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FEATURES GRINDERS - MIXER WITH OPTIMIZATION OF PROCESS PARAMETERS

PhD, Engineering Sciences (Machines and Means of Mechanization of Agricultural Production), PhD, Engineering Sciences (Project and Program Management), Alatoom Mohammad Fayiz Ahmad

The existing constructions of continuous-running fodder choppers-mixers for small cattle were investigated in the article. The analysis of advantages and disadvantages of existing choppers was conducted by abstracting effective areas of their application. It was established that it was inappropriate to chop concentrated and rough feed simultaneously, because the fibrous materials of rough feed reduce the impact force of unmilled grain with the working surface of the chopper. Moreover, the food making aggregate must be equipped with process automated facilities. The basic models were determined, which improvement allows increasing the efficiency of mixing rough, concentrated and succulent feed. In most cases while technological optimization processes in animal industry it is advisable to use the second-order design, because the processes are complex and the significant factor coefficients of regression may appear in the model which have to be raised to second power.

Keywords: feed, cattle, food preparation, chopper - mixer, impact force, automation, aggregate, optimization.

1. Introduction. The full feeding and rational use of forage resources are the main ways of increasing the efficiency of the farm industry, increasing production and reducing production costs. The feeding of the feed majority in its natural form is ineffective as the feed rations should be balanced with the content of protein, carbohydrates, vitamins, minerals and other substances that stimulate the development and ensure the safety of livestock and the high animal productivity.

The most efficient use of feed is achieved by feeding them in the form of complete feed mixtures, balanced in nutritional elements, vitamins, microelements, antibiotics, bio-stimulants, because there is no such a full set in any separate feed form. The resulting mixtures from the feed preparation shops should strictly comply with the set scientifically based ration formulation for the served group of animals, have a set humidity (65 ... 80%) and temperature (in summer – 293 K, in winter – 313 K), a high degree of homogeneity; particles of feed components should

maintain their dimensions. A feed mixture should not be composed of foreign, harmful impurities for animals' health and formations, bacterial seeding and bad odors. It is necessary that only feed of high quality comes into the food preparation shop, that the technology and preparation terms are strictly kept [19].

2. Analysis of recent research and publications and the problem statement.

It is known that by sheep growing they are fed with multicomponent feed mixtures, which include rough, succulent and concentrated feed. It is not easy to mix these components, because the particles of grain chop and rough feed cut stick to a wet shaving of chopped root crop. It is most effectively to mix such feed components in continuous-running mixers, because the mixing process occurs in a thin layer of the mixture. The theoretical basics for the development of continuous-running mixers haven't been on its final stage yet and require further development.

The basic results of theoretical and experimental researches of the efficiency of fodder chopper-mixers are given in the works of famous scientists: S. V. Melnikov, S. I. Nazarov, V. I. Perednya, L. P. Kartashov and O. V.Tsurkan, O. V. Demin, M.G. Palkin and others [1-4]. The works of these scientists are directed at the intensification improvement of the feed mixing process in continuous-running machines. The improvement of the working body which can chop several types of fodder and, at the same time, effectively mix chopped components makes the relevancy of our research.

3. The purpose and objectives of research is the study of the design features of continuous-running mixers with the definition of the operating parameters optimization.

To achieve this goal it is necessary to solve the following tasks:

- to analyze the structure of food choppers-mixers for feeding the small cattle;
- to study the advantages and disadvantages of the existing choppers-mixers with justification of areas of their effective use;
- to examine the operation principle of the existing designs of continuous-running fodder mixers with a rotating tanker;
- to develop a design

4. The methods and results of research

4.1. Analysis of the constructions of choppers-mixers

The effective sheep breeding is impossible without using multicomponent fodder (fodder mixtures) in ration.

A composition of loose fodder mixtures for small cattle is the following: 20 – 40% - straw, 12 - 26 – hay, 40 - 60 – silage, 7 - 17% – mixed fodder.

A composition of granulated fodder mixtures for small cattle is the following: 35 - 50% – straw, 18 - 30 – grass meal, 20 - 40 – hay and grain fodder, 14 – 20% – mixed fodder.

Taking into consideration the above-mentioned facts, we can say that increase of the efficiency of the fodder mixing process for small cattle can be achieved using a mixing working body which can move effectively groups of particles of different size from one position into another. Moreover, an effective mixer must provide a continuous technological process with minimal energy and human resources expenses. It is also very important to take into account the fact that a fodder mixture of high quality can be obtained only from properly ground components.

At present, the fodder chopper-mixer ISK-3 is very widespread (Fig. 1).

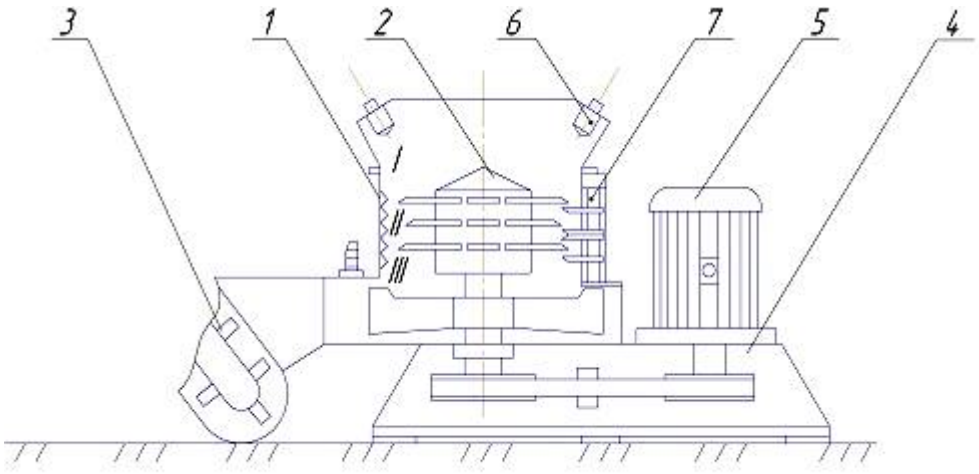


Fig.1. Fodder chopper-mixer ISK-3:

1 – toothed deck; 2 – knife rotor; 3 – unloading conveyor; 4 – frame; 5 – power-driven station; 6 – nozzle; 7 – countercut; *I* – inlet chamber; *II* – chopping and mixing chamber; *III* – unloading chamber.

The productivity of the machine which works at mixing can reach 25 t/h, at mixing with partial regrinding – up to 5 t/h, at chopping, for example, of straw – up to 3-4 t/h at the cutting length of up to 30 mm, and 4-8 t/h at the cutting length of 50 mm.

The distinctive feature of these machines is a vertical or horizontal position of two augers of a higher pitch. It allows obtaining a loose fodder mixture from several components. The availability of adjustable counter cuts permits changing a degree of chopping fodder mixture components. The productivity of such machines makes 12 t/h, the tanker capacity – 12 m^3, the mixing time – 5-7 minutes; the weight – up to 5300 kg; it is unitized with a 1,4-2 ton-force class tractor [5, 6].

The chopper-mixer provides mixing of silage, straw, edible roots and mixed fodder with a degree of homogeneity – 80-90%; engine's installed capacity is 39,2 kW; rotor's rotational frequency – 17 c^{-1}; machine's dimensions –1600x1090x1150 mm; weight with an unloading conveyor – 2200 kg. The chopper-mixer is operated by one worker.

Advantages of ISK-3:

1) continuity of the process;
2) simplicity of the design;
3) chopping and mixing is carried out simultaneously;
4) protection against consequences in case if extraneous objects get into the working zone;
5) high homogeneity of mixture.

Disadvantages of ISK-3:

6) high energy intensity of the process of fodder mixture preparation;
7) granulated fodder can't be added to a fodder mixture without being destructed;
8) it doesn't mix fodder with grass meal;
9) it doesn't chop concentrated fodder;
10) the machine is stationary.

The analysis of existing designs of continuous-running fodder mixers has showed that such machines work effectively as a part of feed processing units.

A new high-efficiency feed-processing plant should include four self-contained modules (figure 2):

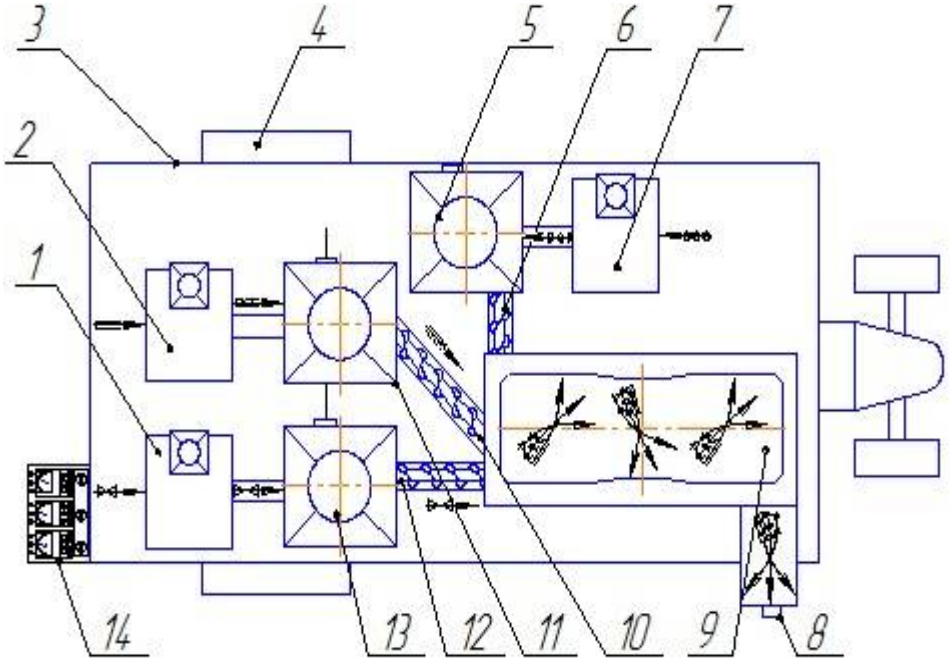


Fig. 2. Schematic diagram of the fodder chopper-mixer:

1 – a chopper of rough feed; 2 – a chopper of concentrated feed; 3 - frame; 4 - undercarriage; 5 – tanker for shavings of succulent fodder; 6 - shaving dispenser; 7 – a chopper of succulent feed; 8 - mass sensor; 9 - mixer; 10 - dispenser of the concentrated feed; 11 – tanker of concentrated feed; 12 - dispenser of rough feed shreddings; 13 – tanker for rough feed shreddings; 14 –control board.

- a chopper of succulent feed 7 (root crops, vegetables, fruits, melons, etc.) with a storage tanker 5 and a dispenser 6;

- a chopper of rough feed 1 (hay, straw, etc.) with a storage tanker 13 and a dispenser 12;

- a chopper of concentrated feed 2 (grain materials) with a storage tanker 11 and a dispenser 10;

- a scientifically based continuous-running fodder mixer 9 provides a high degree of homogeneity of the mixture (80-90%).

Also the feed preparation unit must be equipped with the process automation tools (sensor that registers a mass of the food mixture coming from the mixer 8, and common remote control of all independent modules of the chopper-mixer 14), the undercarriage 4 and the unloading chute.

The aggregate continuous-running fodder chopper-mixer is equipped with L-shaped beaters, the beaters are fixed with an interval from each other. This allows lifting a part of the feed mixture's layer at a height, bigger than the slope of repose of its components. This effect prevents the formation of the circulation center of the mixture's components and mixing is provided by the alternately changing the layers' position. Furthermore, the mixture's shape, consisting of two truncated cones 4 connected by a smaller base, provides a varying value of the components' angular velocity, which also has a positive effect on the efficiency of the mixing process.

The winding provides two complete material rotations. The cones are connected by a cylindrical insert. After passing the first cone the fodder is additionally mixed in the symmetrically located second cone. The mixer's setting angle is changed by a screw mechanism. The mixer's design allows to change the number and shape of the winding's blades, as well as the diagram

The analysis of existing designs of continuous-running fodder mixers showed that increasing the mixing efficiency is achieved by using rotating drums with screw and blade working bodies located on them.

In existing designs of continuous-running fodder mixers with a rotating tanker a mixing process occurs in such a way [9]. At the circulation motion in the cross-sectional view of the drum all the material can be divided into rising (zone *ACBM*) and rolling down (zone *ACBN*) layers (Fig. 3).

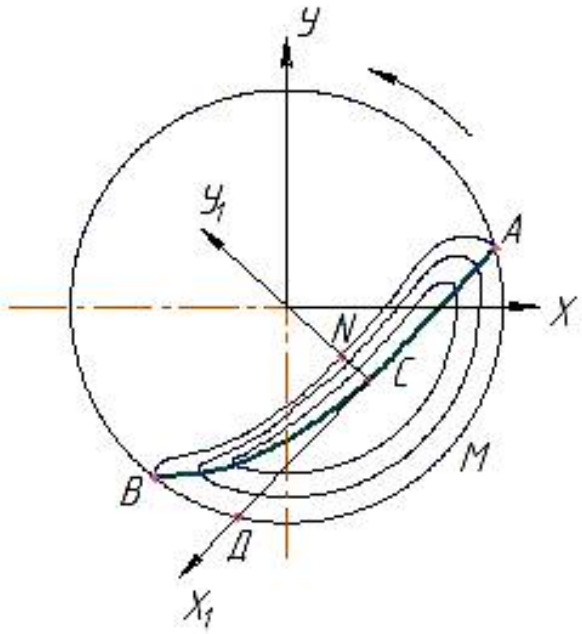


Fig. 3. The principle of operation of existing designs of continuous-running fodder mixers with a rotating tanker.

The constantly developing food resources (the appearance of new types of premixes, increasing the range of pelletized feeds, etc.) requires the creation of conditions for the intensification of the mixing processes.

Continuous running fodder mixers are most promising, among which mixers with rotating tanker are of the most practical and scientific interest.

A line *ABC* is a border of the layers division. A Point *C* is a circulation center, around which bulk material is circulating. On the section *AC* the transit of particles from a rising layer to the rolling down layer happens, and on the section *CB* conversely, from the rolling down layer into the rising one. In the rising layer particles move in concentric circles with a center on the drum rotation axis and with the angular velocities equal to the angular velocity of the drum rotation.

Preparation of a food mixture consisting of three components: (40% - shreddings of rough feed (hay), 45% - shaving of feeding root crops, and 15% - milled grain) requires a fundamentally different approach [1-6, 10, 11]. The working tools of the mixer should prevent the formation of the circulation center (see point *C* in Fig. 3), and the mixing should occur by alternately changing the layers' position.

This principle of mixing was taken as a basis for the mixer proposed by us (Fig. 4).

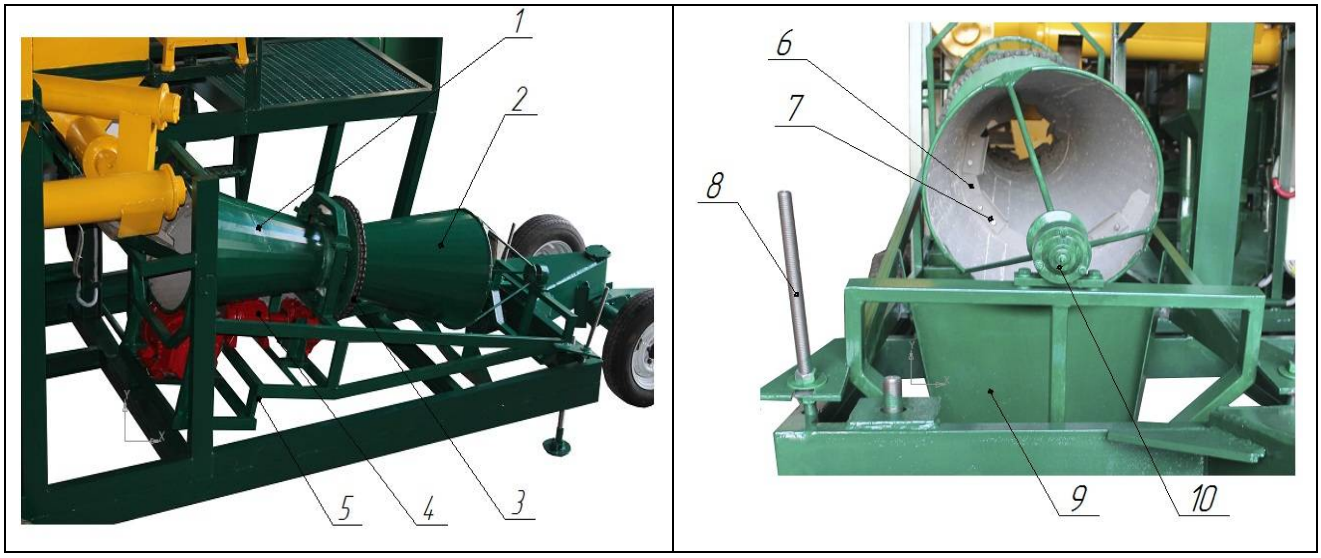


Fig. 4. Continuous-running fodder mixer: *а* – side view;
б – view from the side of the final product unloading; 1, 2 – front and back cone, accordingly; 3, 4 – mechanism of the mixer's drive; 5 – movable frame; 6 – screw winding; 7 - L-shaped beaters; 8- mechanism of changing the setting angle of the mixer; 9 – discharge chute; 10 – supporting block.

The rotational frequency of the continuous- running mixer is smoothly regulated with a help of a direct current motor, controlled from a common control panel through the original transformer regulator. The interval of mixer's variable speed is 0-200 min^{-1}.

The mixer works in the following way. The components of the feed mixture (crushed grain, succulent and roughage fodder) are fed into the mixer with a help of proportioning devices. The front cone 1 with a help of the winding 6, situated on its inner surface, catches components and sets them moving along a spiral path. The winding is equipped with L-shaped beaters 7 with a length 100 mm, the beaters are fixed with an interval of 75 mm from each other. This allows lifting a part of the feed mixture's layer at a height, bigger than the slope of repose of its components. This effect prevents the formation of the circulation center of the mixture's components and mixing is provided by the alternately changing the layers' position. Furthermore, the mixture's shape, consisting of two truncated cones connected by a smaller base, provides a varying value of the components' angular velocity, which also has a positive effect on the efficiency of the mixing process.

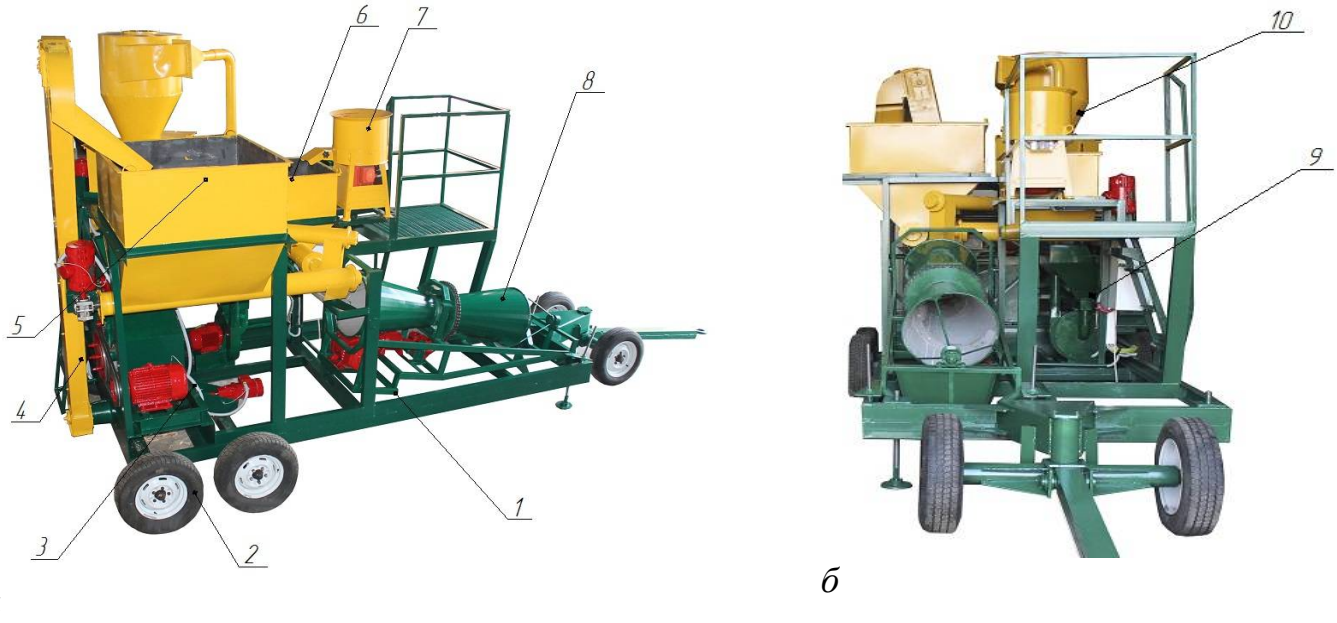
The winding provides two complete material rotations. The length of the each cone is 750 mm. The cones are connected by a cylindrical spacer plate of the length of 250 mm. The diameter of the larger base of the cones is 500 mm and of the smaller

base is 250 mm. After passing the first cone the feeding stuff is additionally mixed in the symmetrically-situated second cone. The installation angle of the mixer is changed by a screw mechanism 8 of the movable frame 5 from 0 to 25 degrees. The mixer's design allows changing the number and shape of the winding beaters, and the scheme of their installation. At the present time the mobile feed preparation shops with a batch mixer such as ISRV-12 and RSC-12 [7,8] have been developed and are used. The main disadvantage of these feed preparation shops is a low degree of homogeneity of the feed mixture, caused by the need to mix a large amount of feed ingredients at once. In its turn, this disadvantage can be eliminated by the use of the continuous-running mixers.

The feed preparation shops КЦС-100/1000, КЦС-200/2000, КЦС-2000 КЦС-3000 КЦС-6000 ("Maiak-6" (Lighthouse)) are very widespread using a commercially available equipment set. The new standard projects of feed preparation shops 801-460, КЦК-5, КЦО-5, КПО-150, and others were approved. The sets with a type КЦС are designed for the feed preparation shop equipment of specialized pig farms with the concentrate-root type of feeding. Due to the high degree of harmonization the five complexes (12 ... 14 machines each) are formed of the 19 ones, differing from each other in productivity and a kind of prepared feed.

In food preparation shops the food mixtures of high quality with a humidity of 65 ... 75% with steaming the individual components are prepared and the porridge is cooked for pigs and others. The food preparation shops КЦС -2000 КЦС-6000 (("Maiak-6" (Lighthouse) are used in the fattening farms with a livestock of 2, 3 and 6 thousand pigs, and КЦС -100/1000 and КЦС -200/2000 are used on the mixed pig-breeding farms, respectively, with 100 and 200 breeding pigs with a breech and the 1000 and 2000 fattening animals.

The machines of food preparation shops are linked together in the process lines. The line of the tuberous roots includes a conveyor and chopper of tuberous root crops. The concentrated feed line includes the feeder. The green mass and hay flour line consists of a chopper 3, a universal crusher 5, a feeder 4 and a drag conveyor 2. The skimm line includes a centrifugal flow pump and a storage reservoir for milk 9. In the food preparation shop КЦС -200/2000, this line is also provided with a unit 10 for preparing a substitute for the milk. In Lugansk NAU a feed preparation shop with a continuous-running mixer was developed (Fig. 5).



а *б*

Fig. 5. Mobile feed preparation shop for small cattle : *а* – side view; *б* – front view; 1 – frame; 2 – undercarriage; 3 – chopper of rough feed; 4 – elevator; 5 – tanker-feeder of chopped rough feed; 6 - tanker-feeder of chopped succulent feed; 7 – chopper of succulent feed; 8 – a continuous-running food mixer; 9 – a chopper of concentrated feed; 10 - tanker-feeder of chopped concentrated feed.

This feed preparation shop allows to chop rough, succulent and concentrated feed, to store milling products in the tankers, to dispense milling products and mix them, preparing a food mixture with a high degree of homogeneity.

The originality of the proposed feed preparation shop is as follows [5]:

- a feed preparation shop is transportable;
- a feed preparation shop allows both simultaneously and independently perform operations of chopping, dosing and mixing. In addition, you can chop rough, succulent and concentrated feed either simultaneously or separately;
- a design of a feed preparation shop allows you to unload the prepared food mixture both in a feed dispenser and in the feed cribs for small cattle;
- a food mixture is prepared in a continuous-running mixer, which allows mixing dry shreddings of hay and grain chop with a wet shaving of root crop with a high degree of homogeneity;
- a continuous-running mixer consists of two truncated cones connected by a smaller base, the inner surface of which is equipped with a screw winding.

The winding is equipped with L-shaped blades 100 mm long, the blades are installed with a distance of 75 mm from each other. This allows rising a part of a food mixture's layer at a height bigger than the angle of repose of its components. This effect prevents

the formation of the circulation center of food mixture's components and mixing is provided by an alternately changing of the layers' position. The novelty of the design solutions of the mixer is confirmed by the patent of Ukraine № 70668. The control of all units of the feed preparation shop is carried out by one operator from the common control unit.

The use of this feed preparation shop allows mechanizing and optimizing the process of food preparation in some sheep enterprises of farms completely. The feed preparation shop's productivity is 1000 kg / h. The total capacity of all the electromotors of the food preparation shop is 12,9 kW.

At the alternate work of choppers in the field environment the food preparation shop works effectively from the alternating-current generator with a capacity of 4 kW.

If necessary, the food preparation shop can be additionally equipped with an autonomous system of metered irrigation of the finished food mixture with an aqueous solution of biologically active supplements or medications. While distributing food directly to the feed cribs, the unloading part of the mixer is additionally equipped with an unloading conveyor and a sensor, registering a distribution of food per second.

4.2. Optimization of technological process parameters

In most cases while technological optimization processes in animal industry it is advisable to use the second-order design, because the processes are complex and the significant factor coefficients of regression may appear in the model which have to be raised to second power. That is why we used a three-tiered plan of Box-Benkin for three factors, which requires the least number of tests.

The structurally-technological parameters of the continuous-running fodder mixer are set according to the experimental design. With an average confidence level of p = 0,95 and a maximum error $\varepsilon = \pm 3\sigma$ we selected triplicate experiments. A randomization was performed - experiments were conducted in a sequence of increasing random numbers of the table.

Table 1 – Coding of the factors and choice of intervals of their variability.

Name	Value		
Designation of factors	X_1	X_2	X_3
Name of factor	Rotor speed, n_c U/min	Feed of components to the mixer q_c, kg/s	3. Mixer's angle of slope, γ_c, °
Basic level	19	0,11	12
Interval of variability	2	0,01	1
Highest level of	21	0,12	13

factor			
Lowest level of factor	17	0,10	11
Response function	У – Energy intensity of the feed mixing process, $E_{Y,}$ *kWh/t*		

The experimental results were processed using the program Statistica 8.0 for Windows. The homogeneity of variance, the statistical significance of the regression coefficients and the adequacy of the models were tested. As a result of the calculations the regression equation in decoded form was obtained.

$$E_Y = 11{,}472187 - 0{,}617291 \cdot n_c + 0{,}015521 \cdot n_c^2 + 25{,}041666 \cdot q_c -$$
$$- 104{,}166666 \cdot q_c^2 - 1{,}086250 \cdot \gamma_c + 0{,}039583 \cdot \gamma_c^2 - 0{,}249999 \cdot n_c \cdot q_c +$$
$$+ 0{,}005000 \cdot n_c \cdot \gamma_c + 0{,}250000 \cdot q_c \cdot \gamma_c, \text{ kWh/t.} \quad (1)$$

The resulting regression equation allows us to estimate the impact of the factors on the technological process of feed mixing and optimize the mixer's settings. The rotor speed has the greatest impact on the energy intensity of the mixing process. In order to find the optimal (minimum) values of the energy intensity of the feed mixing process it is necessary to solve the equation (1).

$$\begin{cases} \dfrac{d\Im_y}{dn_c} = -0{,}617291 + 0{,}031042 \cdot n_c - 0{,}249999 \cdot q_c + 0{,}005000 \cdot \gamma_c; \\ \dfrac{d\Im_y}{dq_c} = 25{,}041666 - 208{,}333332 \cdot q_c - 0{,}249999 \cdot n_c + 0{,}250000 \cdot \gamma_c; \\ \dfrac{d\Im_y}{d\gamma_c} = -1{,}086250 + 0{,}079166 \cdot \gamma_c + 0{,}005000 \cdot n_c + 0{,}250000 \cdot q_c. \end{cases} \quad (2)$$

After solving the system of equations (2) with the Cramer method using the computer program "Mathcad 15" we'll receive the optimal values of the factors for the receiving three-component feed mixture, presented in the table 2.

Finding the optimal values of the factors.

$$\begin{cases} \dfrac{d\Im}{dn_c} = -0{,}617291 + 0{,}031042 \cdot n_c - 0{,}249999 \cdot q_c + 0{,}005000 \cdot \gamma_c; \\ \dfrac{d\Im}{dq_c} = 25{,}041666 - 0{,}249999 \cdot n_c - 208{,}333332 \cdot q_c + 0{,}250000 \cdot \gamma_c; \\ \dfrac{d\Im}{d\gamma_c} = -1{,}086250 + 0{,}005000 \cdot n_c + 0{,}250000 \cdot q_c + 0{,}079166 \cdot \gamma_c. \end{cases} \quad (3)$$

$$\Delta = \begin{cases} +0,031042 - 0,249999 \cdot +0,005000; \\ -0,249999 - 208,333332 + 0,250000; \\ +0,005000 + 0,250000 + 0,079166. \end{cases} = 0,52$$

$$\Delta x_1 = \begin{cases} -0,617291 - 0,249999 \cdot +0,005000; \\ 25,041666 - 208,333332 + 0,250000; \\ -1,086250 + 0,250000 + 0,079166. \end{cases} = 9,7$$

$$\Delta x_2 = \begin{cases} -0,617291 + 0,031042 \cdot +0,005000; \\ 25,041666 - 0,249999 + 0,250000; \\ -1,086250 + 0,005000 + 0,079166. \end{cases} = 0,06$$

$$\Delta x_3 = \begin{cases} -0,617291 + 0,031042 \cdot -0,249999; \\ 25,041666 - 0,249999 - 208,333332; \\ -1,086250 + 0,005000 + 0,250000. \end{cases} = 6,3$$

$X_1 = \Delta x_1 / \Delta = 9,7 / 0,514 = 19,70$ U/min;
$X_2 = \Delta x_2 / \Delta = 0,06 / 0,52 = 0,115$ kg/s;
$X_3 = \Delta x_3 / \Delta = 6,3 / 0,52 = 12,20$ °.

Table 2. – Results of the calculation of the factors' optimal value.

Name of the factor	n_c U/min	q_c, kg/s	γ_c, °
Factor's value	19,7	0,115	12,2
Energy intensity of the feed mixing process $Э_y$ = 0,463 kWh/t			

On the basis of the obtained data using the program Statistica 8.0 [140] the two-dimensional cross sections were constructed. The two-dimensional cross sections were constructed at optimum values of the third factor (Fig. 4.6).

The above graphic-analytical analysis of the mathematical model using two-dimensional cross-sections and solution of the models in Mathcad 15 showed the optimal values (a combination) of the studied factors (see the table 2).

A flow of components in a mixer has the greatest impact on the energy intensity of the mixing process of rough, succulent and concentrated feed in the proposed mixer, as evidenced by the maximum coefficient of regression. The minimum possible energy intensity of the process is 0,463 kWh / t.

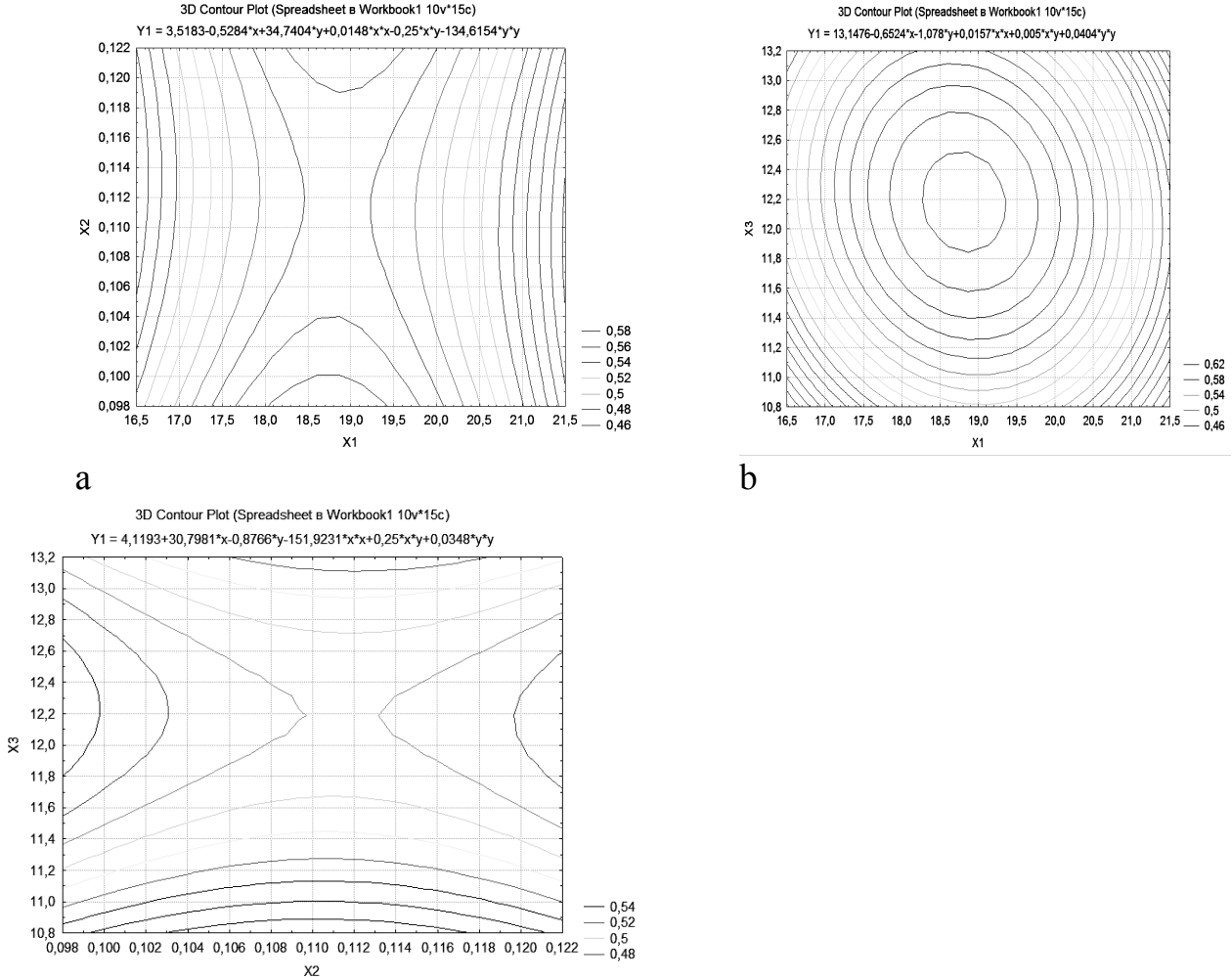


Fig. 6. Energy intensity of feed mixing process in a continuous-running fodder mixer at a fixed value of one factor:
a - X3 (γs = 12,2 °); *b* - X2 (q_c = 0,115 kg / s); *c* - X1 (n_c = 19,7 rotations/min).

The above mentioned results of the experimental study confirm the current hypothesis on improving the efficiency of the technological process of mixing rough, succulent and concentrated feed by the use of a continuous-running mixer's design with a rotating tanker, which is represented by a two truncated cones, which are installed inside with a winding and blades.

One of the important issues is to maintain farm machinery and equipment constantly in a good working condition. The farm repair service, repair and service enterprises of different levels of AIC of Ukraine play here the decisive role. In service, a differentiated approach in determining the frequency and complexity of engineering design activities for different types of machines is provided for machinery and equipment of livestock farms. The aggregate-node repair method is considered to be the most promising for the machine and tractor fleet of households, providing the replacement of faulty components and assembly units for new or repaired from the exchange fleet.

A wide variety of food preparing machines indicates a need for a specific representation of each type of these machines and simultaneously possibilities of the use of standard, unified technologies for their repair productivity of animals.

Conclusions.

1. It is inappropriate to chop concentrated and rough feed simultaneously, because the fibrous materials of rough feed reduce the impact force of grain with the working surface of the chopper, that is why equipping the screw working bodies with knives doesn't give the desired degree of chopping all components of feed mixtures for feeding small cattle

2. The mobile feed preparation shop for small cattle should chop rough, succulent and concentrated feed, accumulate the milling products in tankers, dose the milling products and mix them, preparing a food mixture with a high degree of homogeneity.

3. It is advisable to mix the above mentioned feed components in the continuous-running fodder mixer.

4. The effective continuous-running fodder mixer should lift a part of the food mixture's layer at a height, bigger than the slope of repose of its components. This effect prevents the formation of the circulation center of the mixture's components and mixing is provided by the alternately changing the layers' position.

5. The results of the experimental research confirmed the theoretical backgrounds for the study of the technological process of mixing rough, succulent and concentrated fodder by a continuous-running mixer with a rotating tanker. The discrepancy between the results of experimental and theoretical studies on the set optimal mixer's modes of operation does not exceed 4-8%.

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