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**ENERGY INTENSITY OF THE PROCESS OF DESTRUCTION OF FEED GRAIN IN
CONDITIONS OF DYNAMIC CONTACT INTERACTION WITH THE EDGE OF THE DISC
IMPACTOR**

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*In the feed industry raw material, grinding is an integral part of the production cycle. However, this process is characterized by significant energy consumption – from 3 to 100 kW * hour per ton of finished goods, and only a part of it is directly spent on grinding. Therefore, this scientific research is aimed at minimizing the consumption of energy resources by technological machines – crushers and improving the energy efficiency of the process in general is an urgent issue.*

A powerful modern research method of studying complex objects is system analysis, which enables to modernize existing machines and design new ones without conducting a large number of expensive physical experiments. Unfortunately, this method is not yet widely used in the research and design of new machines for processing agricultural products, since there are no developed and substantiated engineering theories describing the behaviour of the processed material in the workspace of the technological machine.

Grinding grain with a moisture content indicator at the level higher than the base condition, there is a low efficiency of the method of impact grinding, that is determined by the increased plasticity of the material and an increase in the value of the marginal deformation, which can lead the grain towards destruction. A partial solution of this problem is possible when combining the method of cutting and hammering, which has formed the basis of a technical solution implemented in the scientific laboratory of Vinnytsia National Agrarian University, where the design has been developed and experimental verification of the vibrating crusher have been carried out. Further improvement of the energy efficiency of the technological operation of grain grinding requires theoretical researches of the dynamics of the process, and determining the minimum amount of energy required for destruction.

The article deals with the laws of solid mechanics and the use of rheological methods in researching disperse systems, it presents the values of absolute deformation and the work that is carried out during the destruction of maize grain under the influence of applied impact-cutting load in analytical and graphic form. Moreover, the results of this research help us to establish the marginal values of plastic and elastic absolute deformations occurring in the material, which is a prerequisite for the theoretical substantiation of the grinding law.

Key words: grinding, maize grain, relative deformation, plasticity, fragility, destruction, impact, cutting.

F. 8. Fig. 4. Table. 1. Ref. 15

1. Introduction

The number of vegetarians on Earth is gradually increasing. But not so fast to Cereal grains contain up to 50% or more starch. It is a valuable carbohydrate, but an animal spends much energy on its assimilation, which could be directed to the formation of fat and other useful products. In a crushed form cereal grains make 65...70% of the total feed mass [1, 2, 3, 4].

Grinding greatly affects the efficiency of the use of grain feed. For example, the daily pig growth when feeding them with a small feed mixture is 15-19% higher compared to the growth received when feeding with



a mixture of a large fraction. Evenly chopped forage is better mixed and easier to digest. Furthermore, the grinding of grain products in the feed preparation for the needed fraction, along with other methods of processing, significantly expands the range of possibilities to use feed, thereby increasing the feed base for animal husbandry [5, 6, 7]. However, it is necessary to strive to avoid excessive grinding, since with thin grinding there are large losses from spraying flour, dusty fractions, and the specific energy consumption for grinding is increased by 2-3 times compared to medium and large grinding. At the same time, a part of the feed is poorly absorbed by animals.

Thus, grinding largely determines the feed quality, their digestibility by animals and birds and has a significant influence on the growth of enterprise productivity, rhythmicity of work and the production cost of finished goods [8, 9, 10], and reducing the energy intensity of the process is an urgent task.

2. Analysis of recent researches and publications

Nowadays, hammer crushers have become widely used on livestock farms and feed productions for grinding grain [3]. In these technological machines, the destruction of the material occurs in a consistent course of stages: applying a distributed load to the flat face of a hinged hammer, the emergence of various kinds of deformations in the body and the growth of stresses, the achievement of limit values of stresses and deformations, breaking of atomic and molecular bonds [2].

Fragile and plastic destruction occur mainly in the process of crushing. A slight deformation of the material is typical by for fragile destruction, and after the destruction there are no residual deformations. The applied energy is spent on overcoming the forces of mutual adhesion of particles, that is, on the formation of a new surface. During the destruction of plastic materials, energy is spent both on breaking structural bonds and on significant plastic deformations. Moreover, the energy spent on deformation is converted into heat.

The strength limit of the material and its maximum deformation is determined by the structural-mechanical characteristics of the grain and depends on the variety, size, density, moisture content, temperature, etc. Thus, with an increase in moisture content, there is a decrease in fragility and strength limits with a simultaneous increase in plasticity and absolute deformation, which the grain can perceive before the destruction begins.

Grinding fragile materials requires much lower energy consumption compared to plastic ones. As it has already been mentioned, the fragility and plasticity of materials are determined by their physical conditions, from energy viewpoints it is advisable to grind the material in a fragile state.

The experience has shown that feed grain with moisture content exceeding the basic conditions is mainly used for the feed production. This can be explained by both the material aspects (the market value of crude grain is much lower) and the production capabilities of a particular enterprise.

In order to reduce costs, it is quite promising to introduce machines for grinding grain, proposed by Serheiev N.S. [4], Abramov A.A. [5], Nanka O.V. [6], the operation principle of which is based on the combination of cutting and chipping methods. The advantage of such combination is the local excessive stress of surface micro volumes in places of loading. In the process of cutting, the blade of the knife is headed into the product and a specific pressure is created near the surface of the contact, sufficient to destroy the body.

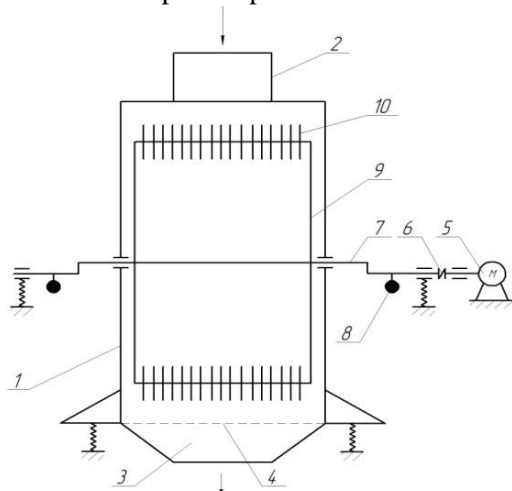


Fig. 1. Principal scheme of the vibratory disc crusher

On the basis of the laboratory of the department of technological processes and equipment for food and processing industries at Vinnitsia National Agrarian University, a the disc vibratory crusher has been developed (Fig. 1), in which, when the electric motor 5 is turned on, 5 torsion torque through the clutch 6 is transmitted to the kinematic shaft 7 with counterweights 8, the rotation of which leads to the creation of a combined power and torque imbalance of the rotor 9 placed on it with axles and disc beats 10 [7].

The processing material continuously enters through the loading neck 2 and is crushed in the process of rotating and oscillatory movement of the disc beats 10. With a decrease in particle size, crushed material under the influence of centrifugal



forces and variable loads through the sieve surface undergoes intensive classification: particles equal to or smaller than the diameter of the holes of the sieve 4 are unloaded through the neck 3, the rest – for re-grinding [7].

This combination of grinding methods (impact and cutting) makes it possible to process unconditioned raw materials with a high moisture content index while reducing energy consumption for this technological operation, which has been confirmed by the results of experimental researches.

However, despite the overall decrease in energy intensity, a further energy saving measure requires a deeper theoretical research of the interaction of the material with the impactor of the technological machine.

3. Aim of the article

The aim of research is theoretical study of the energy intensity of the process of grinding material with a vibrating crusher while combining impact and cutting effects by assessing the destruction operation for a separate grain.

4. Research materials and methods

The scientific provisions of this article are based on the classical theory of mechanical oscillations, the theory of vibration grinding, the mechanics of dispersion medium, the mechanics of solids, and theory of strength III.

To determine the values of elastic and plastic deformations of the body, rheological methods of studying dispersed systems have been used. We have also applied software Excel and MathCad 15 for analytical research and graphical interpretation of the results to verify the grain destruction.

The object of technological action (research material) is the grain of dent corn. The object of research is the energy intensity of the process of destruction of a separate grain in the conditions of impact-cutting action. The subject of the study is a change in the structural-mechanical and physical-mechanical characteristics of a separate grain while interacting with the impactor of the crusher.

5. Research results

Maize grain is a complex corn, which is a single entire organic compound sharply heterogeneous in its structure, physical properties, chemical composition, absolute mass, biological purpose of anatomical parts (embryo, endosperm, outer and inner shells), and can be presented in the form of elastic-viscous-plastic, colloidal, capillary-porous body, having a protein shell, starch filler and cellulose shell. In view of this, structural-mechanical characteristics can be generally represented by a rheological model that has a serial connection of the Maxwell model of the perfect body (describes the elastic shell of the grain, with bound moisture), the parallel connection of Hooke's model of a perfectly elastic body with Saint-Venant's model of the perfectly plastic body (describes the behaviour of floury endosperm containing an elastic-plastic starch filler) and the model of the Kelvin body (describes the behaviour of an elastic germ containing molecular moisture), that is M-HStV-K body. The mathematical description of the behaviour of the proposed rheological model under the influence of applied force F is quite fully reflected in the reported results of previous researches. [8].

The process of destruction of grain by impact cutting consists of three sequential phases. The first phase reveals itself in the contact of the grain with the blade, resulting in a compression stress, which is characterised by the magnitude of its deformation. The second phase occurs when the compressive stress reaches a certain limit caused by the strength of the grain, and is manifested in the formation of cracks in it. The third phase is the ultimate destruction of the coherent structure [9].

Since maize grain is an aggregate of individual bodies of inhomogeneous structure, some of which have a lower yield strength than others. If some force F is applied to the body, some parts of it are subjected only to elastic deformations, and others begin to flow, after a while they are gradually released from stress and it begins to distribute to more elastic parts of the grain, therefore, the stress in this part increases and deformation increases. [10].

As a result of the theoretical research of rheological characteristics of maize grain, the rheological model has been offered (Fig. 2) and the analytical dependence of absolute deformation occurring in the M-HStV-K body has been defined:

$$\gamma = \left[\tau \left(\frac{e^{-\frac{2\mu\tau}{\eta}} - 1}{2\mu} - \frac{e^{-\frac{\mu\tau}{\eta}} - 1}{\mu} \right) \right]^{\frac{\mu\tau}{\eta}} . \quad (1)$$

where τ is a tangential stress, MPa; μ – the shear modulus, MPa; η – the coefficient of viscosity, MPa·s.

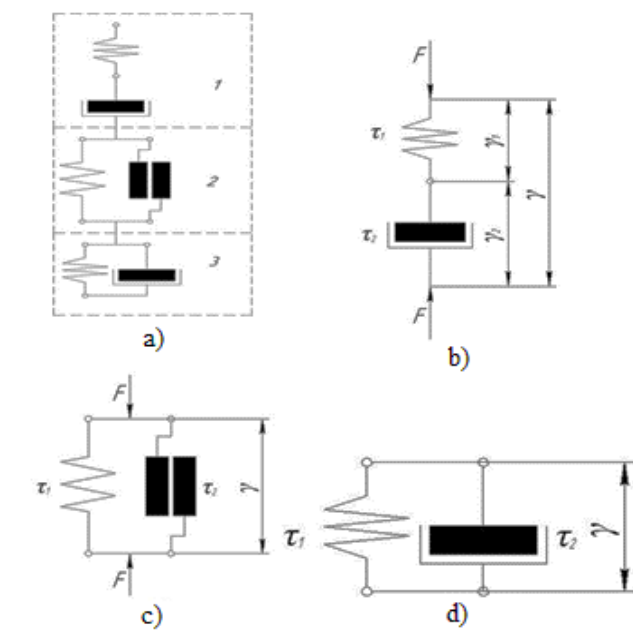
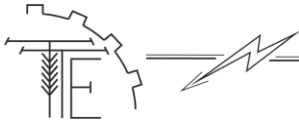


Fig. 2. Proposed Rheological Model: a) maize grain; b) shell; c) endosperm; d) germ

As it has been already noted, the structural-mechanical indicators of the material significantly are significantly affected by moisture content. Table 1 shows the values of rheological coefficients for the selected material (dent corn grain) depending on the moisture [11–13].

Table 1

Values of rheological coefficients for maize grain [8]

Moisture content W, %	13-14	16-17	19-20	22-23	25-26
Shear modulus, μ (MPa)	8,61	5,07	3,05	2,43	2,25
Viscosity coefficient, η (MPa·s)	29,68	20,22	14,22	11,51	10,87
Strength limit, τ_{\max} . (MPa)	2,9	1,75	1,035	0,875	0,825

Absolute deformation, which occurs in the grain under the influence of the applied load, can be presented in the form of:

$$\Delta h = \gamma \cdot b, \quad (2)$$

where: γ – relative deformation of the material; b – grain thickness, mm.

Theoretically, the operation destruction of one grain in the conditions of impact-cutting load can be found with the help of dependence:

$$A^T = F \cdot \Delta h = F \cdot \gamma \cdot b, \quad (3)$$

where: F is the force applied to the grain, H.

Since normal stresses arising in the grain under the influence of the applied force can be presented in the form of:

$$\sigma = \frac{F}{A}, \quad (4)$$

where A is the area of the cross section of the grain, m^2 ;

Then:

$$F = \sigma \cdot A. \quad (5)$$

Taking into consideration theory of strength III single-axis load:

$$\tau_{\max} \approx \frac{\sigma}{2}, \quad (6)$$

$$\sigma = 2\tau_{\max}. \quad (7)$$

Substituting the expressions (1) and (7) in (3) we shall obtain:



$$A^T = 2\tau_{\max} \cdot A \cdot \left[\tau_{\max} \cdot \left(\frac{e^{\frac{2\mu t}{\eta}} - 1}{2\mu} - \frac{e^{\frac{\mu t}{\eta}} - 1}{\mu} \right) \right]^{\frac{\mu t}{\eta}} \cdot b. \quad (8)$$

To solve and graphical interpretation of the obtained equations (1) absolute deformation of the maize grain under the influence of impact-cutting load, the Excel software environment was used, as a result of which graphical dependencies have been received (Fig. 3).

Analytical and graphical interpretation of the equation (8), characterising the theoretical work of destruction of maize grain by the impactor of the vibrating disc crusher, has been carried out in the mathematical environment MathCad 15 (Fig. 4). The database has been accepted and it includes the following values: rheological coefficients at different moisture content indicators; mean geometric characteristics of the grain [14] and the range of tangential stresses $\tau = 0 \dots 6$ MPa.

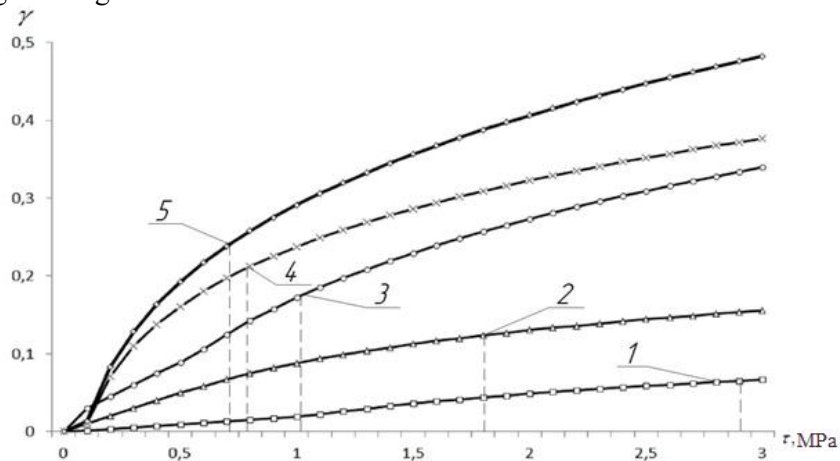


Fig. 3. Dependence of the relative deformation of maize grain on tangential stresses at moisture values [8]: 1 – W=13-14%; 2 – W=16-17%; 3 – W=19-20%; 4 – W=22-23%; 5 – W=25-26% – the strength limit of the material.

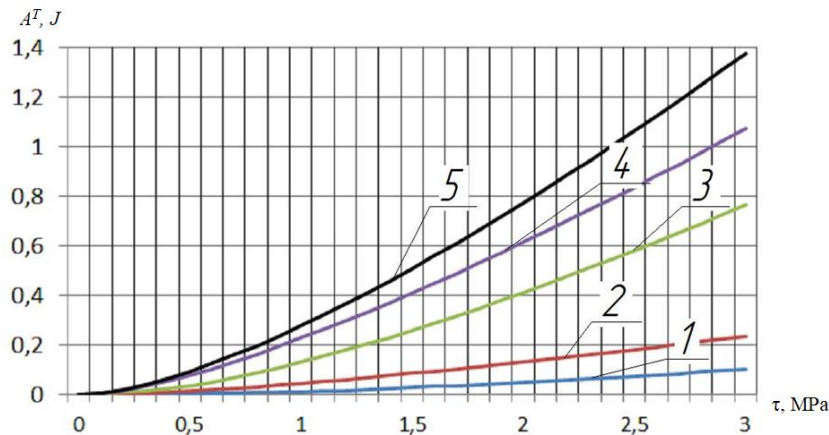


Fig. 4. Dependence of theoretical work of destruction of maize grain on normal stresses at moisture values: 1 – W=13-14%; 2 – W=16-17%; 3 – W=19-20%; 4 – W=22-23%; 5 – W=25-26%

6. Conclusions

The nature of the curves (Fig. 3) allows us to assume that at the initial phase of applying the load to the grain, there are mainly elastic deformations, which is reflected in the form of straight sections on the graphs (linear dependencies which can be approximately described according to Hooke's law). Thus, for grain with moisture content W=25-26% (curve №5) in the interval of tangential stresses $\tau = 0 \dots 0.19$ MPa, there is a rapid linear increase in relative deformation to a value of 0.08. With further increase ($\tau = 0.19 \dots 0.825$ MPa) the shape of the deformation curve changes somewhat and takes the form of a branch of parabola, which may



indicate the predominant plastic deformation that occurs in the grain, up to its destruction at $\tau = 0.825$ MPa and relative deformation of 0.24.

When destroying the grain, with a moisture content index of 13-14% (Fig. 4), the theoretical work of destruction includes work on overcoming elastic and plastic deformations and makes up 0.09 J, with higher moisture values, for example, 25-26% of this indicative is 0.195 J. This difference in the operation of destruction arises from scattering a part of the kinetic energy of the impact disc in the grain due to its plastic deformation, and necessitates further researches aimed at increasing the energy efficiency of the grinding process.

The obtained results of structural-mechanical characteristics and theoretical work of grain destruction have made it possible to assess the marginal values of plastic and elastic deformations occurring in the material, which is the basis for further research of the dynamics of the process of grinding maize grain with the vibratory disc crusher, particularly, establishing the correlation between the variance of the material and energy consumption for its achievement.

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ЕНЕРГОЄМНІСТЬ ПРОЦЕСУ РУЙНУВАННЯ ФУРАЖНОГО ЗЕРНА В УМОВАХ ДИНАМІЧНОЇ КОНТАКТНОЇ ВЗАЄМОДІЇ ІЗ КРОМКОЮ ДИСКОВОГО УДАРНОГО ЕЛЕМЕНТА

Подрібнення сировини в комбікормовій промисловості є невід'ємною частиною виробничого циклу. Проте, даний процес характеризується значними витратами енергії – від 3 до 100 кВт · год на



тонну готової продукції, причому тільки частина її витрачається безпосередньо на подрібнення. Тому, наукові дослідження спрямовані на мінімізацію споживання енергетичних ресурсів технологічними машинами – дробарками та підвищення енергоефективності процесу в цілому є актуальною задачею.

Потужним сучасним методом вивчення складних об'єктів є системний аналіз, який дозволяє модернізувати наявні та конструювати нові машини без проведення великої кількості дорогих фізичних експериментів. На жаль, цей метод поки що недостатньо широко застосовується при дослідженні і проектуванні нових машин для переробки сільськогосподарських продуктів, оскільки відсутні розроблені і обґрунтовані інженерні теорії, що описують поведінку оброблюваного матеріалу в робочому просторі технологічної машини.

При подрібненні зерна із показником вологовмісту вище базисної кондиції спостерігається низька ефективність способу подрібнення ударом, що зумовлено підвищеною пластичністю матеріалу та збільшенням значення граничної деформації, яку зерно може сприймати до руйнування. Часткове вирішення даної проблеми можливе при комбінуванні способу різання та удару, що і лягло в основу технічного рішення реалізованого у науковій лабораторії Вінницького національного аграрного університету, де було розроблено конструкцію та здійснено експериментальні випробування вібродискової дробарки. Подальше підвищення енергоефективності технологічної операції подрібнення зерна потребує здійснення теоретичних досліджень динаміки процесу, та визначення мінімальної кількості енергії, необхідної для руйнування.

В статті, базуючись на законах механіки твердого тіла та шляхом застосування реологічних методів дослідження дисперсних систем представлені значення абсолютної деформації та роботи яка здійснюється при руйнуванні зернини кукурудзи під дією прикладеного ударно-різального навантаження в аналітичній та графічній формі. Крім того, результати даних досліджень дозволяють встановити крайові значення пластичних та пружних абсолютних деформацій, що відбуваються в матеріалі, що є необхідною умовою для теоретичного обґрунтування закону подрібнення.

Ключові слова: подрібнення, зернина кукурудзи, відносна деформація, пластичність, крихкість, робота руйнування, удар, різання.

Ф. 8. Рис. 4. Табл. 1. Літ. 15

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