ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research, volume 393
The Fifth Technological Order: Prospects for the Development and Modernization of the Russian Agro-Industrial Sector (TFTS 2019)

Theoretical Description of Caryopsis Segment Motion in Feed Grain Shredder with Curved Cutting Elements

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***Abstract*— A theoretical description of the motion of the caryopsis segment in the channel of the working body of the proposed feed grain shredder with curved cutting elements is presented. A system of differential equations is proposed that determines the required value of the channel necessary and sufficient to rotate the caryopsis segment by the cut plane to the cutting plane. According to the results of numerical solution of the presented system of differential equations, graphic dependences for peas and wheat are obtained, confirming the hypothesis that the caryopsis or segment is rotated by a long axis to the cutting zone in a very small period of time with a slight movement through the channels of the feed grain shredder. This gives us the right to conclude that the cutting of the segment of the caryopsis by the next stage of the working bodies of the proposed feed grain shredder occurs along the plane of the previous cut. Grinding of caryopsis of fodder crops and their segments occurs first of all across the smallest section and thereby the energy intensity of process of grain crops grinding on the average decreases by 11,9 %, and productivity of the shredder with cutting elements of the curvilinear form increases by 10,7 %.**

Keywords—shredder, cutting elements, curvilinear shape, movement of caryopsis segment, energy intensity, productivity.

I. Introduction

The most important criterion of survival in modern market conditions is the competitiveness of livestock products and increase of its production. Therefore, the search for innovative technologies, machinery and equipment in animal husbandry, including feed grain shredders, could possibly increase the profitability of this industry[1,2]. When preparing compound feeds at the places of consumption[3], the main grinding operation is applied. Studies have proved and confirmed that this operation is the most energy-intensive. Currently, the labor intensity is significant and accounts for more than 50% of the total costs in the technology of compound feeds preparation in agricultural production [4,5]. For feed grain grinding in forage preparation, commercially available hammer crushers are the most common. It is known that in such machines, the destruction of caryopsis is more profitable to produce due to a large number of shocks at lower voltages. Despite the constant improvement and modernization of their designs, they have a number of significant drawbacks. Such as high power consumption for the technological process [6], a high proportion of the pulverized fraction of the grinding product that does not meet zootechnical requirements [7].

When grinding, the hard shell of the grain is destroyed, the ability to chew better is facilitated, the area of the contact surface with the gastric juice increases, which contributes to a better effect on digestibility. This helps to speed up the digestion processes, increase the digestibility of grain feed nutrients and increases the energy efficiency of the feed.

II. Research methodology

The impact of crushing machines on the process of grinding feed grain design parameters has been studied by many scientists. It is noted that the value of the cutting angles, which are formed by the cutting edges of the working bodies of the grain material shredder, affect the energy intensity and productivity of the material processing operation [8,9,10]. From the point of view of reducing the energy intensity of the process in impact-centrifugal type crushers, it is more profitable to destroy the grain in 1...2 strokes [11]. As a result of many years of research, it was concluded that multistage grinding should be carried out with intermediate separation of grinding products. The author recommends two complete systems "crushing machine-separator" and one incomplete, including only a crusher[12]. This will allow to obtain a more aligned granulometric composition of the finished product that meets the zootechnical requirements, to reduce the energy consumption of the working process of the shredder due to the timely withdrawal of crushed particles [13]. The expediency of the use of cutting and chipping with the use of "pinched" blade impact on the caryopsis[14] is proved. It is known that in a centrifugal-rotary shredder, in accordance with the change in the coefficient of friction of the grain material on the working bodies, the first cutting pair is cut into segments [15]. It is established that such machines are the most effective for grain material grinding. In the works [8,15] it was determined that in the working channel of such a shredder the segment of caryopsis is rotated by the cut plane along the cutting element. The subsequent stage of the working bodies of the shredder will produce cutting of the segment of the caryopsis mainly along the plane of the preliminary cut of the previous stage.

In the case of using the working bodies of the shredder with curved cutting elements, it is also possible to significantly reduce the energy intensity of the technological process and significantly align the granulometric composition of the finished crushed product [16,17].

III. Results and discussion

To verify the validity of our hypothesis, we consider the scheme of movement of the segment of the caryopsis along the working surface of the disk of the proposed feed grain shredder with curved cutting elements (figure 1).

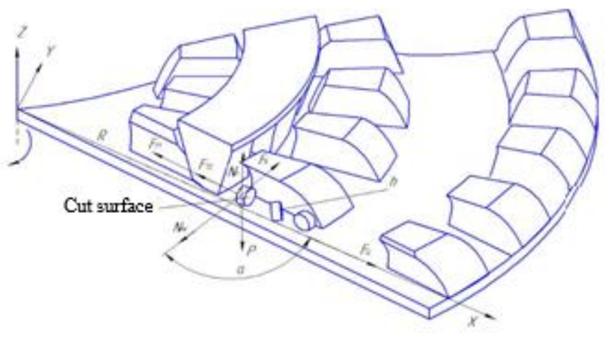


Fig. 1. Grain material segment at the outlet from the first ring of feed grain shredder working bodies

On the caryopsis which moves along the wall of the through groove on the working body, the following forces act (figure 2):

h - height of the caryopsis;

the Coriolis force is $F_k = 2m\omega V_0 \cos\alpha$, N;

the force of gravity P = mg, N;

centrifugal force $F_ц = m\omega^2 R$, N, where $\omega = \pi n/30$;

normal reaction of the cutting element wall N_{FK}, N;

normal gravity reaction N_p, N;

friction force F_{T1} = fmg acting on the surface of the disc;

Friction force $F_{T2} = 2fmgV_0$, acting on the surface of the blade, N, g - acceleration of free fall; f - coefficient of caryopsis friction on the surface of the disk; ω - angular rate of disk rotation; m - caryopsis weight, kg; n - rotor speed, min^{-1}, where V_0 - caryopsis speed on the surface of the disk, m/s.

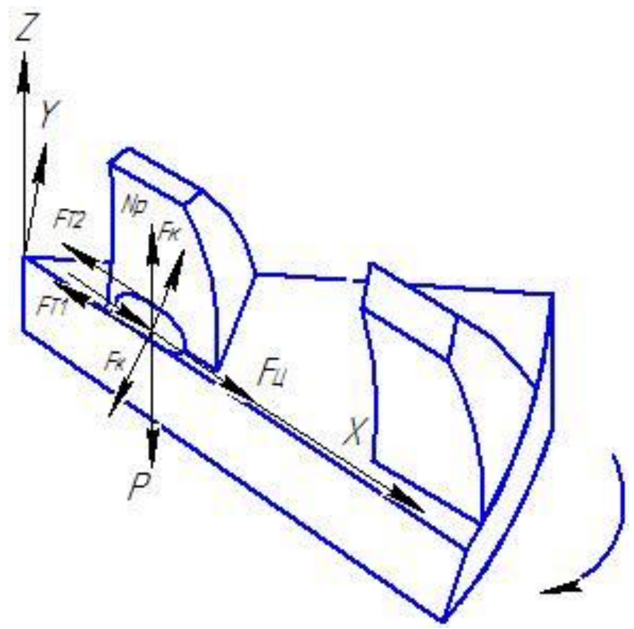


Fig. 2. Scheme of movement of caryopsis feed crop along the working surface of the disk of the proposed shredder

For caryopsis feed crop the basic law of dynamics will have the following form:

$$ma = \sum \vec{F} + \vec{F}_Ц + \vec{F}_К \qquad (1)$$

where a - acceleration of the free fall of the caryopsis, m/s^2; $\sum F$- the geometric sum of the forces acting on the grain, N:

$$ma = 2\, f m\omega V_0 \cos\alpha + f\, mg + mg + m\omega^2 R + 2\, f\, m\omega V_0 \cos\alpha \qquad (2)$$

Projecting equation (2) on the X-axis, on which the radius of the disk is located, we obtain the following formula:

$$ma = m\omega^2 R - 2fm\omega V_0 - fmg \qquad (3)$$

is known that a body with uniformly accelerated motion, having no initial rate, will pass a path that will be calculated according to the following dependence:

$$L = \frac{at^2}{2} \qquad (4)$$

It is established[7] that to calculate the thickness of the caryopsis, which will be cut off at the first stage of the working bodies, follows by the formula

$$S = \frac{(\omega^2 R - fg - 2f\omega)t^2}{2} \qquad (5)$$

The theoretical determination of the direction of rotation of the caryopsis segment requires the determination of the moment of force:

$$J_z \ddot{a} = F_K b \cos a + F_Ц b \sin a - F_{T2} b \sin a, \qquad (6)$$

where

$$J_z = ma^2 + \frac{m}{5}\left(a^2 + \left(\frac{h}{2}\right)\right) = \left(\frac{6}{5}a + \frac{h^2}{4}\right). \qquad (7)$$

According to the results of calculations, it can be seen that at the optimal cutting speed is approximately (230 rad/s), the thickness of the caryopsis is 1 - 3 mm. The particle sizes at the output from the first stage do not differ from the particle sizes obtained on the prototype [8].

The cutting elements of the working bodies of the shredder actively interact with particles of caryopsis. At the second and next stages of grinding, the caryopsis particle moves along the surface of the wall of the through groove mainly by the surface that was obtained after the previous grinding of fodder crops caryopsis.

The probabilistic nature of the orientation of the caryopsis moving on a flat surface under the action of gravity is known. Researchers Yu.V. Terentyev, V.A. Kubyshev, A.I. Klimok, and others argued that in order for the caryopsis to be oriented in the right direction of motion, the instability of the caryopsis on the plane is necessary. The stability of the body is influenced by such factors as the weight of the body, the distance at which the tipping force is applied and the area of support [18].

The basic law of dynamics is the following form for the relative movement of the caryopsis segment of feed crops on a flat area:

$$m\vec{a} = \vec{F}_{T1} + \vec{F}_{T2} + \vec{P} + \vec{F}_{Ц} + \vec{F}_{K} \tag{8}$$

Project the motion of the caryopsis segment on the X, Y, Z axis. As a result we obtain:

$$\begin{cases} m\ddot{X} = F_{Ц} - F_{T1} - F_{T2}, \\ 0 = F_K - N_{F_K}, \\ 0 = N_p - P. \end{cases} \tag{9}$$

where α is the relative motion of the caryopsis segment ($a = \ddot{x}$).

or

$$\ddot{x} = -2\omega f\dot{x} + \omega^2 x - gf. \tag{10}$$

Rotation of the caryopsis segment around the Z axis

$$J_z\ddot{a} = F_K b\cos a + F_{Ц} b\sin a - F_{T2} b\sin a, \tag{11}$$

where

$$J_z = mb^2 + \frac{m}{5}\left(b^2 + \left(\frac{h^2}{2}\right)\right) = \frac{24b^2 + 5h^2}{20} \tag{12}$$

$$\ddot{a} = \frac{2\omega\dot{x}\cos a + \omega^2 x\sin a - gf\sin a}{\dfrac{24b^2 + 5h^2}{20}} \tag{13}$$

From the above equations (10) and (13) we obtain a system of equations:

$$\begin{cases} \ddot{x} = -2\omega f\dot{x} + \omega^2 x - gf \\ \ddot{a} = \dfrac{2\omega\dot{x}\cos a + \omega^2 x\sin a - gf\sin a + \dfrac{\dot{x}^2}{\rho}}{\dfrac{24b^2 + 5h^2}{20}} \end{cases} \tag{14}$$

where x - the movement of the particle at the moment of cut.

α - the angle between the cut plane of the segment and the plane of the cutting element;

The obtained system of equations (14), as can be seen, allows us to study not only the translational, but also the rotational movement of the caryopsis segment of feed crops when moving along the rotor of the feed grain shredder along the wall of the cutting element, which has a curvilinear shape.

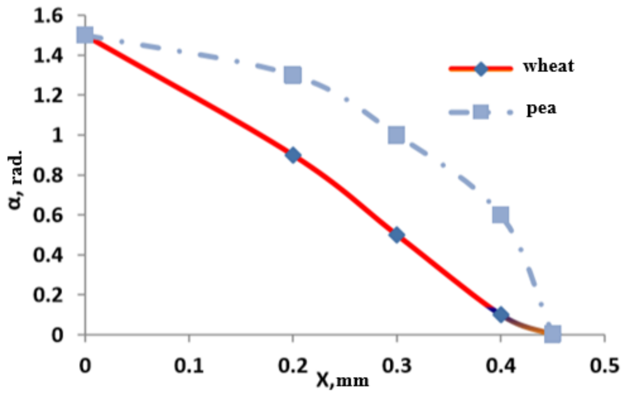
The first equation of the system (14) with initial conditions will be equal to:

$$\begin{cases} x(0) = x_0, \\ \dot{x}(0) = 0 \end{cases} \tag{15}$$

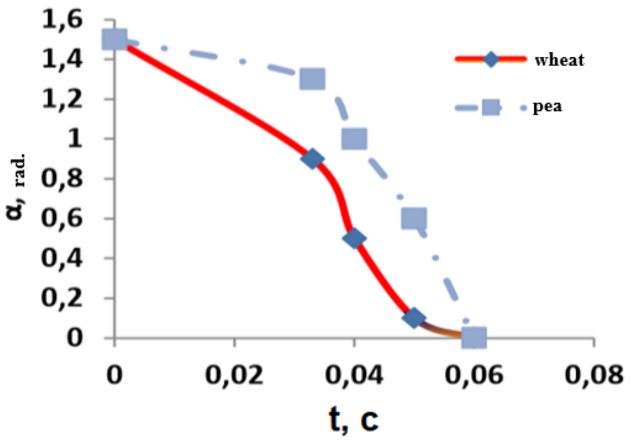
This linear inhomogeneous differential equation of the second order with constant coefficients is nothing but the Cauchy problem, known from the course "Mathematics".

The second equation of the system (14) admits a solution in the form of a general integral (implicitly).

According to the results of numerical solution of the proposed system of equations in the MS Excel program, graphical dependences of the rotation angles of the caryopsis for peas and wheat on the movement x and on the time t when moving along the rotor, along the wall of the curved cutting element (figure 3) are obtained.



a



b

Fig. 3. Dependence of rotation angles of caryopsis α of feed crops when moving along the rotor, along the wall of the cutting element of curved shape: a - on x movement; b - on t time

From the analysis of the given graphic dependences it follows that they have the same tendency of development for all values of a segment on diameter of various feed crops. It should also be noted that the number of curves presented is chosen only for reasons of clarity for both wheat and peas caryopsis, although they differ in the shape of the particles.

By the nature of the curves (figure 3), it can be noted that the caryopsis or caryopsis segment of feed crops has time to turn a long axis to the cutting zone in a very short period of time (less than 0.1 s) with a slight movement (less than 0.5 mm).

IV. Conclusion

1. The hypothesis of determining the required channel size for turning the caryopsis segment by the cut plane to the

cutting plane in a very short period of time with a slight movement is confirmed. A system of equations (14) is proposed to describe the theoretical motion of both the caryopsis and its segment in the channel of the working body of the feed grain shredder with curved cutting elements.

2. Grinding of caryopsis and their segments is carried out mainly across the smallest cross-section and thus reduces the specific energy intensity of the process of grain crops grinding by an average of 11.9 %, and the productivity of the grinder with curved cutting elements increases by 10.7 % [10].

REFERENCES

[1] V. A. Pivarchuk, U. K. Sabiev, and A. V. Chernyakov, Workshop on mechanization and technology of animal husbandry: Study guide. Omsk: Publishing house FSEI HPE OmSAU, 2004. (in russ.)

[2] V. A. Pivarchuk and U.K. Sabiev, Course and diploma design on mechanization and technology of animal husbandry: study guide, 2nd ed. Omsk: Publishing house FSEI HPE OmSAU, 2004. (in russ.)

[3] U. K. Sabiev, Intensification of technological processes of preparation of compound feeds in the conditions of agricultural enterprises: Authors Abstract of Doctor of Science Dissertation (Technical Sciences). Barnaul, 2012. (in russ.)

[4] U. K. Sabiev, E. V Demchuk, V. V. Myalo, and A. S. Soyunov, “Innovative equipment and production method for mixed fodder in the conditions of agricultural enterprises,” IOP Conference Series: Materials Science and Engineering, Vol. 221, 2017. [VIII International Scientific Practical Conference "Innovative Technologies in Engineering, 2017]. https://doi.org/10.1088/1755-1315/221/1/012020

[5] U. K.Sabiev, A. N. Yatsunov, and A.V. Chernyakov, “Main principles of production of highly homogeneous loose feed mixes by vibration,” International Journal of Mechanical Engineering and Technology, Vol. 9, No. 10, pp. 1220-1227, 2018.

[6] I. Ya. Fedorenko, S. V. Zolotarev, and A. A. Smyshlyaev, “Influence of the number of strokes required for the destruction of grain on the energy of the grinding process,” Storage and processing of farm products, No. 6, pp. 53-54, 2001.

[7] U. K. Sabiev and A. S. Pushkarev, “Comparative analysis devices for crushing grain materials,” Vestnik Omskogo Gosudarstvennogo Agrarnogo Universiteta (Bulletin of Omsk State Agrarian University), No. 1, pp. 221-226, 2016.

[8] N. S. Sergeev, Centrifugal-rotary feed grain grinders: Authors Abstract of Doctor of Science Dissertation (Technical Sciences). Chelyabinsk, 2008.

[9] U. K. Sabiev and V. V. Fomin, “Device for the grinding of grain materials,” Vestnik Omskogo Gosudarstvennogo Agrarnogo Universiteta (Bulletin of Omsk State Agrarian University), No. 2, pp. 75-76, 2008.

[10] U. K. Sabiev and V. V. Fomin, “Decrease in power consumption of crushing of grain in small-sized centrifugal grinder,” Omsk Scientific Bulletin, No. 2, pp. 167-170, 2011.

[11] V. A. Demidov and S. E. Chirkov, Grinding impact action machines. Moscow: Mashinostroenie, 1969.

[12] I. B. Shagdyrov and I. B. Baldanov, Mechanical-technological basis for the creation of multi-stage feed grain shredders. Ulan-Ude: publishing house of BSAA n.a. V.R. Filippov, 2010.

[13] I. Ya. Fedorenko, V. V. Sadov, Technological optimization of the economic feed-milling enterprises. Barnaul: RIO of Altai SAU, 2017.

[14] U. K. Sabiev, D. N. Pirozhkov, and I. U. Sabiev, “Some regularities of grinding feeder grain using impact by blade,” Vestnik Omskogo Gosudarstvennogo Agrarnogo Universiteta (Bulletin of the Altai State Agrarian University), No. 12, pp. 132-137, 2014.

[15] U. K. Sabiev and V. V. Fomin, “Mathematical model of caryopsis segment movement in centrifugal-rotor crushing machine for fodder grain,” Dostizheniya nauki i tekhniki APK (Achievements of science and agriculture technique), No. 2, pp. 62-65, 2010.

[16] U. K. Sabiev, A. S. Pushkarev, I. U. Sabiev, and V.V. Fomin, Patent No. 162055 of the Russian Federation. Device for grain materials grinding. Publ.B.I. No. 14. 2016.

[17] A. S. Pushkarev, Increasing the efficiency of the grain grinding process by using working bodies with curved cutting elements: Authors Abstract of Candidate of Science (PhD) Dissertation (Technical Sciences). Barnaul, 2018.

[18] A. I. Klimok, “Justification of the optimal profile of the working surface of the sieve,” in Cleaning and post-harvest processing of grain: Trudy Chelyabinskogo instituta mekhanizatsii i ehlektrifikatsii sel'skogo khozyajstva, vol.62. Chelyabinsk, 1973, pp. 161-167.