesis of Doctor of Sciences (Engineering)/ Rohatynskyi Roman Mykhailovych (Механіко-технологічні основи взаємодії шнекових робочих органів з сировиною сільськогосподарського виробництва : дис. докт. техн. наук), p. 502, Kyiv;

[9] Volkov R .A., Gnutov A. N., Diachkov V. K. and others, (1984), Conveyors (Конвейеры): Guide – under the editionship of Y.A. Perten, *Mechanical engineering,* p. 367, Leningrad;

[10] Zubtsov M.E., (1980), Sheet metal stamping (Листовая штамповка), *Machine building*, p.432. Leningrad;

[11] *** All Union State Standards Augers for agricultural machinery, (1973), AUSS 2705-73, Standards publisher, p.16, (National standards of Ukraine).