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DESIGN AND EFFICIENCY OF A STRING HULLING MACHINE FOR BUCKWHEAT

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ABSTRACT

An important task of food engineering, namely grain processing and the pro-duction of cereals and fodder, is the improvement of hulling equipment and the creation of complex technological lines for the processing of the original crops is gaining particular relevance. The reason

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ABSTRACT

for this is the need to carry out several preparatory stages, and, as a result, the use of additional equipment. To solve this problem, a string hulling device had been developed, the use of which allows reducing the number of operations due to the exclusion of preliminary sorting into fractions and wet-heat treatment. These operations are required by other hulling machines included in the technological lines of buckwheat processing. The structural scheme of the string hulling device had been developed and the principle of the shell removal operation had been substantiated. Theoretical studies had been carried out by the methods of analysis and synthesis of the mechanics of destruction and systematic analysis of the process of buckwheat hulling by impact. Experimental studies had been carried out using a laboratory string hulling device. The conducted analytical studies made it possible to determine the regularity between the physical and mechanical characteristics of buckwheat and the critical linear impact speed necessary for the destruction of the shell. This allows deter-mining the frequency of rotation of the string at which the destruction of the shell will occur while preserving the integrity of the core. Experimental studies made it possible to determine the quality of buckwheat hulling by determining the coefficient of integrity of the kernel and the coefficient of hulling. It has been determined that the ranges of the rotation frequency of the strings required to ensure a high degree of the buckwheat hulling technological process efficiency are within 15.8-16.9 s^{-1}.

Introduction

At the current stage of development of the processing industry, it is economically advantageous to focus on the engineering of equipment for processing grain into groats at the places where raw materials are grown (Kovalenko et al., 2021; Faichuk et al., 2022). This enables the manufacturer not to depend on the purchase prices for raw materials, but to sell the finished product (Bulgakov et al., 2019a; Bulgakov et al., 2019b). Hulling of cereal raw materials is one of the most important processes of processing grain into cereals, as the volume of production and the quality of the final product depend on its quality. Modern buckwheat hulling equipment is adapted for use in large-scale grain factories, in particular, due to the use of traditional technology, which includes operations of sorting into fractions and hydrothermal treatment prior to hulling. Performing these operations significantly increases the number of equipment in the technological line, significantly reduces specific productivity and increases the cost of groats. The creation of hulling devices that would allow processing grain of different fractions without the use of preliminary sorting can significantly increase the efficiency of grain hulling and grain production. This opens up prospects for the creation of low-power lines directly at the places of grain cultivation and storage and also to increase the productivity of existing technological lines at grain factories and reduce the cost of production of finished grain products (Lazaro et al., 2014; Ikubanni et al., 2017).

To ensure the destruction of the shell without violating the integrity of the kernel, it is necessary for the working body to achieve a speed at which the energy received by the grain will be sufficient to destroy its shell, but will not cause damage to the kernel. That is, the limiting level of the speed range is the lowest speed of the working body, which will cause the destruction of the core upon impact. Analysis of the issues of fracture mechanics will allow us to consider the process of destruction of the buckwheat grain shell as a process of brittle destruction, that is, the appearance of micro- and macrocracks before the complete destruction of the shell.

Modern engineering equipment for hulling in buckwheat groats production lines is divided into equipment which working parts exert compression and shear on the grain, with a predominance of external friction, and equipment in which impact is used (Vishwakarma et al., 2016; Vishwakarma et al., 2018).

The first subgroup includes machines in which hulling is performed due to compression and shear forces with the predominance of external friction. A feature of the hulling process in the devices of this subgroup is the hulling of grain in one layer due to the interaction of the grains with the working bodies, which requires mandatory preliminary sorting into fractions (Merko, 2010).

For buckwheat hulling with a short compression and shear force, roller deck machines with one or two decks are used (Kuzmychev, 1989; Yalpachyk. et al., 2018). Hulling takes place in the working zone formed between the rotating roller and the concave top of the tray. The working bodies are an abrasive rotating roller and a fixed deck (decks), which are almost adjacent to the roller with an abrasive (for buckwheat) or rubberized (for millet) surface.

Due to the tetrahedral shape, buckwheat does not roll well from an inclined plane, the abrasive deck is installed on the side of the roller so that the working area has a vertical, strongly inclined working area, due to which the grain will not be retained and crushed excessively. The shape of the working gap, called sickle-shaped, contributes to smaller grain crushing. Such a shape will be formed if the roller and the working surface of the deck are described by the same radius, practically this is achieved by rubbing the deck against the roller (Yalpachyk et al., 2018). When the sheet is moved away from the roller to create a gap, the latter has a smaller value in its upper and lower parts and a larger one in the middle (Zaitsev, 1974). Grain hulling occurs mainly in the upper and lower parts of the deck, and the grains formed in the upper part of the deck by hulling pass freely in the middle of the zone without significant crushing. When hulling millet, the working gap between the roller and the rubberized deck is wedge-shaped, that is, it decreases from the intake to the output of the product (Haponiuk et al., 2018; Osypov, 2012).

To increase the efficiency of grain hulling, two-deck machines can be used, as well as machines with a deck with a combined surface (the upper part is made of abrasive, the lower part is rubberized) (Ivanovs et al., 2020; Lü et al., 2019).

For adjusting the gap in the multipurpose roller decking machines there is a double device for moving the deck, which allows setting one or another form of the working gap (Hrosul, 1999; Anosike et al., 2016).

It is known that when hulling on a roller decking machine, the loss of grain that goes to hulling is approximately 20%. The design of these machines does not allow adjusting the parameters of the technological process without stopping the machine. The direction of improvement of roller-decking machines is to improve the drive of the working bodies, namely, the version of the layout with a rotating roller and a deck that performs an oscillating movement along the axis of rotation of the roller, which allows simplifying the design of the drive (Borysov et al., 2020; Nwaigbo et al., 2008). However, the main drawback of such machines is that they need a strictly sorted fraction of grain to be supplied into them. Due to this requirement, the grain supplied for processing by hulling on rolling mills must be divided into

4-5 fractions. This requires an additional sorting operation and significantly reduces the productivity of the technological line (Chernysh, 2016).

The second group of existing technological equipment for hulling buckwheat in terms of the principle of action includes machines in which grain hulling occurs due to a single or multiple impact (Zhen et al., 2022; Siqin and Wenliang, 2013). Impact machines are promising for use in grain processing lines, which, to a greater extent than existing equipment, meet the requirements of resource-saving technologies and are suitable for hulling grain of various crops (Brasalyn, 1983).

It had been experimentally established that the least amount of energy is spent on the destruction of the shell, while keeping the kernel intact, when the grain hits the tray directly. With a direct impact, the kinetic energy of the seed is not lost to friction against the cutting board, but is spent on the deformation of the seed shell, which ensures a better quality of their hulling, since the number of unshelled and unshelled seeds in the shell decreases (Eremenok, 2001).

In work (Kudriavtsev and Vatutyn, 1991), a design of a centrifugal seed rake with a stepped deck had been introduced, in which the impact is close to a direct one. However, this machine has significant drawbacks: the stepped deck has zones where the conditions for a direct impact are not met; increased aerodynamic resistance; lack of adjustment of the angle of impact on the deck depending on changes in the technological properties of the processed raw materials.

One of the main directions of the engineering of such hulling machines is the determination of the optimal size and shape of the rotor, increasing the wear resistance of the working parts, the use of reliable variators to regulate the speed of rotation of the rotor. Unfortunately, despite the prospects for using equipment of this type, a significant drawback is the significant specific energy consumption of the process (Parton and Borskovskij, 1985; Kovalov and Donets, 2017).

The basis of the second type of machines for hulling grain with a single blow should be attributed to the string hulling device. (Yalpachyk et al., 2004) As mentioned above, a direct impact is optimal for the most effective shell destruction. Taking into account these studies, a string hulling device had been developed in the laboratory of the Department of Equipment for Processing and Food Production named after Professor F. Yu. Yalpachyk of the Dmytro Motornyi Tavria State Agrotechnological University (Ukraine). The introduction of a new design of the working bodies allows to ensure the consistency of the direct blow, the normalization of the number of blows, the reduction of the metal content of the device and, as a result, the energy consumption of the hulling process.

The developed string working body of the device for grain hulling by blow allows ensuring the constancy of a one-time direct blow, namely, a string that is rigidly installed in a plane that is perpendicular to the plane of grain fall. The energy that occurs when hulling products hit the disc is directed to their removal. As a result of a one-time direct impact, the energy spent on destroying the shell is reduced, while preserving the entire core, which leads to a decrease in the energy intensity of the device. Despite the progressiveness of the impact method itself, impact hulling equipment has not received a significant degree of implementation in modern production lines due to insufficient research into this process.

Based on the review of the existing methods of action on the grain during buckwheat hulling, it had been determined that the method of impact action in a string huller is promising for research based on the criteria of energy and resource saving, as well as universality of application. The use of this equipment makes it possible to significantly reduce the energy consumption of the process due to the fact that the design provides for the movement of grain by self-flow, without providing the grains with additional acceleration. The introduction of a string hulling device into the technological scheme makes it possible to reduce the number of technological operations (exclude the operation of grain sorting) and accordingly the equipment used.

An important kinematic indicator of the impact hulling process, which affects the quality and yield of hulled grain, is the rotation frequency of the working body.

The object of research of this article is a string hulling device, and the subject is kinematic and structural parameters and regularities of buckwheat hulling in it.

The engineering of a new hulling device, in which grain hulling is carried out by impact, allows to determine the main parameter to be the frequency of rotation of the working parts. The quality of the hulling process and the energy consumption of the installation depend on it. Therefore, the purpose of these studies is the development of the string hulling device, namely the determination of the optimal parameters of the rotor rotation frequency for obtaining high-quality separation of the shell from the grain during the production of buckwheat groats (Radchenko, 1998). Evaluation of the effectiveness of the hulling process is possible on the basis of a complex criterion of effectiveness, which takes into account the main changes in the grain through local criteria, the meaning and nature of which changes can be determined only experimentally (Samoilov et al., 2017; Xu et al., 2021).

To achieve the set aim, it is necessary:

- to conduct analytical studies and establish the range of critical times when hulling buckwheat groats in a string huller;
- to experimentally establish the optimal frequency of the rotor rotation to obtain high-quality hulling.

Materials and Methods

Theoretical studies had been carried out by methods of analysis and synthesis of the mechanics of destruction and systematic analysis of the process of buckwheat hulling by impact. Experimental studies had been conducted using a laboratory string hulling device. The basis of experimental research is the determination of the quality of buckwheat grain hulling. The purpose of the process of the original crops hulling with a blow is to destroy the shells of the original crops while preserving the integrity of the core.

Experimental studies had been conducted in order to assess the quality of the process of the original crops hulling by impact, to determine the technological parameters of hulling and the process of supplying grain flow to the hulling zone, as well as to verify the performed theoretical studies. The research had been carried out in the laboratory of the Department of Equipment for Processing and Food Production named after Professor F. Yu. Yalpachyk of the Dmytro Motornyi Tavria State Agrotechnological University (Ukraine), where a hulling device of impact action had been created using nodes of the hulling-sorting complex of the APK - 300M (Ukraine) (Figure 1) (Yalpachyk and Fuchadzhy, 2004).

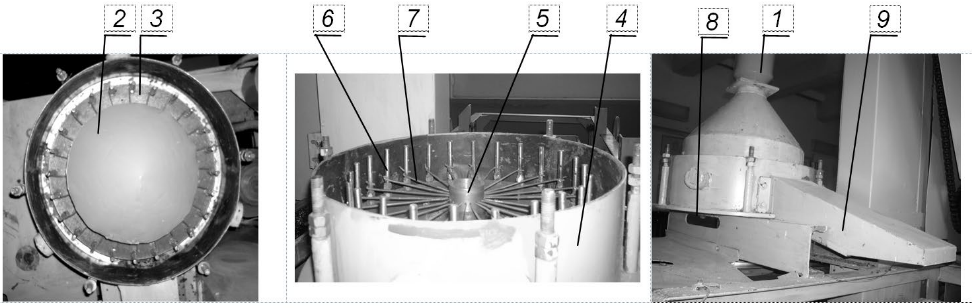

Figure 1. String hulling device: 1 – feed hopper; 2 – guide cone, 3 – disc; 4 – body; 5 – string distributor; 6 – string holder; 7 – string, 8 – impeller, 9 – outlet pipe

The hulling device consists of the following main functional units: a feeding unit, a hulling chamber and a drive. The device for hulling grain contains a feeding unit, which consists of a feeding hopper 1 and a guide cone 2 with its base facing the disk 3. The disk 3 is located in the cavity of the housing 4 and is rigidly fixed in a horizontal position on the shaft. Above the disc 3, strings 7 are installed, one end is radially fixed in the string distributor 5, which is attached to the shaft, and the other - in the string holder 6.

The string holders 6 are located on the periphery of the disc 3 and are separated from the body 4 by a partition that prevents the "hammer crusher effect" from occurring. Hulling products are removed from the disc surface due to centrifugal force. An impeller is installed in the cavity under the disk, which helps to accelerate the removal of hulling products to the outlet nozzle 9.

The pre-cleaned grain without sorting into fractions by size entered the feed hopper 1 and, passing through the channel created by the housing 4 and the guide cone 2, enters the working zone, which is created by the disk 3, fixed rigidly in the horizontal plane on the shaft, and the housing 4. Such feeding ensures that the grain reaches the periphery of the disk 3, thereby realizing a one-time direct impact, in which the same destructive force acts on the grain. Strings 7 rotate in a plane perpendicular to the plane of grain fall, which ensures a constant direct impact.

The frequency of rotation of the shaft had been determined by a mechanical centrifugal tachometer of the time type IO-10 (Ukraine) designed for measuring the rotation frequency in the range of 25-10000 rpm in five ranges. The measurement error of the device is ±2% of the maximum limit in each range.

A generalized assessment of the effectiveness of hulling or crushing processes can be the product of the main indicators of the technological and technical efficiency of the hulling device (Merko, 2010; Pascuzzi, 2017).

$$E_p = C_p \cdot F_c \tag{1}$$

where:

C_p – is the hulling coefficient,

F_c – is the core integrity factor.

But the use of such an indicator does not provide an objective assessment of the process, since it does not distinguish the independent influence of technological and technical efficiency, does not take into account their separate contribution to the final result, and allows for the possibility of its equal values at different values of the components.

The hulling coefficient is determined by the formula (Borysov et al., 2020, Xu et al., 2021).

$$C_p = \frac{H_1 - H_2}{H_1} \tag{2}$$

where:

H_1 – is the content of unshelled grains in the grain,

H_2 – is the content of unshelled grain in the hulling product at the exit from the machine.

The disadvantage of such an indicator is that it does not take into account data on the quality (Voloshenko et al., 2019; RTM 8.55.00.112-88, 1988) and the composition of the initial grain, by-products of processing and shelled kernel, which leads to inadequate conclusions when using it.

The influence of the phenomenon of core crushing in hulling devices on the technical efficiency of their work can be taken into account (Yarum, 2014) using the core integrity coefficient.

$$K_{ic} = \frac{\Delta k}{\Delta k + \Delta d + \Delta m} \tag{3}$$

where:

Δk – amount of whole grain obtained during the hulling proces,

Δd – amount of crushed grain obtained during the hulling proces,

Δm – amount of flour obtained during the hulling process.

In view of the above, it is appropriate to consider not only the index of hulling efficiency, but also the coefficients of hulling and kernel integrity.

To perform the experiment, samples had been selected in accordance with DSTU ISO 13690:2003 “Grains, legumes and products of their grinding. Sampling” (International Organization for Standardization, 2003). Massive amounts of millet and buckwheat had been obtained. The determined indicators of buckwheat grain quality were: initial moisture content – 12.4%; weight of 1000 grains – 19.2 g; film density – 19.3%; grain admixture content – 1.8%; content of garbage admixture – 2.4%; content of broken grains – 0.8%

The quality indicators of buckwheat samples used for experimental research correspond to DSTU 4524:2006 “Buckwheat. Specifications”.

Results and Discussion

Analytical determination of the critical frequency of the rotor rotation

Hulling refers to the process of brittle destruction, because the destruction of the shell, which is more fragile compared to the core of the grain, occurs (Mudasir and Charanjiv, 2016; UN Economic Grimmission for Europe, 1991).

When analyzing the literature in which the issues of fracture mechanics are considered, a crack can be interpreted as a limit case of a narrow cavity, namely as a gap (Parton and Boryskovskij, 1988). At the moment when the body perceives the load, the corresponding surface load occurs, the edges of the crack move relative to each other 32. It had been found that the cracks in the body are considered as rupture surfaces of the displacement vector (Rozhnovskyi, 2000; Alamooti and Mahmoodi, 2015).

To ensure the destruction of the shell without violating the integrity of the kernel, it is necessary for the working body to achieve a speed at which the energy received by the grain will be sufficient for the destruction of its shell (Figure 2) (Zhuravel et al., 2020).

The upper limiting level of the speed range is the lowest speed of the working body, which will cause the destruction of the core upon impact (critical speed) (Solomka and Kovbasa, 2009; Malanychev, 2000).

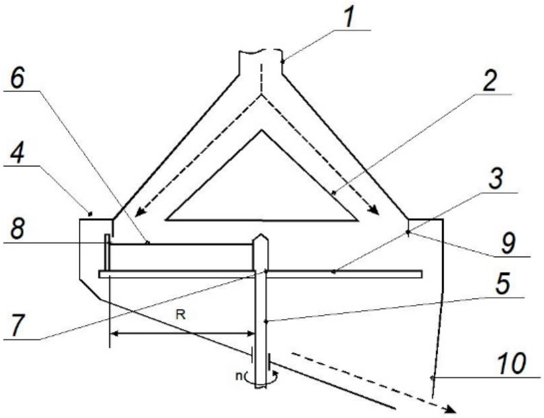

Figure 2. Scheme of the string hulling device: 1 – feed hopper; 2 – straight cone; 3 – disc; 4 – body; 5 – shaft; 6 – strings; 7 – string distributor; 8 – string holder; 9 – partition; 10 – outlet pipe

Upon impact, the string transmits an impact impulse to the particle (Panasiuk, 1988):

$$P = m \cdot v_s \cdot (1 + k) \tag{4}$$

where:

m – mass of the system, (kg)
v_s – linear speed of the string at the point of collision, ($m \cdot s^{-1}$)
k – recovery factor

If we accept the assumption that the shell collapses under the condition that the length of the crack in it reaches the dimensions of its (shell) thickness, then, after analytical transformations, we will have a formula for calculating the critical speed of collision of a particle with a string, when developing in it as a result impact of the dominant shear stress (Deynichenko et al., 2014).

$$v_k = \frac{T}{\rho \cdot cos\alpha} \cdot \sqrt{\frac{\pi \cdot \gamma \cdot E}{(1-v^2) \cdot (b^3 - b^{`3})}} \tag{5}$$

where:

T – impact pulse time, (s)
ρ – shell density, (kg m^{-3})
α – angle at which the collision occurs, (degrees)
γ – coefficient expressing the specific surface energy of destruction,
E – modulus of elasticity, (N·m^{-2})
ν – Poisson's ratio,
b^3 – volume of grain with shell, (m^3)
b'^3 – volume of the grain core, (m^3)

Due to the fact that the impact in the process considered by us is direct, that is when $\alpha = 0$, and moving to a specific type of grain crops, let us assume that the shell of the grain is isotropic in terms of mechanical properties and has the correct shape.

The shape of a buckwheat grain is close to a regular tetrahedron, and therefore the volume of the buckwheat shell is determined by the formula:

$$V_g = 0{,}12 \cdot (a_g^3 - a`_g^3) \tag{6}$$

where:

a_g – length of the edge of the grain, (m)
a_g' – length of the edge of the grain kernel, (m)

For buckwheat, we will get it:

$$v_k = \frac{T}{\rho} \cdot \sqrt{\frac{\pi \cdot \delta \cdot E}{(1-v^2) \cdot 0{,}12 \cdot (a_g^3 - a`_g^3)}} \tag{7}$$

In his works, Irvin, based on the analysis of the energy of elastic and plastic deformations in the crack zone, suggests that for materials to which the energy treatment of brittle fracture can be applied, the energy of plastic deformation should not be taken into account (Samoichuk et al., 2023; Malkina et al., 2022). In connection with the above, the energy for plastic deformation of the grain shell will not be taken into account in further calculations. Empirical formulas obtained during the processing of data obtained as a result of research can be presented in a general form (Solomka and Solomka, 2014; Solanki et al., 2018).

$$E = 10^8 \cdot (a_1 + a_2 \cdot P + a_3 \cdot W) \tag{8}$$

where:

a_1, a_2, a_3 – constant coefficients,
W – grain moisture.

When the string hits the grain, an instantaneous force acts on the grain, which can be determined using the formula:

$$P = \frac{2 \cdot m \cdot v_s}{T} \tag{9}$$

Based on the fact that for buckwheat

$$m_g = 0{,}12 \cdot \rho \cdot a_g^3 \tag{10}$$

we get:

$$E_g = 10^8 \cdot \left(a_1 + 0{,}24 \cdot a_2 \cdot \frac{\rho \cdot (a_g^3 - a`^{3}_{g})}{T} \cdot V_{bg} + a_3 \cdot W\right) \tag{11}$$

Taking the assumption that $(1 - v^2) \approx 1$, due to the fact that v^2 is a small value, and taking into account the geometric shape of the grain shells, we obtain

$$V_{bg} = \frac{T}{\rho} \cdot \sqrt{\frac{\pi \cdot \delta \cdot E}{0{,}12 \cdot (a_g^3 - a`^{3}_{g})}} \tag{12}$$

Taking the assumption that for buckwheat

$$a = 0{,}12 \cdot 10^{-8} \cdot \rho^2 \tag{13}$$

$$b = 0{,}24 \cdot a_2 \cdot T \cdot \pi \cdot \rho \cdot \gamma \tag{14}$$

$$c = \pi \cdot \gamma \cdot T^2 \cdot \frac{a_1 + a_3 \cdot W}{a_g^3 - a`^{3}_{g}} \tag{15}$$

we get:

$$V_k = \frac{b + \sqrt{b^2 + 4ac}}{2a} \cdot \tag{16}$$

After having transformed of the equation

$$V_{bg} = 10^8 \frac{T \cdot \pi \cdot \gamma}{\rho} \cdot \left(a_2 + \sqrt{a_2^2 + 8{,}3 \cdot 10^{-8} \frac{a_1 + a_3 W}{\pi \cdot \gamma \cdot (a_g^3 - a`^{3}_{g})}}\right) \tag{17}$$

The coefficient expressing the value of the specific surface energy of destruction for buckwheat and other crops is determined by the formulas:

$$\gamma = \frac{\pi \cdot a_g \cdot \sigma_k^2}{2 \cdot E_k} \tag{18}$$

After transformations and simplifications, we get

$$V_{bg} = 4.93 \cdot 10^8 \frac{T \cdot a_g \cdot \sigma_k^2}{E_k \cdot \rho} \cdot \left(a_2 + \sqrt{a_2^2 + 1.68 \cdot 10^{-8} \frac{E_k (a_1 + a_3 W)}{a \cdot \sigma_k^2 \cdot (a_g^3 - a`^{3}_{g})}}\right) \tag{19}$$

Based on this, finally, we will obtain a formula for determining the critical frequency of rotation of the string

$$n_{kg} = 7.85 \cdot 10^7 \frac{T \cdot a_g \cdot \sigma_k^2}{E_k \cdot \rho \cdot R} \cdot \left(a_2 + \sqrt{a_2^2 + 1.68 \cdot 10^{-8} \frac{E_k (a_1 + a_3 W)}{a \cdot \sigma_k^2 \cdot (a_g^3 - a`^{3}_{g})}}\right) \tag{20}$$

As can be seen from the obtained equation, the rotation frequency of the strings depends on many factors, namely:

- grain properties: modulus of elasticity (E), stress (σ), density (ρ), shell dimensions (a_g; a_g');
- structural and technological parameters of the equipment: impact pulse time (T) and impact radius (R).

Let's perform calculations for formula (20) for indicators of the batch of buckwheat that was subjected to hulling

$$n_{kg} = 7.85 \cdot 10^7 \frac{10^{-5} \cdot 0.003 \cdot 10^{14}}{3.12 \cdot 10^9 \cdot 170 \cdot 0.11} \cdot \left(4.52 \cdot 10^{-4} + \sqrt{(4.52 \cdot 10^{-4})^2 + 1.68 \cdot 10^{-8} \frac{3.12 \cdot 10^9 (2+5 \cdot 0.12)}{0.004 \cdot\cdot 10^{14} \cdot (0.004^3 - 0.003^3)}}\right) = 16.5 s^{-1} \tag{20}$$

Thus, as a result of the conducted theoretical research, an equation had been obtained for determining the critical linear speed of impact necessary for the destruction of the shell, and the calculation had been made to determine the rotation frequency of the string at which the destruction of the shell will occur while preserving the integrity of the core.

Results of experimental studies of the hulling process in a string hulling device

According to the obtained experimental data, we had built graphic dependences of hulling coefficients, kernel integrity and hulling efficiency to show how they depend on the rotation frequency of the strings. (Figures 3-5).

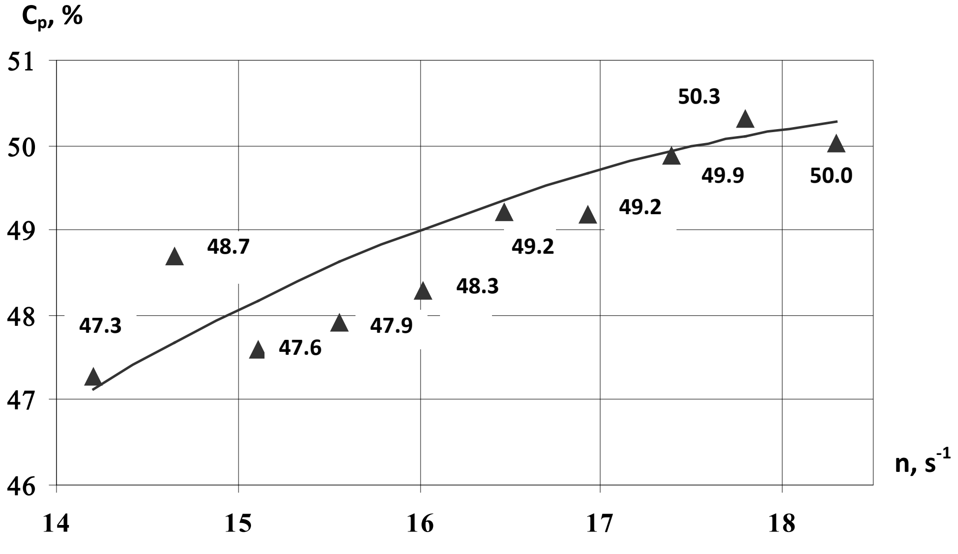

Figure 3. Experimental dependences of the hulling coefficient for buckwheat (K) on the rotation frequency of the string (n)

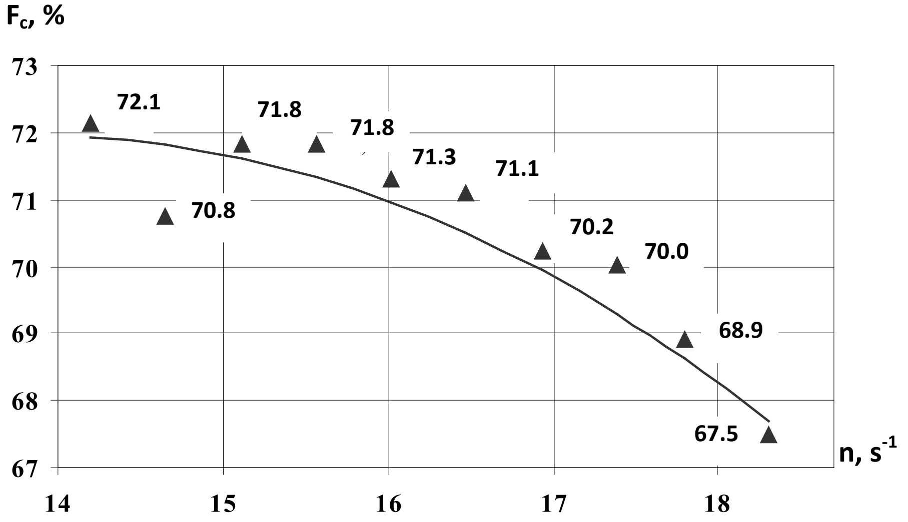

Figure 4. Experimental dependence of the coefficient of integrity of the kernel (F_c) for buckwheat on the rotation frequency of the string (n)

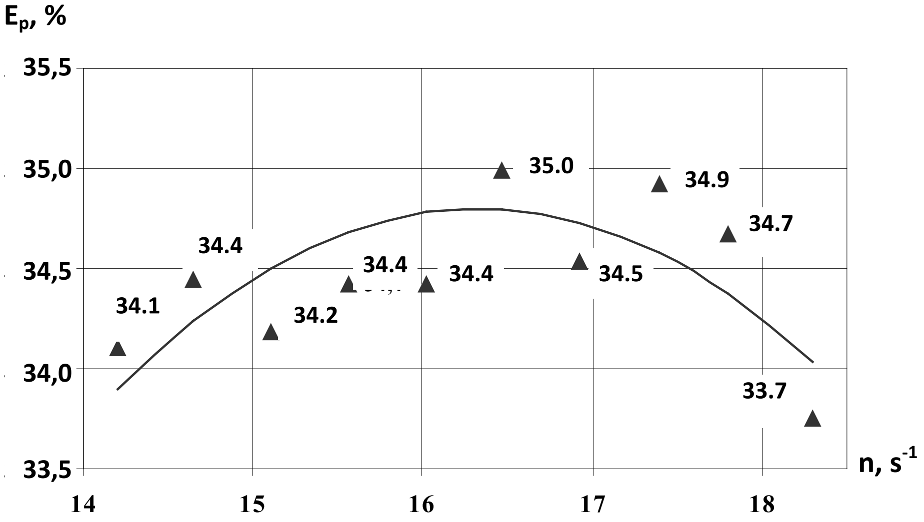

Figure 5. Approximate dependence of buckwheat hulling efficiency (E) on string rotation frequency (n)

A decrease in the rotation frequency causes a decrease in the hulling coefficient, since the impact force decreases, and accordingly, the resulting impact on the shell is insufficient for its complete destruction. Whereas cracking of the shell occurs without the final hulling of the grain due to an insufficiently intense load. That is, a large part of the grain is partially hulled and needs to undergo the technological operation of hulling again.

As the rotation frequency increases, we observe a decrease in the integrity coefficient of the core, since the energy received by the shell causes destruction not only of the shell, but also of the less fragile core.

Since the generalized assessment of the effectiveness of the hulling process is the product of the above-considered hulling coefficient and the integrity of the core, the following graphical dependence had been constructed a priori (Figure 5). As the frequency of rotation of the strings increases, we observe an increase in the hulling efficiency index until a certain kinematic mode has been reached. With a further acceleration of the rotation frequency, the effectiveness of hulling is reduced due to a sharp decrease in the amount of whole grains obtained in the hulling process.

Analysis of the response surface (Fig. 3) showed that an increase in the rotation frequency of the strings contributes to an increase in the hulling coefficient in the considered range of indicators (Eremenko, 2001). Thus, an increase in the rotation frequency of the strings by 3 rpm will cause an increase in the hulling coefficient by 4.3%.

The rotation frequency of the strings has the greatest influence on the coefficient of integrity of the core (Figure 4): when the frequency of rotation is increased by 3 rpm (from 15 to 18 rpm), the considered criterion for buckwheat decreases by 4.76% (Nwaigbo et al., 2008).

The analysis of the response surface (Figure 5), which graphically describes the dependence of the efficiency of hulling on the rotation frequency of the strings, showed the presence of an extremum, which is formed when certain kinematic modes have been reached (for buckwheat - 15.8-16.9 s^{-1}) (Malanychev, 2000).

The analysis of experimental graphical dependencies showed that the rotation frequency of the strings exerts the greatest influence on the coefficients of hulling and integrity of the core, and accordingly, on the efficiency of the hulling process. At the same time, the significance of the coefficients for both factors determines the need to take them into account when ensuring the effective operation of the device (Yarum, 2014).

The results of the experimental studies confirmed the theoretical ones, since the rotation frequency calculated according to the formula for the experimental batch of buckwheat is 16.5 rpm, which is within the limits of the experimental optimum and coincides with the range obtained as a result of the experiment of the string hulling machine (Rozhnovskyi, 2000).

Conclusions

1. The process of hulling of the original crops consists of repeatedly passing the product through the hulling device (buck-wheat – 10-15 passes). Engineering and optimization of the string hulling device allows to significantly reduce the number of passes, because only with a single pass of buckwheat, the hulling efficiency is 32-35%.

2. The conducted analysis of the functioning of the techno-logical process of impact hulling showed that the technical and economic essence of the task consists in harmonizing the techno-logical indicators of work in order to increase the processing efficiency of the cereals from the original crops. The speed at which the string collides with the grain has the main influence on the effectiveness of the impact hulling process. The equation for calculating the critical speed had been obtained depending on the main parameters of the process of the impact treatment of raw materials. Calculations according to this equation showed that the calculated critical value of the rotation frequency is 16.5 s^{-1}. Thus, the developed analytical dependencies can be used to calculate the kinematic parameters of the string hulling device.
3. The relationship between the kinematic parameter of the hulling process of the original crops by impact and the efficiency of the technological process had been experimentally determined by analyzing the coefficients of hulling and kernel integrity. It had been determined that the ranges of the rotation frequency of the strings required to ensure a high degree of efficiency of the technological process of buckwheat hulling are within 15.8 - 16.9 s^{-1}.

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KONSTRUKCJA I WYDAJNOŚĆ STRUNOWEJ MASZYNY DO OBŁUSKIWANIA GRYKI

Streszczenie. Ważnym zadaniem inżynierii żywności jest projektowanie maszyn, urządzeń i linii technologicznych do przetwarzania plonów uprawa rolniczych. Jednym z problemów dotyczących obróbki płodów rolnych jest efektywne obłuskiwanie gryki w celu pozyskania kaszy. Aby rozwiązać ten problem, opracowano urządzenie do obłuskiwania strunowego, którego zastosowanie pozwala zmniejszyć liczbę operacji ze względu na wykluczenie wstępnego sortowania na frakcje i obróbki cieplnej na mokro. Operacje te są wymagane przez inne maszyny do obłuskiwania wchodzące w skład linii technologicznych przetwarzania gryki. Opracowano schemat konstrukcyjny urządzenia do obłuskiwania strunowego i uzasadniono zasadę operacji usuwania łuski. Przeprowadzono badania teoretyczne metodami analizy i syntezy mechaniki zniszczenia oraz systematyczną analizę procesu obłuskiwania gryki metodą udarową. Badania eksperymentalne przeprowadzono z wykorzystaniem laboratoryjnego urządzenia do obłuskiwania strunowego. Przeprowadzone badania analityczne pozwoliły na określenie prawidłowości pomiędzy fizycznymi i mechanicznymi właściwościami gryki a krytyczną liniową prędkością uderzenia niezbędną do zniszczenia łuski. Pozwala to na określenie częstotliwości obrotu, przy której nastąpi zniszczenie łuski przy zachowaniu integralności rdzenia orzeszka. Badania eksperymentalne umożliwiły określenie jakości łuszczenia gryki poprzez określenie współczynnika integralności rdzenia orzeszka i współczynnika łuszczenia. Ustalono, że zakresy częstotliwości obrotów strun wymagane do zapewnienia wysokiego stopnia wydajności procesu technologicznego łuszczenia gryki mieszczą się w granicach 15,8-16,9 s^{-1}.

Słowa kluczowe: inżynieria procesów spożywczych, łuszczenie gryki, urządzenie do łuszczenia strunowego, łuszczenie udarowe, skuteczność łuszczenia gryki, współczynnik łuszczenia