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Estimation of parameters and operating modes of the screw cutting device

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Estimation of parameters and operating modes of the screw cutting device

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Abstract. The research is directed from the theoretical aspect to the development of the design of a new grinder, characterized by low energy and metal consumption. The work investigates the relationship of geometric parameters and speed modes of operation with quantitative and qualitative indicators of the screw cutter system. It is possible to increase the degree of chopping of the stems only by reducing the average cut length, i.e. by increasing the rotational speed screw knife. The experiments shows the average slice lengths and the corresponding productivity of the screw cutting pair depending on the speed of rotation of the knife. That for compliance with zootechnical requirements, modes n= 550-650 rpm.(l_{av} = 8-4,5 sm) - with vertical loading, and n= 400-450rpm (l_{av} = 5,5-4 sm) – at inclined feed at an angle β = 450. An increase in the frequency of rotation of the knife leads to a sharp decrease in the productivity of the cutting pair. The above numerical examples are selected in accordance with the parameters of the experimental setup and show good agreement with the experimental results.

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1. Introduction

For grinding roughage, the industry produces various machines and feed preparation units. However, most of them do not provide the degree of grinding, regulated by the zootechnical requirements, and have a very high energy consumption of the process, and the machines are material-intensive and dimensional. In addition, many shredders are not easy to use and are not reliable enough. A significant disadvantage of shredders is their high cost, which makes it impossible to use a number of machines in personal subsidiary and farms. Therefore, the development of a shredder that would be suitable for farms with different livestock in terms of productivity, energy intensity of the process and quality of work is an urgent task that requires a scientific approach.

Many of our and foreign scientists have made a significant contribution to the study of the processes of grinding stalk feed in agricultural production: V.P. Goryachkin, V.A. Zheligovsky, N.E. Reznik, S.V. Melnikov, V.R. Aleshkin, Bremer G.I., Braginets N.V., Budashov I.A., Vertiy A.A., Volkov I.F., S.F. Volvak, Demchenko V.N., K.Astanakulov and many others [1-3].

From the analysis of literary sources, sliding cutting is the most promising for grinding coarse stalked fodder. Since this type of grinding, implemented in efficient drum grinders, does not require the use of complex working bodies and allows to reduce the energy consumption of the grinding process due to the rational distribution of forces acting on the crushed stems. In addition, the design of the working bodies providing sliding cutting allows to reduce the material consumption of drum shredders [4-6].

It is of interest to use a screw cutterbar as a chopper for coarse and succulent feed. Currently, there are known works in which the theoretical aspects of screw cutters are considered in relation to field harvesting machines.

The beginning of serious development of theoretical foundations for calculating the main parameters and operating modes of screw devices for harvesting grain cereals was laid by V.A. Selivanov (Volgograd Agricultural Institute). With regard to rough-stemmed crops, the works of Sakharov VV, Turaev T., Alijanov D. (TIIAME) and others are of interest [6-9]. Also known are the works of a number of authors in relation to coarse-stemmed (reed), thin-stemmed crops (grasses, soybeans) and concentrated feeds etc [10-15].

The screw cutter device, having the advantages of rotary and segment-finger devices, makes it possible to reduce energy consumption by more than six times on continuous crops of fine-fiber crops, and 2-3 times on row crops of coarse-stemmed crops. The cutterbar can be used at theoretically unlimited forward speeds. The above design and technological advantages of the screw cutter-grinder in comparison with existing machines determine the relevance of research.

The research is directed from the theoretical aspect to the development of the design of a new grinder, characterized by low energy and metal consumption.

2. Methods

The screw grinder of coarse-stemmed crops consists of a screw 1, a screw knife 2, feeding the neck 3 with a counter plate 4 (Figure 1). The stems are fed into the feeding throat and, under the action of gravity, fall into the solution of the cutting pair, are brought with a screw knife to the counter part and cut.

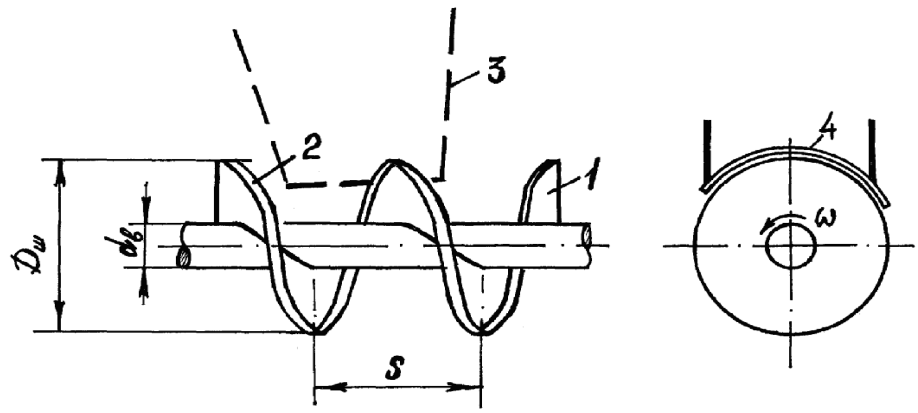

Figure 1. Screw grinder diagram

The time of movement of the screw knife at the moment of entry into the feed neck (point A, Figure 2) until the moment of exit (point C), provided S≥L and S = const, is also the cutting time for one turn of the screw knife, and at S≥ D is determined by the angle of rotation of the knife

$\alpha = 2\arcsin\frac{S}{D}$ and time $t_{\text{cut}} = \frac{L}{S} * \frac{n}{60}$,

here n is the frequency of rotation of the knife, rpm.

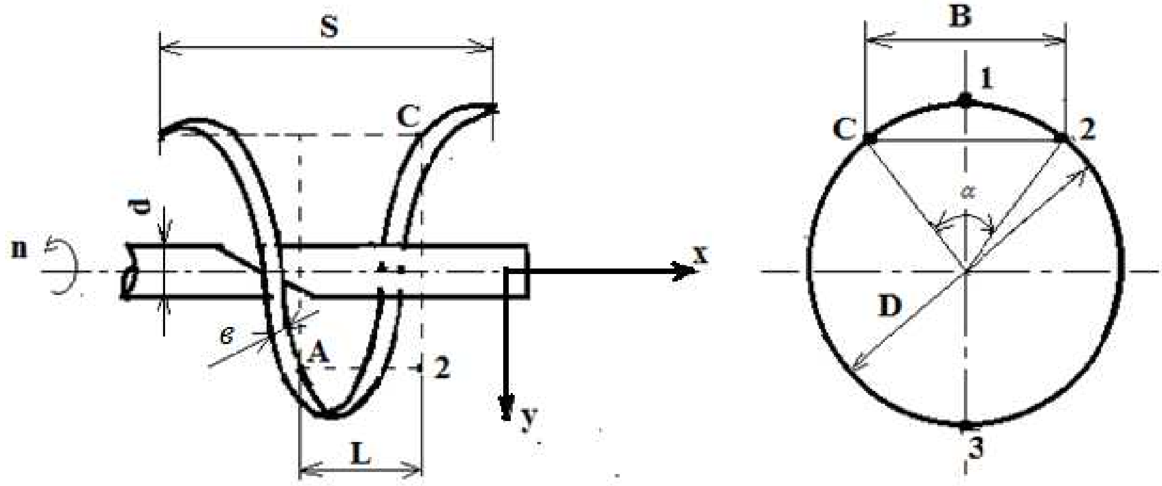

Figure 2. Diagram of a screw cutting pair to determine the main parameters and operating modes

Helical knives with variable pitch $S \neq const$, i.e. with $S = f(x)$ - as a function of axial movement, can be used to change the amount of sliding cutting within the permissible angle of pinching of the stem in the cutting pair.

With gravitational vertical feeding of the stem material, the possible amount of stem submersion is determined depending on the width of the loading window "B" and is determined from the expression

$$l = D * \cos\frac{\alpha}{2} = D * \cos(\arcsin\frac{B}{D}) \quad (1)$$

where D- is the diameter of the screw knife,
B- is the width of the feed neck.

With B = D, α = 0, we obtain the maximum immersion value l_{max} = D, and with α = π l_{min} = 0.

In the free fall of the body, we have $\frac{d^2y}{dt^2} = q, \quad \frac{dy}{dt} = qt + v_0, \quad y = \frac{qt^2}{2} + v_0 t$,
and when the stem moves into the feeding throat with an initial speed
v_0 = 0, then the stem immersion time $t = \sqrt{\frac{2y}{q}}$, a through the immersion length

$$t = \sqrt{\frac{2l}{q}} = [2\frac{D}{q} * \cos(\arcsin\frac{B}{D})]^{1/2} \quad (2)$$

From (2) we get $t_{max} = \sqrt{\frac{2D}{q}}$, t_{min} = 0. In this case, the time of one revolution of the screw knife can be trev≥tmax or trev <tmax . In the first case, the height of the cut stems is determined by equation (1).

For example, with D = 0.4 m (experimental setup) $t_{max} = \sqrt{\frac{2*0,4}{9,8}} = 0,3\ s$,

we get the rotational speed of the screw knife n=$\frac{60}{0,3} = 200 rpm$, and the average length of the stem segments will be the maximum possible for any width of the loading window within B ≤ D. When B =

D, i.e. at $\frac{\alpha}{2} = 90^0$, the average length of the cut off particles of the stem lav = 31.4 sm, and at B <D, for example, at $\frac{\alpha}{2} = 60^0$ we get

$$l_{\text{av max}} = \frac{R}{\sin{\alpha/2}}\left(\frac{\pi}{3} + \sin{\alpha/2} * \cos{\alpha/2}\right) = 34{,}41sm.$$

A further decrease in the rotational speed of the screw knife does not change the average cutting height, but leads to a decrease in productivity.

An increase in the rotational speed of the screw knife leads to a decrease in the length of the crushed particles and an increase in productivity, because the turnover time of the knife is $\frac{60}{n}$, then at $v_0 = 0$ the average value of the cut stems will be

$$l_{\text{av}} = \frac{1}{2} q \left(\frac{60}{n}\right)^2$$

This equation can be used only under the condition n≥200 min -1(for the example under consideration), due to the constancy of values lav ≠const in the frequency range n<200 rpm.

When feeding stems along an inclined tray, the feed rate can be adjusted by changing the angle β (Figure 3) from 0^0 at β = arctan$f$ (where f is the coefficient of friction of the stems along the inclined tray) to 90^0 at the maximum free fall speed v_{max} = qt.

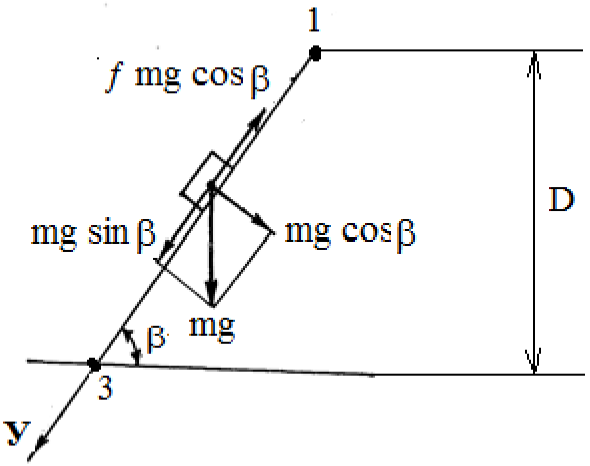

Figure 3. Diagram of the forces in the free fall of the stem.

Figure 3 It can be seen that whence $m\frac{d^2y}{dt^2} = mg\sin\beta - fmg\cos\beta = mg(\sin\beta - f\cos\beta),$

when the initial speed at point 1 (at the moment of entering the throat) is equal to zero, the displacement along the Y axis

$$Y = \frac{qt^2}{2}(\sin\beta - f\cos\beta) \tag{3}$$

From the equilibrium condition sinβ-$f$cosβ = 0 and f = 0.3, we obtain the minimum tilt angle β = 17^0, at which the relative movement of the stem along the inclined plane is impossible. If the stem moves from point 1 to point 3 (from the loading window to the lower part of the auger casing), then the value Y = $\frac{D}{\sin\beta}$, taking this into account from equation (3), we obtain the maximum travel time from point 1 to point 3.

$$t_{\max} = [\frac{2D}{q \sin\beta(\sin\beta - f\cos\beta)}]^{1/2} \quad (4)$$

With one revolution of the screw knife, during this time we will get the minimum permissible rotational speed

$$n_{\min} = \frac{60}{[\frac{2D}{q\sin\beta(\sin\beta - f\cos\beta)}]^{1/2}} \quad (5)$$

$$n_{\min} = \frac{60}{\sqrt{\frac{2D}{q}}}$$

At β = 90^0 from equation (5) we obtain - or vertical feeding stems; at $n_{min} = 200$rpm; at β = 17^0 and f = 0.3 n_{min} = 0; at β = 45^0 and f = 0.3 t_{min}= 0.34s and n_{min} = 175rpm.

For the case under consideration, the maximum possible stem length (distance between points 1 and 2 - Figure 3)

$$l_{max} = \frac{D}{sin\beta} = 56{,}57\ sm.$$

For the rest of the stems, the length is determined from the equation

$$l' = l * (\sin\beta - f\cos\beta) \quad (6)$$

Taking into account the above results for the case of an inclined feed

$$l_{\text{av max}} = \frac{R}{\sin^{\alpha/2} * \sin\beta}(\frac{\pi}{3} + \sin^{\alpha/2} * \cos^{\alpha/2}) \quad (7)$$

Productivity with relative supply of stems volumetric

$$Q = \frac{1}{10^6} * l_{av} * d_{av} * B * n$$

(8)

Here dav -is the average diameter of the stems, sm;
l_{av} - the average length of the cut for one revolution of the knife, sm;
B -is the width of the working neck, sm;
n- knife rotation frequency, rpm.

3. Results and discussion

The results obtained make it possible to obtain the maximum and average lengths of the stems segments per one turn of the screw knife. In this case, the gravitational loading in a vertical plane perpendicular to the screw knife shaft and loading along an inclined plane at an angle β within tgβ ≥ f are considered.

Figures 4 and 5 show the results of calculating the cut lengths with a screw cutter at different frequencies of its rotation and width feeding throat (angle α- figure 2) and the radius of the auger casing. From Figure 4 it can be seen that as the angle α/2 approaches zero, the length of the segments tends to the diameter D - with vertical feeding of stems and KD, where K>1, with inclined feeding. In this case, the conditions for the complete filling of the screw cavity with the stems within the angle α, and one turn of the knife (one cut) occurs during $t_{\max} \geq \sqrt{\frac{2D}{q}}$. However, in this case, the cut length, including their average values (as in the case under consideration), may not correspond to zootechnical requirements for grinding coarse-stemmed crops.

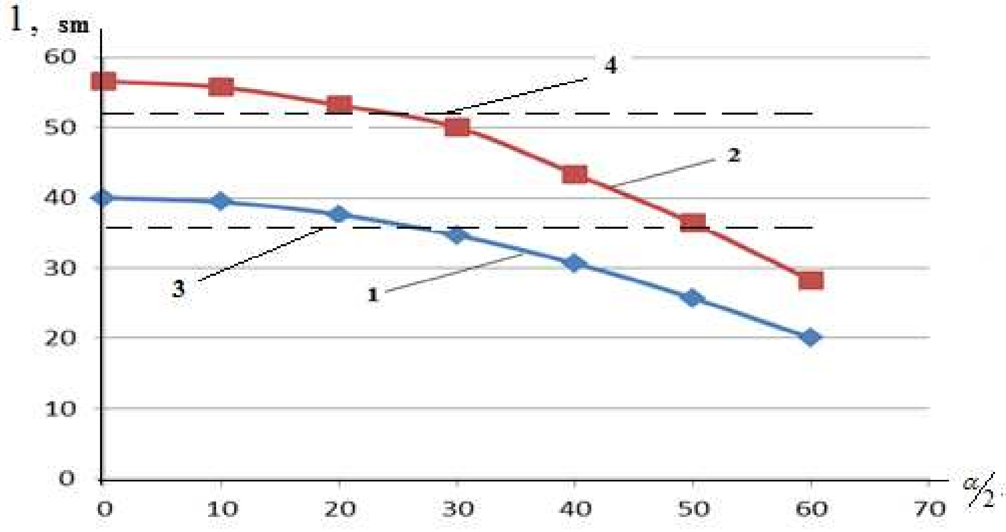

Figure 4. Cutting length of stems depending on the angle
1 - with vertical loading; 2-when loading at an angle β = 450; 3-average maximum slice length at n≤ 200 min-1; 4- average maximum cut length at n≤ 175 min-1 and β = 450.

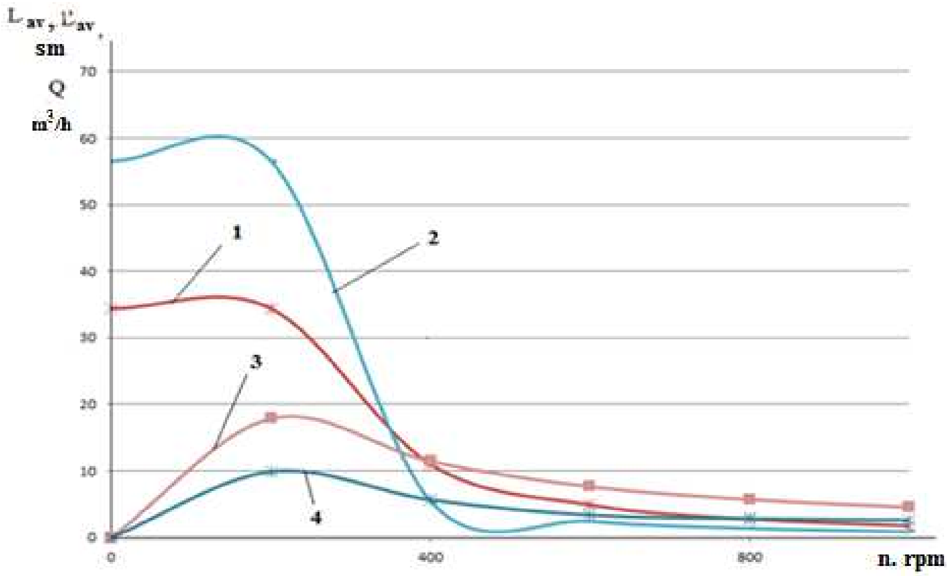

Figure 5. Dependence of the heights of the cut l_{av} - with vertical loading ($\beta = 0^0$) and l^1_{av} when loading at an angle $\beta = 45^0$ and corresponding volumetric productivity.

1- l^1_{av} at $\beta = 45^0$; 2- lav at $\beta = 0^0$; 3- Q- at $\beta = 0^0$; 4- Q- at $\beta = 45^0$.

It is possible to increase the degree of chopping of the stems only by reducing the average cut length, i.e. by increasing the rotational speed screw knife. Figure 5 shows the average slice lengths and the corresponding productivity of the screw cutting pair depending on the speed of rotation of the knife. Figure 5 shows that for compliance with zootechnical requirements, modes n= 550-650 rpm. (l_{av} = 8-4,5 sm) - with vertical loading, and n= 400-450rpm (l_{av} = 5,5-4 sm) – at inclined feed at an angle β = 450. An increase in the frequency of rotation of the knife leads to a sharp decrease in the productivity of the cutting pair. The above numerical examples are selected in accordance with the parameters of the experimental setup and show good agreement with the experimental results.

4. Conclusion

A theoretical analysis of the main parameters and operating modes of the screw grinder of coarse-stem crops, which can be taken as a basis for the design of machines.

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