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JUSTIFICATION OF THE DESIGN PARAMETERS OF THE WORKING CHAMBER OF THE OIL CAKE CRUSHER

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The article considers the issue of substantiating and optimizing the design parameters of the working chamber of a hammer crusher intended for grinding oil cake in order to improve the efficiency, productivity and energy performance of the grinding process. The relevance of the study is determined by the fact that the installed power of the electric drive of existing hammer crushers often does not fully correspond to the geometric dimensions and technological capabilities of the working chamber, which may limit throughput, reduce the stability of operation and increase specific energy consumption. The influence of the diameter of the working chamber, the effective area of the sieve and the diameter of its holes on the intensity of material grinding, pressure formation in the annular product layer, particle movement and sieve throughput is substantiated.

An experimental approach to determining the rational power of the electric drive depending on the main structural and technological parameters of the crusher is proposed. Particular attention is paid to the dependence of specific energy consumption on the degree of crusher loading, working chamber dimensions and sieve parameters, as well as to their influence on the quality and uniformity of the obtained ground product. The methodological basis of the work consists of experimental studies carried out on a specially manufactured crusher with a variable working chamber diameter ranging from 400 to 1200 mm. Barley with a moisture content of 13% was used as the model material during the experiments.

As a result of the research, rational operating modes were established that provide a favorable combination of minimum specific energy consumption, high productivity and the required grinding quality. The obtained dependencies make it possible to more accurately coordinate the power of the electric drive with the geometric parameters and throughput capacity of the working chamber. The research results can be used in the design, modernization and engineering calculation of hammer crushers for livestock and feed production, contributing to improved energy efficiency, reduced operating costs and more rational use of technological equipment.

Keywords: *hammer crusher, working chamber, chamber diameter, sieve, specific energy consumption, productivity, electric drive power, cake grinding, design parameters, energy efficiency.*

Eq. 5. Fig. 2. Ref. 10.

1. Statement of the problem

Modern trends development techniques for preparation feed in livestock farming associated with the increase energy efficiency processes crushing, reduction specific expenses electricity and provision stable qualities ready product. One from promising directions achievement the specified indicators are improving constructive parameters hammerhead crushers , in particular working camera , which determines area sieve , intensity percussion actions and pass ability cars .

Simultaneously existing hammer crushers that used in animal husbandry, not always are working with maximum efficiency. Power their electric drive often does not allow fully download crusher, and the dimensions working cameras are not responding established power engine. This leads to increased specific expenses energy, reduction performance and deterioration quality indicators grinding [1].

Special relevance acquires definition influence diameter working cameras on the process grinding. Change diameter accompanied change sieve area, quantity blows hammers on the product per unit of time, pressure in the annular layer and the curvature of the sieve. All these factors directly affect the necessary power electric drive and specific flow rate energy. Existing constructions mainly focused on fixed dimensions cameras

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and do not take into account opportunities optimization diameters for different types sieves and types raw materials. This causes necessity development scientifically justified technical and technological approach to choice constructive parameters working hammer crusher chambers

2. Analysis of recent research and publications

The problem of increasing the efficiency of hammer crushers is the subject of a significant amount of research in the field of agricultural production mechanization [1]. It becomes especially relevant when working with various types of feed raw materials, in particular, cake and grain, the physical and mechanical properties of which significantly affect the grinding process.

Domestic studies [3] show that the power of the electric drive of DKU-type crushers often does not correspond to the dimensions of the working chamber, which limits the possibility of full loading of the machine. It has been experimentally established that increasing the power of the drive electric motor allows reducing specific energy consumption with a corresponding increase in productivity. At the same time, changing the width of the working chamber is equivalent to the parallel operation of several crushers and does not significantly affect the intensity of the grinding process itself. Instead, changing the diameter of the chamber changes both the sieve area and the dynamics of the impact interaction of the hammers with the product.

When the diameter of the working chamber increases at a constant circular speed of the hammers, the number of blows to the product decreases, which reduces the intensity of grinding [4]. With a decrease in diameter, the pressure in the annular layer of the product increases, since the pressure increase is inversely proportional to the radius of the rotor. In addition, an increase in the radius reduces the curvature of the sieve and the area of the projection of the holes onto the normal plane, which can affect the throughput [5] .

However, the existing studies do not sufficiently address the complex influence of the working chamber diameter on the optimal power of the electric drive for different sieve hole diameters. Most of the work is focused on fixed structures, while the relationship between the design parameters of the chamber and the energy and quality indicators of the grinding process requires additional experimental justification.

3. Purpose of the study

The purpose of the study is to substantiate the design parameters of the working chamber of the hammer mill and determine the influence of the chamber diameter and the diameter of the sieve holes on the optimal power of the electric drive, specific energy consumption, and machine productivity.

4. Results and discussion

Hammer crushers, widely used in livestock farming for grinding grain and cake, are not always able to operate in the mode of maximum energy efficiency. The main reason for this is the mismatch of the power of the electric drive with the capabilities of the working chamber: the engine often does not allow to fully load the machine, as a result of which the specific energy consumption remains elevated [6] . Experimental studies conducted on a serial DKU crusher with a nominal capacity of 1500 kg/h showed that increasing the power of the drive electric motor to 20 kW is accompanied by a noticeable decrease in the specific energy consumption. This indicates the presence of a reserve for increasing efficiency due to the correct coordination of the drive power with the parameters of the working chamber.

When studying the characteristics of hammer crushers in detail, it is worth noting that the power of the electric motor, as a rule, does not correspond to the dimensions of the working chamber, which is the main factor determining the performance of the machine. Changing the geometric dimensions of the working chamber directly affects the area of the sieve, and therefore the throughput and the required power of the electric drive. The area of the sieve can be changed in two ways: by changing the width of the chamber or by changing its diameter.

Changing the sieve area by increasing (or decreasing) the width of the working chamber has practically no effect on the intensity of the crushing process itself [7, 8] . Such a change is equivalent to the parallel operation of several identical crushers and only scales the productivity in proportion to the width. On the other hand, changing the diameter of the working chamber significantly changes the physics of the process: not only the sieve area changes, but also the frequency of hammer blows on the product particles, the pressure in the annular layer of the material and the conditions of the passage of particles through the sieve holes.

When the diameter of the working chamber increases, while maintaining a constant circular speed of the hammers, the number of blows per unit mass of the product per unit time decreases. This leads to a decrease in the intensity of grinding [9] . On the contrary, with a decrease in the diameter of the working chamber, the

pressure in the annular layer of the product increases. The increase in pressure in the layer is inversely proportional to the radius of the crusher rotor:

$$\Delta P \infty \frac{1}{R}. \quad (1)$$

where ΔP – pressure increase in the annular layer, Pa; R – radius of the rotor (working chamber), m.

In addition, as the radius of the working chamber increases, the curvature of the sieve decreases. As a result, the projection area of the sieve holes on the plane normal to the sieve surface decreases [10] . This can negatively affect the throughput of the sieve. All of these factors have a complex effect on the amount of required power of the crusher's electric drive.

To quantitatively determine the influence of the diameter of the working chamber on the optimal power of the electric drive, a series of experiments were conducted on a specially manufactured experimental setup. The design of the setup allowed changing the diameter of the working chamber in the range from 400 to 1200 mm. The drive was carried out by an electric motor with a power of 40 kW. The experiments used interchangeable sieves with a hole diameter of 1.7; 2.5; 3.5 and 4 mm. Barley with a moisture content of 13% was used as the grinding object. The results of the experiments are presented in graphs (Fig. 1 and Fig. 2).

From the analysis of the graph in Fig. 1, a clear relationship between the specific energy consumption and the degree of loading of the crusher follows. With increasing loading, both the power consumption and the productivity increase simultaneously. In this case, the increase in productivity occurs much faster than the increase in the power consumption, as a result of which the specific energy consumption decreases. The decrease in the specific energy consumption continues to a certain critical limit, the value of which depends on the diameter of the sieve holes and the design features of the crusher.

If the load exceeds this limit, the efficiency of the machine decreases. Therefore, to maximize the use of energy spent on grinding, the crusher must be loaded to the limit mode. In this case, the grinding module increases slightly due to the reduction of the proportion of dust particles, which has a positive effect on the quality of the finished product.

The lowest value of specific energy consumption is achieved above the limit point of the direct proportional dependence of the effective (useful) energy consumption on the crusher productivity. This follows from the following relations:

Specific cost energy in the limit point direct proportionality:

$$A_1 = \frac{N_{xx}+N_1}{Q_1} \quad (2)$$

where A_1– specific energy consumption at the limit point, kWh /t;N_{xx}– idle power of the crusher, kW; N_1– useful power at the limit point, kW; Q_1– productivity at the limit point, t/h.

Lowest specific energy consumption (optimal mode):

$$A_1 = \frac{N_{xx}+N_2}{Q_2} \quad (3)$$

where A_1– specific energy consumption at the minimum point, kWh /t; N_{xx}– idle power of the crusher, kW; N_2 – useful power at the minimum point, kW; Q_2– productivity at the minimum point, t/h.

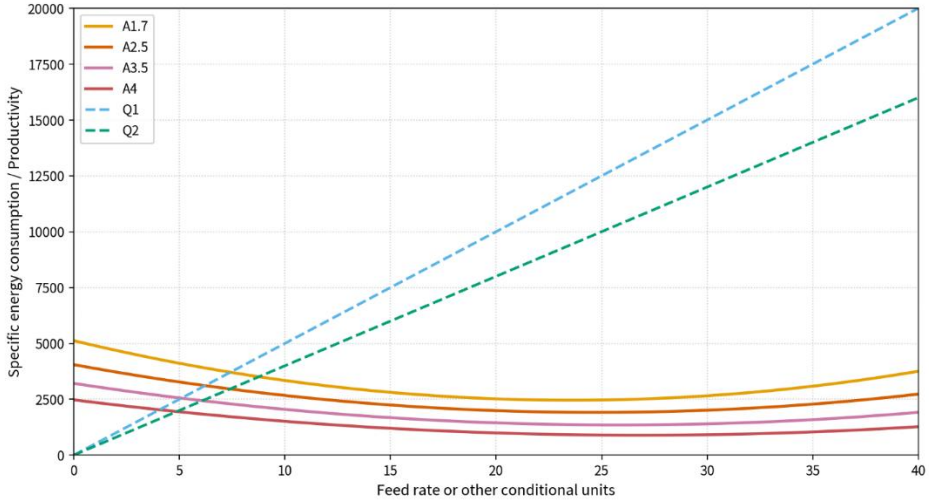


Fig. 1. Dependence of specific energy consumption and productivity of the hammer mill on drive power

Correlation between these values can be write in the form:

$$A_2 < A_1, \text{at} Q_2 > Q_1 \quad (4)$$

Based on experimental data, a graph was constructed (Fig. 1), which demonstrates the dependence of specific energy consumption (A) and productivity (Q) on the power of the electric drive when grinding barley with a moisture content of 13% on sieves with a hole diameter of 1.7; 2.5; 3.5 and 4 mm.

The second graph (Fig. 2) illustrates the dependence of the power consumed by the electric motor on the working chamber diameter for different sieve aperture diameters. The curves correspond to different sieve aperture sizes.

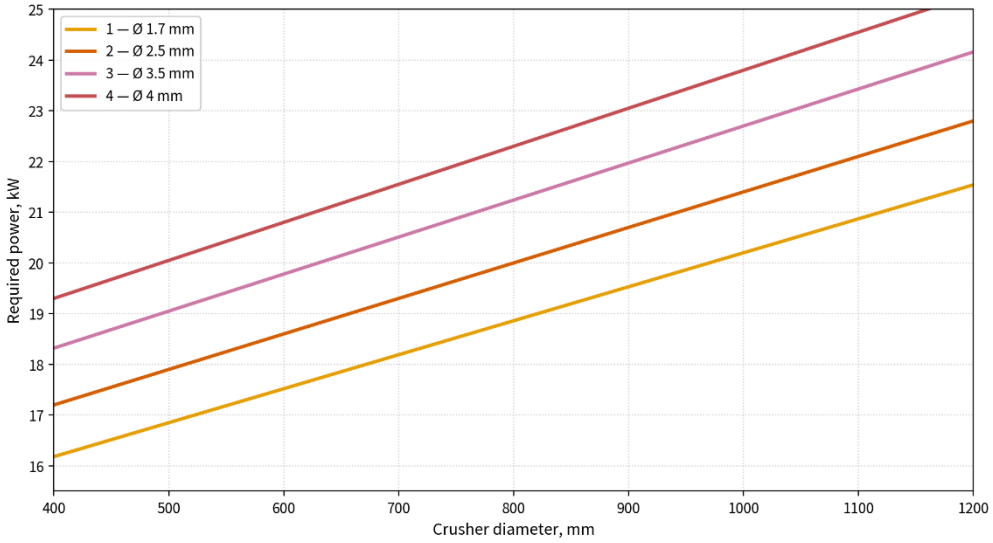


Fig. 2. Dependency of required motor power on crusher diameter

The obtained results indicate that an increase in the sieve aperture diameter leads to an increase in the power required by the electric motor. For fixed design parameters of the hammer crusher, the power demand of the drive motor is significantly influenced by the sieve aperture size. Since commercially available crushers are typically equipped with interchangeable sieves of different aperture diameters, selecting an appropriate electric motor becomes more challenging. In practical calculations, a permissible deviation of ±30% from the minimum calculated power value may be adopted for a specific set of sieves.

For the investigated operating conditions, a sieve with an aperture diameter of 4 mm is considered the reference configuration. The use of sieves with smaller apertures (1.5–1.7 mm) at the same motor power increases the specific energy consumption and may reduce the crusher throughput due to greater resistance to material passage through the sieve. Therefore, the selection of the sieve aperture diameter should be based on a compromise between the required particle size, crusher productivity, and energy efficiency.

Of particular importance is the dependence of power on the diameter of the working chamber: reducing the diameter from 1200 mm to 400 mm requires an increase in drive power by about three times. This dependence is practically constant for all the sieves studied and can be described by the relationship:

$$\frac{N_{400}}{N_{1200}} \approx 3 \quad (5)$$

where N_{400} – the required power for chamber diameters of 400 and 1200 mm, respectively.

Thus, to ensure minimum specific energy consumption and maximum efficiency of the hammer crusher, several interrelated conditions must be observed.

First, the machine should be loaded as close as possible to the optimum point, which lies above the limit of the direct proportional relationship between useful power and productivity. It is in this zone that the specific energy consumption reaches its lowest value. At a lower load, part of the power is spent inefficiently, and when the optimal limit is exceeded, the efficiency decreases again due to overloading of the working chamber and deterioration of the conditions for product separation through the sieve. In addition, operation in the optimal mode helps to reduce the amount of dusty fractions and improve the quality of the finished feed.

Secondly, the power of the drive motor must be matched to the largest diameter of the sieve holes in the set supplied with the crusher. Since sieves with different hole diameters (from 1.7 to 4 mm) significantly affect the required power, choosing a motor with the largest hole allows you to avoid both underloading and overloading the machine. In this case, the permissible power deviation can be taken within ±30% of the minimum calculated value. Working with sieves of smaller diameter with the same motor power leads to an increase in specific energy consumption, although productivity can increase by 15–20%.

Thirdly, when designing or upgrading a crusher, it is imperative to take into account the influence of the diameter of the working chamber. Reducing the diameter from 1200 mm to 400 mm intensifies the crushing

process by increasing the pressure in the annular layer of the product and increasing the frequency of hammer blows. However, this is accompanied by a significant (approximately threefold) increase in the required power of the electric drive. Therefore, the choice of the chamber diameter should be a compromise solution between the desired crushing intensity, the available engine power and the performance requirements.

Following these recommendations allows you to significantly increase the energy efficiency of hammer crushers, reduce specific electricity consumption, and ensure stable quality of the crushed product when working with various types of raw materials, in particular, cake and grain.

5. Conclusions

As a result of the conducted experimental study, the influence of the main design parameters of the working chamber of the hammer crusher on the energy and quality indicators of the crushing process of cake and grain materials was substantiated. It was shown that the power of the electric drive, the diameter of the working chamber and the diameter of the sieve holes are interrelated factors that determine both the productivity of the machine and the specific energy consumption.

It has been established that changing the diameter of the working chamber significantly affects the intensity of the grinding process. Reducing the diameter from 1200 mm to 400 mm while maintaining the circular speed of the hammers leads to an increase in the required power of the electric drive approximately three times. This is explained by the increase in pressure in the annular layer of the product (the increase in pressure is inversely proportional to the radius of the rotor) and an increase in the frequency of hammer blows on the material particles. At the same time, increasing the diameter of the chamber reduces the intensity of grinding due to a decrease in the number of blows per unit of time and a change in the curvature of the sieve, which affects the throughput of the holes.

It has been experimentally confirmed that the specific energy consumption decreases with increasing crusher loading to a certain limit point. Further exceeding this mode leads to a decrease in efficiency. The lowest value of the specific energy consumption is achieved in the zone above the limit point of the direct proportional dependence of useful power on productivity. At the same time, the grinding modulus increases slightly due to a decrease in the proportion of dust particles, which has a positive effect on the quality of the finished product.

It has been established that the power of the drive electric motor depends on the diameter of the sieve holes. An increase in the diameter of the holes is accompanied by an increase in the required power. Since serial crushers are equipped with sets of sieves with different hole diameters (1.7; 2.5; 3.5 and 4 mm), it is advisable to select the electric motor based on the sieve with the largest hole diameter, allowing deviations within ±30% of the minimum power value. Working with sieves of smaller diameter at the same engine power leads to an increase in specific energy consumption, although productivity can increase by 15–20%.

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ОБҐРУНТУВАННЯ КОНСТРУКТИВНИХ ПАРАМЕТРІВ РОБОЧОЇ КАМЕРИ ПОДРІБНЮВАЧА МАКУХИ

У статті розглянуто питання обґрунтування та оптимізації конструктивних параметрів робочої камери молоткової дробарки для подрібнення макухи з метою підвищення ефективності, продуктивності та енергетичної результативності процесу подрібнення. Актуальність дослідження зумовлена тим, що встановлена потужність електропривода існуючих молоткових дробарок часто не повною мірою відповідає геометричним розмірам і технологічним можливостям робочої камери, що може обмежувати продуктивність обладнання, погіршувати стабільність його роботи та підвищувати питомі витрати електроенергії. Обґрунтовано вплив діаметра робочої камери, ефективної площі решета та діаметра його отворів на інтенсивність подрібнення матеріалу, формування тиску в кільцевому шарі продукту, характер переміщення частинок і пропускну здатність решета.

Запропоновано експериментальний підхід до визначення раціональної потужності електропривода залежно від основних конструктивних і технологічних параметрів дробарки. Особливу увагу приділено залежності питомих витрат енергії від ступеня завантаження дробарки, розмірів робочої камери та параметрів решета, а також їх впливу на якість і рівномірність одержаного подрібненого продукту. Методичною основою роботи є експериментальні дослідження, проведені на спеціально виготовленій дробарці зі змінним діаметром робочої камери від 400 до 1200 мм. Як модельний матеріал під час дослідів використовували ячмінь вологістю 13 %.

У результаті досліджень встановлено раціональні режими роботи, які забезпечують сприятливе поєднання мінімальних питомих витрат енергії, високої продуктивності та необхідної якості подрібнення. Отримані залежності дають змогу точніше узгоджувати потужність електропривода з геометричними параметрами та пропускною здатністю робочої камери. Результати дослідження можуть бути використані під час проєктування, модернізації та інженерного розрахунку молоткових дробарок для потреб тваринництва і кормовиробництва.

Ключові слова: *молоткова дробарка, робоча камера, діаметр камери, решето, питома витрата енергії, продуктивність, потужність електропривода, подрібнення макухи, конструктивні параметри, енергоефективність.*

Ф. 5. Рис. 2. Літ. 10.

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