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INTENSIFICATION OF THE PROCESS OF DOSING BULK CONCENTRATED FEEDS BY SIEVE HOPPER

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Дослідження присвячено розробці та обґрунтуванню параметрів дозуючого пристрою, який встановлюється у технологічному процесі виробництва сипких концентрованих кормів. Проведено аналіз конструкцій дозаторів, способів підвищення продуктивності та якості їх роботи, визначено перспективи розвитку даного напрямку. Підвищення ефективності дозування досягнуто шляхом модернізації решітного дозатора з розрідженою видачею дозованого матеріалу за рахунок використання отворів у вигляді пятипелюсткової епіциклоїди.

Для визначення раціональних конструктивно-технологічних параметрів модернізованого решітного дозатора проведено математичне моделювання руху сипкого середовища, обрані умови процесу, встановлені кінцеві математичні вирази. Окрім параметрів решітного дозатора у виразах та експериментах враховано властивості сипких кормів. Визначені діапазони варіювання розмірів отворів нижнього та верхнього решіт, амплітуда та частота їх коливань, що є значущими параметрами процесу дозування сипких кормів на запропонованому дозаторі.

Результати моделювання підтверджено проведеними експериментальними дослідженнями. Експериментально встановлені залежності продуктивності решітного дозатора його від конструктивно-кінематичних параметрів, у базовому та модернізованому варіантах. Використавши данні залежності, за умови максимальної ефективності дозування, визначені діапазони варіювання продуктивності модернізованого дозатора, які склали 0,75...2,6 т/год. Встановлено, що використання решіт з активаторами підвищують продуктивність дозатора на 15...44,4 %. Адекватність розробленого математичного моделювання підтверджена допустимою розбіжністю результатів з експериментами, яка не перевищила 5 %.

В результаті дослідження отримана методика досліджень дозаторів решетного типу, яка передбачає можливості дослідження впливу форм та розмірів отворів на ефективність дозування сипких кормів

Ключові слова: дозатор, концентрований корм, віброрешето, рівномірність дозування, активатори просіювання, діаметр отвору, амплітуда коливань

1. Introduction

Livestock production is a priority for the economies of many European countries and demands the improvement of its profitability by increasing the volumes with a parallel reduction in cost.

Modern livestock maintains the positive dynamics of its growth. Thus, milk yields of cows reach up to 12 thousand kg of milk per lactation, live weight of chickens reaches up to 3 kg for 40 days, the growth of pigs is up to 1 kg per day etc. [1]. A similar intensity is explained to a great extent by breeding new breeds, lines, crosses, that is, genetic research. The growth of efficiency requires adequate nutrition, which is determined by the energy, amino acid, protein, mineral and vitamin directions, and ultimately contributes to the implementation of genetic potential of animals. For example, in pork production, coefficient of the potential realization is influenced by the genetic potential by 20 %, by the microclimate by 20 % and by feeding by 60 % [2]. Feeds take a significant part in the production costs of the final product of livestock.

In modern farm animals feeding, there prevails the formulation containing grain: in combined feeds for swine and poultry, its content can reach 90 % of the total weight, for ruminants – 30 %, for cows – up to 45 % [1]. This is due to the energy saturation of grain mixes of grain crops.

The potential of increasing in livestock production is the application of bulk feed based on scientifically substantiated recipes which include biologically active enzymes. Modern production technologies imply an appropriate quality of feeding. For this purpose, the rations that are balanced in nutritive substances due to the existence of effective additives are used [3]. An increase in productivity of meat, milk and wool due to their application can be up to 25 % a with simultaneous decrease in feed consumption up to 15 %, animal mortality and morbidity rates – up to 40 % [4].

It is worth noting that the lack of micro- and macro-elements in feed rations limits minerals coming to the organism. This leads to disruption of reproductive ability and to the birth of undeveloped young animals, reduced immunity, deterioration in final product quality [5, 6].

However, it is extremely difficult to ensure the uniform distribution of additives in bulk feed due to their low percentage (up to 5 %). This is directly related to the technical equipment of the subsystems of different levels in livestock production technologies, which are characterized by continuity and flowing with uniform distribution throughout the year. This reproduction flow is a determining factor in the technological process and ensures its efficient functioning [7]. An insufficient level of technology and technological means decreases coefficient of realization of the genetic potential of animals up to 40 %, their weight losses – up to 80 % and reduces the quality of raw materials up to 50 % [8].

The use of the basic technical means: hoppers, mixers, underframes of feeders cannot meet the increasing demands of production and the technological processes of their operation need improvement.

Thus, making the conditions for creation of forage base with balancing additives and biologically active substances would ensure the intensity of livestock production. In this case, it is necessary to study and optimize the parameters of dosing devices in order to obtain high-quality forage in an adequate amount.

The lack of productivity and the quality of the dosing process during the creation of modern bulk feeds with biological additives require appropriate technical solutions and are a challenge to agriculture of many European countries.

2. Literature review and problem statement

Modern technologies of livestock production require the creation of a balanced diet of bulk feed with additives, which demands effective mixing and dosing. The process of formation of a dose or a flow from the material is considered to be dosing, which is divided into stages [9]: filling with material, formation of a dose (flow), discharge.

It is necessary to separate weight and volume consumption, with continuous or portion operation modes among the existing ways of dosing [10]. The method of weight has high feeding precision (up to 1%), but low productivity. In addition, this method of dosing is difficult to apply and requires specialized maintenance [11]. Volumetric hoppers, unlike weight hoppers are characterized by dosing flow and due to a high quality of dosing are widely used to create most feeds [11].

Volumetric hoppers, depending on structural characteristics, are divided into: chamber-piston, measuring capacities, chain-scraper, worm, rotor, drum, and sieve hoppers [9–11]. The operating conditions of hoppers include: universality of the discharge method (individual or group feeders), absence of the feed contamination, ability to work with bulk feeds and additives, ensuring maximum dosing quality and productivity. Given the above conditions, sieve hoppers are promising.

The main element of most hoppers is the bunker, which is responsible for flowing of assigned volume of bulk materials. In paper [12], the dimensions of discharge openings and shapes of bunkers were optimized, according to the conditions of stable flow, absence of bridging.

The problem of insufficient productivity was partly solved by studying the flow of bulk media from dosing devices [13–15]: under the influence of the force of gravity, by using pistons and blades, and ejecting driven devices. However, the studies partly take into consideration: the interaction of material with the elements of a hopper, mechanical and technological properties of material, and conditions for maximum productivity. Moreover, such models have a complex structure and narrow functionality, that is they work on certain materials. The properties of materials of bulk feeds include moisture content, granulometric composition, density of material, friability, etc.

The existence of vibration has a positive impact on the dynamics of motion, the processes of segregation and sifting through the holes of the particles of loose media [16, 17]. In paper [18], in order to increase the effectiveness of the multi-component dosing process, a vibratory feeder with activators of the spring type was used. The use of vibration and activators in the design of the hopper helped to increase the productivity of the combined fodder unit by 2 t/h and to decrease specific power intensity by 1.2 times.

The use of vibration and taking into consideration the design parameters of a flow hopper, the automation of the dispensing process also exert positive influence on the effectiveness of dosing of bulk materials [19].

In paper [20], the authors designed a mixer for the enrichment of concentrated fodders with vitamins, microelements and biologically active fodder additives, in which a rarefied flow of concentrated fodder is created by a sieve hopper. The hopper (Fig. 1) consists of: a bunker for concentrated fodders, a cylindrical housing, in which the upper and bottom sieves are located, and a discharge neck. The sieves are mounted on top of each other on one axis and have the possibility to make oscillatory movements in the horizontal plane, which are performed in the anti-phase with the help of an appropriate mechanism. This eliminates the need to install devices for bridging destruction.

The upper sieve 8 (Fig. 1) is supporting and takes all the load from the feed, which is in bunker 1. The existence of this sieve reduces the influence of the amount of feed in the bunker on productivity indicators and quality of dosing. In this case, the bottom sieve, thanks to structural (dimensions of openings and pitch of their location) and kinematic (frequency and amplitude of oscillations) parameters determines the performance of the hopper. In the basic variant, the upper 8 and the bottom 3 sieves have round openings.

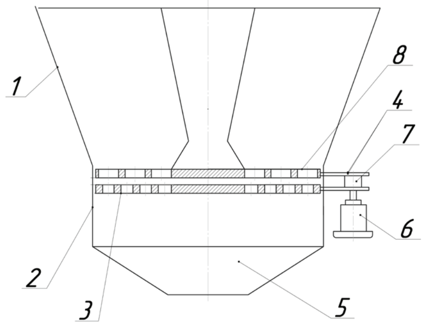


Fig. 1. Sieve bulk feed hopper:
1 — bunker; 2 — cylindrical casing; 3 — bottom sieve;
4 — guides; 5 — neck for unloading; 6 — electric motor;
7 — eccentrics; 8 — upper sieve

Performance of the sieve hopper with continuous feed of bulk material in the vibro-rarified state amounted to 650...1.900 kg/h at non-uniform dispensing up to 3.8 % [21].

The hoppers were analyzed by the following characteristics: simplicity of the designs, the range of variation in performance, ensuring the rarified state of material for further effective mixing, simplicity of setting up and maintenance, reliability and durability, relatively low cost. As a result of the analysis, the object of the research was established – a volume vibro-hopper of continuous action of the sieve type.

However, the studies [16] proved the possibility to increase sifting of the particles of bulk material through a sieve due to the use of activators in the shape of a five-petal epicycloid instead of round openings.

Identity of the processes of a sieve hoppers and grain cleaning vibratory sieve machines, specifically, the existence of vibratory sieves and creation of rarefied medium, makes it possible to apply the sieves with five-petal epicycloid activators (Fig. 2, *b)* instead of the sieves with round openings (Fig. 2, *a*). An increase in the screening capacity of such sieves will allow an increase in the quantity (volume) of the material that passes through the hopper at the normalized dosing quality.

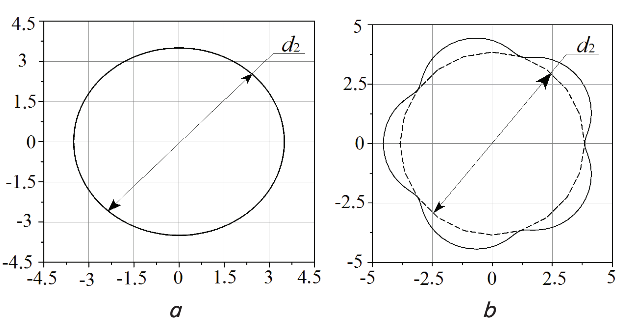


Fig. 2. Types of openings in sieves:
a — basic round; *b* — in the shape of five-petal epicycloid

Theoretical consideration of dynamic processes at flowing of bulk feeds particles from the bunkers of vibro-hoppers has many interpretations, which complicates the research and does not make it possible to obtain the procedure for engineering calculation of operating bodies. A significant number of studies on flowing of bulk materials from hoppers do not provide a full picture about the influence of vibration parameters and working bodies on their operation effectiveness.

Adequate simulation of the motion of bulk materials during their separation into fractions, as well as their passage through the holes of vibratory sieves, was conducted using the analogy with hydro-medium [17, 22] and continuum mechanics [23]. To study the parameters of motion of granular materials, we used the theories of probability of particles passing through the openings [24], as well as the methods of discrete elements [25].

The minimum variance of the results of simulation of motion of granular mixtures with the experimental data was obtained from the use of the analogy with hydrodynamic media [26].

However, these studies do not have a systematic and comprehensive nature, because the dynamic processes of sifting various ЗС through complex openings of vibratory sieves are not considered in totality and from the unified positions. Objective difficulties of such simulation are taking into consideration the devices of a complex shape – activators of SC sifting.

The procedure of studying similar technical solutions and obtaining the mathematical expressions for their operation efficiency is currently an unresolved problem.

All this suggests that the improvement in the sieve hopper by replacing the bottom sieve with basic round openings with the sieve with activators is appropriate and will enhance the effectiveness of dosing bulk feeds. Such improvement requires additional studies in relation to the process of continuous dosing, its effectiveness and practicality of application.

3. The aim and objectives of the study

The aim of this study is to improve effectiveness of the process of dosing bulk feeds through the use of the upgraded sieve hopper.

To achieve the aim, the following tasks were set:

– to develop the technological scheme of operation of the hopper based on the possibilities of increasing the productivity, quality of dosing bulk feeds;

– to develop the mathematical expressions of the dynamics of bulk medium in the hopper, to determine the dependence of the performance of a hopper on its structural and kinematic parameters;

– to carry out experimental testing of the developed hopper, to determine its rational parameters and efficiency.

4. Mathematical modelling of the process of dosing bulk feeds

The sieve hopper consists of two circular sieves of diameter D_1, which are located horizontally at distance h_p (Fig. 3).

At the sieves on the perimeter, there are round openings, which form an active band of width t_p. As noted previously, the openings of the upper sieve of diameter d_1 exceed the diameters of the bottom sieve d_2, that is $d_1 < d_2$.

The dimensions of the openings of the bottom sieve regulate bridging over them. During the oscillations with amplitude A and frequency n_p, the upper sieve destroys bridges and ensures passing of materials.

The flow of bulk material volume per second will characterize the performance of the hopper and is determined from the expression:

$$Q=\left[\frac{\pi}{d_2^2}\left[\left(\frac{D_1}{2}\right)^2-\left(\frac{D_1-2t_p}{2}\right)^2\right]\right]\times$$

$$\times\, n_p\frac{\pi d_2^2}{4}\sqrt{gh_c}\alpha^*\left[1-e^{\left(-\beta\frac{8\pi^{3/2}A}{d_2}\right)}\right], \qquad (1)$$

where α and β are the empirical constants; n_p is the number of oscillations of the sieves per seconds; D_1 is the outer diameter of the sieves; d_2 is the diameter of the openings of the bottom sieve; A is the amplitude in relations to displacement of the points of the outer circle of the bottom sieve; g is the free fall acceleration.

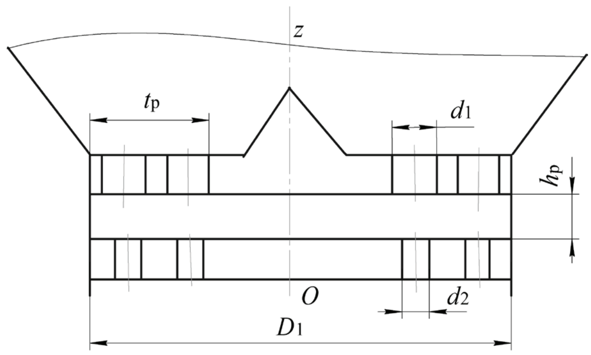


Fig. 3. Schematic of the hopper with a sieve

Given the similarity of the processes of dispensing on the sieve hopper and the processes of separation of grain mixes into factions in grain cleaning machines [16, 17, 22], we produce the replacement and mount the bottom sieves with activators.

The advantages of the sieves with activators are described in [26] and imply an increase in the area of cross-section of the sieve, additional orientation of particles of bulk medium both in openings and in themselves. The effect is achieved due to the rounded shapes of the cycloid petals, which make it possible to rotate a particle around the axis up to the full fit with the opening.

To describe the shape of the basic and the proposed openings, we accepted the parametric equations of: epicycloid:

$$x_1=R_0(k+1)\cos(kt)-h_e\cos(kt+t),$$

$$x_2=R_0(k+1)\sin(kt)-h_e\sin(kt+t);$$

circumference:

$$x_1=R_0\cos(t),$$

$$x_2=R_0\sin(t);$$

where $k=r_e/R_0$, $h_e=2r_e/\pi$; $R_0=d_2/2$ is the radius of the fixed circumference; r_e is the radius of movable circumference.

For modeling, we will accept the condition that there is a two-dimensional periodic structure with period l_1 along axis x_1 and period l_2 along axis x_2.

A change in the flow of granular medium when using non-standard sieves was adjusted with the use of factor B_n, which is determined by the pitch of location and the geometrical parameters of the openings:

$$B_n=\sum_{P=1}^{N}\iint_{S_P}e^{-i2\pi\left(\frac{n}{l_1}x_1+\frac{m}{l_2}x_2\right)}\mathrm{d}x_1\mathrm{d}x_2, \qquad (2)$$

where $S_{p1},S_{p2},...,S_{pN}$ are the areas of the openings of the sieve of the basic cell of dimensions of l_1 and l_2.

The following data were accepted for numerical calculations (Table 1).

Table 1

Data to calculate the performance of the hopper

No.	Parameter	Designation	Value
1	Outer diameter of the sieve, m	D_1	0.3
2	Width of active zone of the sieve, m	t_p	0.05
3	Diameter of openings of the upper sieve, m	d_1	0.018
4	Frequency of oscillations of sieves, s^{-1}	n_p	16
5	Empirical coefficients	α/β	1/0.075
6	Number of openings of the bottom sieve, piece.	N_0	108
7	Amplitude of oscillations of the sieves, m	A	0.01
8	Diameter of the opening of the basic bottom sieve, m	d_2	0.004...0.01
9	Radius of fixed circumference of epicycloid, m	R_0	0.002...0.005
10	Multiplicity of epicycloid	–	5

Using expressions (1) and (2), the data (Table 1), the dependences of volume productivity Q of the sieve hopper on its parameters were obtained.

An analysis of Fig. 4 has revealed that the performance of the hopper increases by 2.6...2.9 times at an increase in the diameter of the openings of the basic bottom sieve in the ranges, in which the studies were performed (4×10^{-3} m up to 10×10^{-3} m). The use of sieves with activators in the shape of epicycloid openings makes it possible to increase performance by 25...30 %, indicating a possible intensification of the dosing process.

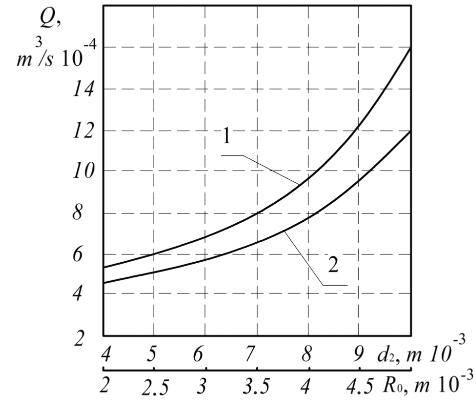


Fig. 4. Dependence of the volume productivity of the hopper on the diameter of the openings of the base bottom sieve d_2 and the radius of the fixed circumference of the epicycloid R_0: 1 – the sieve with activators; 2 – basic sieve

5. Experimental testing of the developed hopper at mixing bulk feeds

Experimental testing of the upgraded sieve hopper of bulk feeds was conducted on the setup (Fig. 5).

For studies, the experimental samples of the bottom sieves of the hopper (Fig. 6) with basic round openings (Fig. 6, *b*) and the activators in the form of openings of the epicycloid shape (Fig. 6, *c*) were made.

The quality of the dosing process was recorded and identified using the broaching tray (sampler) (Fig. 5), which has the form of a duct with compartments. The magnitude of the deviation of the weight of trays' content on the duct regulated the quality of dosing.

Fig. 5. Laboratory setup for studying the process of feed dosing

Experimental value of productivity of the hopper was determined from expression:

$$Q = \frac{\bar{m}}{1000 \cdot t \cdot \rho}, \quad (3)$$

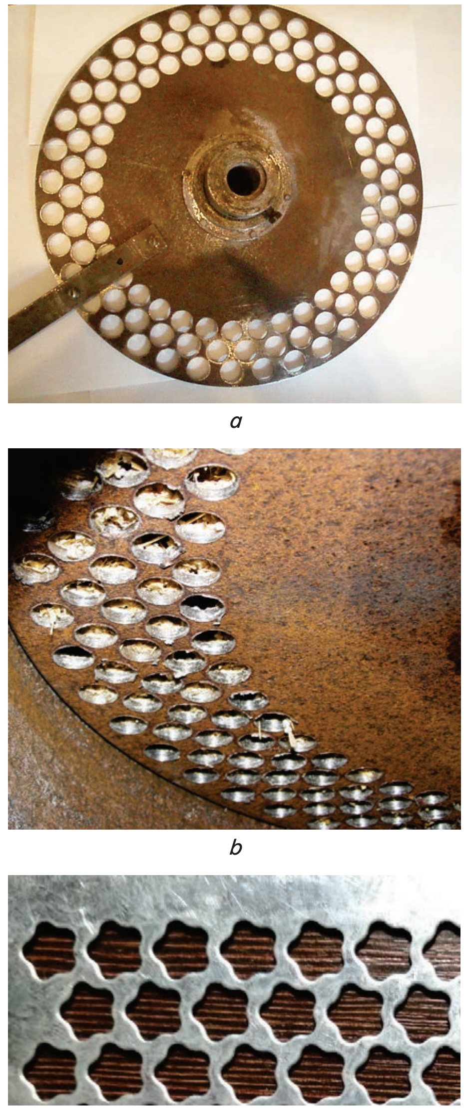
where $\bar{m}$ is the mean weight of the sample, g; t is the time of sampling, s; ρ is the density of loose materials, kg/m^3.

The samples were taken three times, weighed on scales, then the data were averaged.

For experimental studies, wheat bran with the following characteristics was accepted: moisture of 12.7 %; volumetric weight of 437 kg/m^3; average dimensions of particles 0.8×10^{-3} m; coefficient of friction on metal 0.42.

The significant factors that determine the productivity of the sieve hopper are: diameters of the openings of the bottom sieve; amplitude and frequency of oscillations of the sieves. The research results and their comparison with the theoretical ones are shown in Fig. 7.

The experimental research proved the adequacy of the obtained mathematical expressions and revealed the possibility to improve the performance of the hopper through the use of sieves with activators. The productivity of the upgraded hopper amounted to 0.75...2.8 t/h, which exceeds the productivity in the basic variant with a sieve with round openings by 15...44.4 %. An increase in productivity at an increase in dimensions of the openings in the bottom sieve in the basic and upgraded variants was proved. The rational values of the radius of the rigid circumference of the epicycloid are 0.004...0.005 m at module 5.



a

b

c

Fig. 6. Elements of the sieve hopper: *a* — bottom sieve, general view; *b* — base bottom sieve with round openings; *c* — sieve with five-petal epicycloids openings

The discrepancy of the results of theoretical and experimental research (Fig. 7) did not exceed 5 %, which demonstrates the adequacy of the obtained expressions.

Non-uniformity of the release of the flow by the sieve hopper determined the quality of dosing bulk feeds and was in the studies assessed by the variation factor:

$$\nu = \frac{\sigma}{\bar{\chi}} \cdot 100, \quad (4)$$

where σ is the root mean square deviation:

$$\sigma=\sqrt{\frac{\sum_{i=1}^{n}(\chi_V-\bar{\chi})^2}{n-1}}, \qquad (5)$$

where n is the total number of cases; χ_i is the separate value of the varying factor; $\bar{\chi}$ is the mean weighed arithmetic average:

$$\bar{\chi}=\frac{\sum_{i=1}^{m} n_i\chi_i}{n}. \qquad (6)$$

The non-uniformity of dosage of wheat bran with the upgraded sieve hopper amounted to 2.5...3.6 %, which is a permissible value for practice.

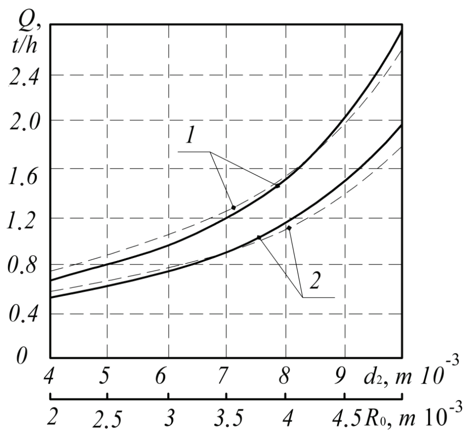


Fig. 7. Dependence of productivity of the sieve hopper on dimensions of openings of the bottom sieve during dosing wheat bran: 1 — the sieve with activators; 2 — the base sieve with round openings; (————) — theoretical research; (– – – –) — experimental research

7. Discussion of results of studying the dosing of bulk feeds at the sieve hopper

The research proved the possibility of intensification of the process of dosing loose materials on sieve hoppers through the use of sieves with high screening capacity. The accepted sieves with epicycloid activators due to their unique characteristics made it possible to intensify screening capacity of bulk feed through the openings, which allowed the increase in productivity of up to 2.8 t/h. The shape and the dimensions of particles of bulk materials that are used for the creation of feeds are diverse and have a wide range of variations [27]. The shape of seeds can be described using the factors of sphericity (roundness) for each type of seeds, with statistical processing the results of measurements and calculations using dispersion or correlation analysis [27, 28]. Similar coefficients are determined by the relationship of dimensions, actual and geometric shape (surface area). A wide range of shapes for grain mixtures of rye, corn, wheat, oats, and other crops, which made up 0.35...0.65 was established with the use of sphericity of particles [27].

The proposed modernization of the hopper involves the use of the bottom sieve with the openings in the form of an epicycloid, which makes it possible to align the level of deviation from the geometrically regular shape – a globe, due to peculiarities of shape (Fig. 2, *b*). The work displays the direction of an increase in productivity, the implementation of which involves the use of a sieve with high screening capacity.

Not only dependences (Fig. 7), but also the procedure of their construction, described in the paper, are important for practice. Using this procedure, it becomes possible to build such dependences of the productivity of the hoppers for combined fodder, coarsely ground barley grain and other bulk feeds. Similar dependences make it possible to control the process and to predict the result.

The research results not only proved the stated method to increase the effectiveness of the dosing process, but also made it possible to establish the parameters of the sieve hopper that are necessary for practice.

To make this research complete, it is required in perspective to carry out the analysis of energy costs of the dosing process and to examine the influence of the properties of bulk feed on the effectiveness of the upgraded hopper. It is equally important in future to pay attention to reliability, specifically, durability of the sieves with the openings of various types. The constraints of the resource of sieves leads to an increase in operating costs requires additional maintenance operations and determines the quality of the processes of dosing, mixing and crushing in the preparation of bulk feeds.

The obtained research results can be used to develop hoppers, mixers in agriculture in the production of high-grade feeding mixtures for animals. The results of the research can be applied in similar machines and dosing processes in the chemical, pharmaceutical, food, and combined fodder industries.

8. Conclusions

1. The technological circuit of the upgraded sieve hopper was substantiated that is promising in terms of maximum effectiveness of the process of dosing bulk feed. Its distinctive feature is the use of the new developed working body of the sieve with the openings in the form of five-petal epicycloid activators. Unlike the working bodies of the basic sieve hoppers, the proposed sieves with activators have the enhanced screening capacity, which allows the improvement of their operating effectiveness.

2. As a result of research, we obtained the mathematical expressions to determine the volumetric flow rate of bulk material with the upgraded hopper, the sieve of which has openings in the form of five-petal epicycloid activators. The feature of the obtained expressions is the existence of the algorithm of taking into account the complex geometric shapes of the openings and their impact on the effectiveness of dosing. The dependences of productivity of the upgraded hopper on its parameters were obtained. The ranges of variation of productivity of the hopper with the base bottom sieve of $4.5...12\times10^{-4}$ m^3/s and of the modernized hopper of $5.5...16\times10^{-4}$ m^3/s were found.

3. Experimental research proved the possibility of an increase in productivity of the hopper due to the use of sieves with activators by 15...44.4 %. We established the ranges of variation of the productivity of the basic and the upgraded sieve hopper for dosing wheat bran, which made up 0.65...1.8 t/h and 0.75...2.6 t/h, respectively. The quality of dosing on the basic and upgraded hopper was determined by non-uniformity of dosing, which made up 2.5...3.6 %. The rational values of the radius of the rigid circumference of epicycloid are 0.004...0.005 at module 5.

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