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Justification of the effective design and operating parameters of the dosing and mixing device for the preparation of compound feed

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Abstract: This article is about the study of the rational design and operational parameters of a dosing and mixing device in order to improve the accuracy of feeding concentrated feed to cows. The object of the research was the process of producing compound feed with dispersing force and the improved design and operational parameters of a screw-type liquid metering mixer. We investigated the operation of the developed experimental mixer in industrial settings (conducting pilot tests and obtaining results on the economic efficiency of its use). The design features of the metering mixer, design parameters for the operating mode, and practical recommendations for use, all of which were justified as a result of the research, are important for feed mills.

Keywords: *Design, Feed production, Rational design and technological parameters, Screw dispenser mixer, Technology, operating parameter.*

1. Introduction

Currently, the country's agricultural sector, which is based on agriculture and animal husbandry, faces challenges including intensifying production, increasing labour productivity, and reducing production costs. The solution of these tasks is possible only based on the complete mechanization of labour-intensive processes and the use of modern technologies. The profitability of production and the volume of livestock production directly depend on the level and quality of animal nutrition, as well as on the balance of the diet, taking into account the nutritional value of feed. Feed metering devices used in feed mills and farms have a number of serious disadvantages. These include the complexity of the design, high metal consumption, low quality of dosing, and high cost. When using dispensers of complex design, labor and material costs for their repair and maintenance increase, and the efficiency of their use decreases. In addition, the feed given to the animal in excess of the norm is not compensated by the product received. This leads to an irrational consumption of feed.

From the above, it can be concluded that the development of a feed dispenser that ensures the effective use of concentrated and compound feeds, promotes the normal development and productivity of dairy cows, high mechanization and automation of the feeding process that meets certain zootechnical and other requirements, is an urgent problem and requires study based on the results of scientific

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research. In this regard, this research work is aimed at developing a method for distributing dry concentrated feed in higher-quality doses, a feed dispenser that meets zootechnical, technological standards and modern requirements of livestock production. Continuous volumetric dosing is a more efficient and less demanding process on the condition of the ingredients, and with the use of appropriate equipment, it allows for the preparation of a feed mixture with the desired quality. For this reason, these types of dispensers are commonly used in feed mills. Additionally, in the best-case scenario, automatic adjustment of material supply can be implemented based on humidity levels [1, 2].

During continuous dosing, all ingredients are added to the mixer in a steady stream according to a predetermined formula for compound feed [3], and mixing occurs continuously.

Considering that the accuracy of dispensers is influenced by numerous factors, it is challenging to determine which dispenser or dosing method increases or decreases accuracy. However, it is worth noting that a well-designed volumetric dispenser, structurally, is not inferior to weight-based dispensers and can ensure accuracy.

Therefore, when choosing a type of dispenser, it is important to consider not only the accuracy requirements, but also the design of the dispenser in relation to the nature of the product to be dispensed. The following requirements apply to metering devices:

- Regulation of the supply of components within the required limits
- Ensuring accuracy and uninterrupted operation of the device
- A simple design with low metal and energy consumption
- Quick adjustment and adjustment based on the type of material and feed rate

It's essential to choose a dispenser that meets these requirements in order to ensure accurate and efficient dispensing.

These special types of dispensers can be used not only as standalone devices but also in combination with other equipment for dispensing multiple ingredients, making them ideal for installation on production lines.

By selecting dispensers with different designs and operating modes, we can divide permanently effective dispersers of dispersed materials into basic categories according to their principle of operation:

- With a tensioning element, such as a spiral tape, plates, or pistons, as a working part.
- With a rotating working part, like a screw or a disc.
- With an oscillating working part, such as vibrating or other oscillating mechanisms.
- Pneumatic dispensers, which operate under the influence of air on the dispersed material.

In this case, the dispersed material is supplied as liquid from a chute installed below the hopper. It should be noted that a hopper can also be dispensed without the use of a dispenser, where the dosing occurs due to the free flow of material through an opening opened by a valve installed at the bottom of the hopper.

The principle of operation of modern dispensers is based on the deformation of elastic elements that convert the force-measuring strain resistance transducers into an analogue electrical signal. These deformations are proportional to the weight of the cargo and change under the influence of gravity. The analogue electrical signal is then sent to the weighing device, where the dispenser's capacity, belt speed, and total weight are displayed.

Discrete dispensers dispense material in equal portions over a set period of time. The amount of material can be adjusted by changing the portion size or the volume per dose. This type of dispenser may not be as accurate as other models, but it is reliable and easy to use.

The classification of metering devices based on their design features is quite diverse. One of the most significant aspects is the classification based on the type of working organ and movement.

This classification is influenced by physical and mechanical properties of materials, such as particle size, dispersion density, fluidity, and adhesion. These factors play a crucial role in determining the classification of metering devices.

Another criterion that affects the classification of metering devices based on design parameters is the density of dispersion of the material. This parameter depends on the flowability of the particulate material, their average density, humidity, and the arrangement of particles in layers. The density of dispersed material is not constant, even when it is at rest. Over time, under the influence of fluctuations in the container walls, it can become compacted, and its dispersion density may reach a limiting value. During movement, displacement, and mixing, the material becomes softer and splits, decreasing the scattering density and approaching a limit value. Scattering materials can be classified based on their dispersion density as: light (less than 600 kg/m^3), medium (between 600 and 11,000 kg/m^3), heavy (between 11 and 20,000 kg/m^3), and very heavy (greater than 20,000 kg/m^3).. When dosing feed mixtures, medium and light dispersion densities are selected [4]. The dosing system has a serious drawback, as the speed and position of the trolley need to be adjusted to the rotational speed of the screw feeder and the current weight of the feed according to the recipe. In this system, the priority is on the sequence of intake of feed material from the hopper, which can lead to changes in the order of feeding material to the weighing truck, reducing productivity and profitability.

The aim of the study is to justify the design and technological parameters of the mixer-dispenser to improve the accuracy of component dosing in the preparation of concentrated compound feed for cows. To achieve this goal, the following objectives have been set:

- Theoretical study of the working process of a screw-spiral dispenser and optimization of factors that affect the accuracy of dosing.
- Study of a model sample of a mixer-dispenser manufactured based on a working hypothesis under laboratory and production conditions and experimental substantiation of rational, constructive, and technological parameters.
- Evaluation of an experimental dispenser from a technological, zootechnical, energetic, and economic perspective.

2. Material and Methods

The main methodological basis for conducting theoretical research is considered to be physics, theoretical mechanics and methods of mathematical analysis. In experimental studies, general measurement methods were used, including the SRT method AIST 19.2 – 2008 [5].

Criticism of Analogues and Prototypes. A device for dosing dispersed materials has been developed. It consists of a loading funnel with a lid, a screw with a hollow shaft, a metering unit with a motor and belt drive, an unloading nozzle, a pneumatic valve, and an oil seal. However, this device has a major drawback: it is unable to ensure even distribution of the required amount of components in the filler when preparing compound feed or premix, leading to loss of valuable protein-vitamin-mineral complexes in powder form.

Additionally, another dispenser of dispersed materials exists. This device comprises a funnel, lid, outlet window, and screw shaft that extends into a ribbon-like spiral, with the distance between the lid decreasing as the inner diameter increases toward the outlet window.

The main drawback of this device is its inability to ensure a uniform distribution of the desired rate of ingredients in the mixture during the preparation of feed or premix for feed, which can reduce the quality of the finished product.

The device, which is a variant of the original idea, is designed for dosing and mixing of dispersed materials. It consists of a hopper for the dispersed materials, working elements of different diameters arranged in an offset position in height, and a conveyor.

Inside the cover of a spiral screw, the working elements are located. Their axes are parallel, and a small-diameter element is placed on top of a larger-diameter one. One end of the larger element protrudes beyond the cover and has a lid. A mixer is placed inside the hopper containing dispersed materials.

When preparing compound feed or a premix for compound feed, the small-diameter screw element supplies dispersible materials such as powdered protein-vitamin-mineral complexes and medicines to the larger-diameter element. A large-diameter screw body, with its tip extending beyond the lid, receives the bulk component or filler of the feed mixture and mixes it with the powdered protein, vitamin, and mineral complex supplied in the mixture to create the final product.

Unfortunately, this device has a disadvantage: when preparing compound feed or premix, it is difficult to ensure an even distribution of the necessary components in the filler, leading to a decrease in the quality of the finished product.

To address this issue, the aim of the improvement is to improve the distribution of the micronutrient complex within the mixed feed or premix to within acceptable limits.

Features of the improvement: This task is achieved through the use of a dosing and mixing device for dispersed materials. The device consists of a hopper for storing trace elements, such as powdered protein-vitamin-mineral complexes and pharmaceuticals. The first working part of the device is an auger, which begins the process of mixing.- A ribbon spiral is connected to a casing, which has a loading neck at the bottom. A second working body begins at the end of the first one and is located below it in the casing. Output legs are connected to this second body. A hopper with a valve feeder for filler (cereals, bran, bulk components) is also connected. An electric motor rotates the second body using a cruciform belt drive with pulleys of different diameters. The first working body mixes the microelement complex and the second one mixes the filling mass. They are connected by the pulleys and the cruciform drive.

The structural and technological design of the improved dosing and mixing device for granular materials is shown in Figure 1. The device comprises a hopper for trace elements (1), the first working element (5), the beginning of which is connected to a loading neck (2), and a lid (6) connected to it. The lid begins with a screw (3) and continues with a ribbon spiral (4). The second working element is (7), the beginning of which coincides with the end of the first element (5) and is located below it in the lid. It consists of a screw (8) connected to it, outlet windows (9), a hopper (11) for filler (e.g., semolina, bran, bulk material) with a valve feeder (10), an electric motor (12) that drives the second element (7), and a transverse belt drive (13) that ensures the movement of the first element (5). The device works by.... Microelements added to the compound feed or premix are weighed in small doses and filled into a microelement hopper in advance. The amount of each microelement is determined according to the recipe, and the component is assembled in a filler hopper to be used as the main ingredient in compound feed or premix. The rate of the component in compound feed is adjusted by a valve dispenser, and the device starts.

At this time, the rotation speed of the screw pair in the first working body is higher than that of the screw in the second working body. This is achieved by using pulleys with different diameters in the two working bodies: small diameter pulleys for the first body and large diameter pulleys for the second body. A cross-belt drive with an electric motor ensures the movement of material from the feeders to the outlet windows in both working bodies.

A metering and mixing device for dispersed materials enables the efficient use of trace elements in the preparation of compound feeds and premixes. This maximizes the potential usefulness of these valuable materials, reduces the likelihood of waste, and, consequently, lowers the cost of production and increases the economic efficiency of the final product.

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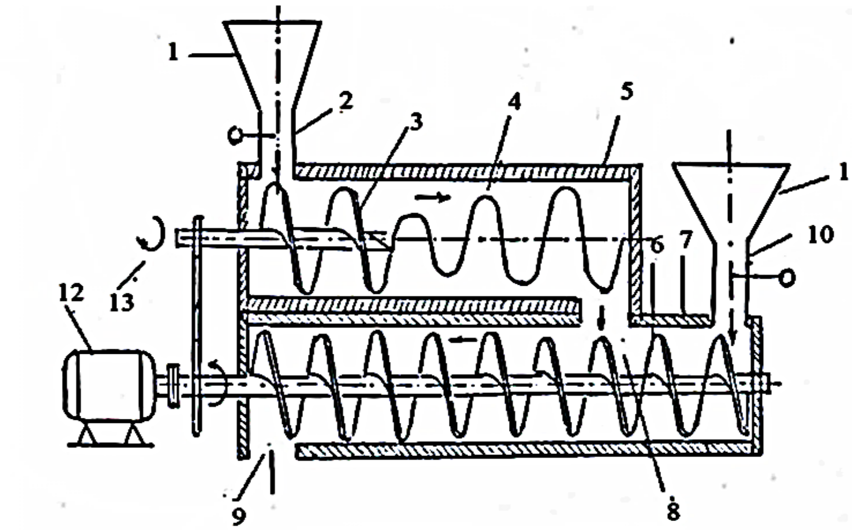

Figure 1.
Diagram of the improved dispenser mixer:

1 - hopper for trace elements, 2 - feeder neck, 3 – auger, 4 - ribbon spiral, 5 - first working body, 6 - second working body, 7 - outlet legs, 8, 9 - valve feeder, 10 - bulk component hopper, 11 - electric motor, 12 - transverse belt drive

3. Results and Discussion

Investigation of the device's performance and dosing errors.
The performance or load of the device is determined by the following formula:

$$Q = \frac{m}{t}, \text{ g/sec} \qquad (1)$$

where m – is the mass of a given fraction of the dispersed component, g;
t – is the time of loading the material into the device, sec.

As a working hypothesis, the constructive structure and principle of operation of the experimental device are described in detail in the second chapter of the work. The essence of the research methodology is as follows. The metering unit is brought to a stable operating mode. Then a sample of the dispersed material is taken every minute. The following formula is used to estimate the dosing error::

$$\eta = \frac{100}{m_{or}} \sqrt{\frac{\sum_{i=1}^{n} \left(m_i - m_{or}\right)^2}{n-1}}, \% \qquad (2)$$

where m_{or} - is the average mass of the material in the sample,q;
$m_i - i$ - the mass of the material in the sample, q;
n – the total number of samples.

Then other parameters characterizing the working body are determined. The coefficient of deceleration of the movement of the mixed dispersed material along the axis. It is determined K_{len} by the following formula:

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$$K_{len} = \frac{\vartheta_{zm}}{\vartheta_{zn}}, \quad (3)$$

where ϑ_{zm} - is the axial velocity of the moving material, m/sec;

ϑ_{zn} - axial speed of the roller surface, m/sec.

The axial velocity of the moving material is expressed by the following formula:

$$\vartheta_{zm} = \frac{L}{t}, m/san \quad (4)$$

where L - is the length of movement of the moving material, m;

t - timeof replecing, sec.

The axial speed of the roller surface is determined as follows:

$$\vartheta_{zm} = \frac{s \cdot n}{60}, m/san \quad (5)$$

where s - is the pitch of the roller, m;

n - the speed of rotation of the roller, min^{-1} .

The coefficient of filling of the coating with a moving flooring material is determined by the following formula:

$$k_f = \frac{G_m}{G_T}, \quad (6)$$

where G_m - is the actual amount of material in the coating, kq;

G_T - the theoretically possible amount of material in the coating, kq.

Theoretically, the possible amount of material in the coating is calculated as follows:

$$G_T = \frac{\pi}{4}\left(D_k^2 - 3\delta^2 L\rho\right), kq \quad (7)$$

where D_k - is the inner diameter of the coating, m;

$\delta -$ diameter of the winding wire, m;

ρ - material density, kq/m^3.

The power consumption is as follows:

$$N = m\omega^3 L^2, kW \quad (8)$$

where m - is the mass of the working body with the material, kq;

ω - the speed of rotation of the electric motor shaft, sec^{-1};

This paper presents the development and characterization of two effective micro-mixing techniques for small volumes of liquid, both based on non-contact systems to avoid contamination between mixing liquids and prevent undesirable crosstalk in biochemical assays.

The principle of these micro-mixing techniques is to control the trajectory and volume of droplets. One method involves simultaneously dispensing two different droplets to create a simultaneous micro-mix (SMM). The other method alternately dispenses two droplets into a single well (AMM).

Both methods aim to induce mixing by controlling the trajectory and volume of the dispensed droplets, allowing for precise control over the mixing process.. In this study, we developed a dispensing system for micro-mixing that uses pressurized air to transfer a liquid from a reservoir to a nozzle through a high-speed solenoid valve. This process creates liquid droplets ranging in volume from several tens of nanoliters to several microliters, depending on the viscosity of the liquid being dispensed.

The droplet volumes were measured under different dispensing conditions, such as varying operating pressure and the opening time of the high-speed valve. We used sodium hydroxide (NaOH) ethanol solution and phenolphthalein ethanol solution with glycerol as the mixing target liquids to quantify the mixing performance Park, et al. [6].

Research into the factors influencing quality has shown that the amount of filler in the total feed mix is an important factor in the preparation of fortified feed and premixes. This research has led to further experiments to determine the individual modes and design parameters for both components of a dosing and mixing device, such as the screw dispenser for dispersed feed and the continuously operating sections with blades for mixing the dispersed feed components.

The loading level of the device was determined by the feed content at 20% and 30% in the screw-liquid dosing section, using a feed material (Table 1).

Table 1.
Change in the loading level of the device depending on the diameter of the coil, which is the main working organ of the metering device.

№	The share of filler in the composition, %	Loading level, Q, kg / min		
		Diameter of the winding		
		50	70	90
1	20	1.8	6.4	11.0
2	30	1.8	4.2	5.0

The recorded values correspond to the values of the winding step S = 73 mm (the step of the winding) and the gap between the winding and the cover b = 7.5 mm. In the subsequent study, the variants of the winding diameter of the installation load and the winding step 73, 7.5 and 54 mm at constant values of the gap between the winding and the cover (d=73 mm, b = 91 mm) were studied.The prices taken are also reflected in Table 2.

Table 2.
Variants of the winding step at fixed values of the winding diameter of the installation load and the gap between the winding and the cover.

№	The share of filler in the composition, %	Loading level, Q, kg / min		
		Diameter of the winding		
		51	73	91
1	20	4.0	6.4	7.2
2	30	2.4	2.5	2.75

From the received prices (Table 1 and Table 2) it can be seen that as the diameter and step of the winding increases, the level of load on the installation (in other words, the possibility of increasing the productivity of the installation) increases. However, this increase was less when the share of filler in the composition increased. Thus, if the filler share in the mixture was 20%, the loading level increased from

51 to 91 mm, if the filling step increased from 4.0 to 7.2 kg/min, if the filler share in the composition was 30%, this increase increased from 2.4 to 2.75 kg/min. It is also possible to observe a similar phenomenon for increasing the diameter of the winding. So, when the diameter of the coil increased from 50 to 90 mm, the filler share was 20%, the loading of the unit was from 1.8% to 11.0 kg/min, and when the filler share in the composition was 30%, the loading only increased from 2.4 to 2.75 kg/ min. This can be explained by the fact that the density of mineral additives is greater in comparison with the density of filler materials.

In the following studies, the influence of the step and diameter of the winding as a working body on power consumption was studied. The prices obtained are reflected in Table 3 and Table 4.

Table 3.
Change in the power required by the unit depending on the diameter of the winding.

№	The share of filler in the composition, %	Required power, N_{doz}>W		
		Coil diameter, S, mm		
		50	**70**	**90**
1	20	41.50	41.75	42.00
2	30	42.75	42.55	42.90

When studying the influence of the coil diameter, its pitch (S = 73 mm) and the gap between the coil and the lid (b = 7.5 mm) were kept constant.

Table 4.
Change in the required power (N_{doz}) of the corrugated metering section depending on the pitch of the coil.

№	The share of filler in the composition, %	Required power, N_{doz}>W		
		Coil diameter, S, mm		
		51	**73**	**91**
1	20	42.00	42.50	42.90
2	30	42.10	42.54	43.10

Experience has shown that, within the permissible operating modes, changing the structural dimensions of the coil does not significantly affect the required strength. An increase in the amount of filler in the composition leads to a slight increase in strength. This can be explained by the fact that the moisture content of the filler is higher (14-15%) than that of other dry dispersible materials. Analysis of the results of experimental studies has shown that the unevenness of the feed mixture, the granulometric composition and energy consumption during dosing and mixing of feed components depend on the initial physical and mechanical properties of feed products, as well as design and operating parameters.

With the specified values of the parameters of heterogeneity or uniformity of the feed mixture, the total required power was, respectively, δ = 7...11; λ = 93...89 %; N = 35...4.94 kW. A comparison of the results of experimental studies with theoretical values, which are the main functional interactions for the proposed technical solution, showed that they do not exceed 5... 8%. Verification of the obtained optimal parameters in the proposed experimental samples confirmed their compliance with the criteria for optimizing zootechnical standards.

4. Conclusion

The working hypothesis of a dosing mixing device, based on the targeted connection of screw and spiral structures, is theoretically and practically justified. This device promotes the effective use of trace elements in the preparation of feed and premixes, maximizing the benefits of these materials and reducing the likelihood of losses. As a result, the cost of the final product is reduced and economic efficiency is increased.

The design and technological innovation of this metering mixer has been approved by the Intellectual Property Agency of the Republic of Azerbaijan, with patent number F 2025 0011.

The device developed as a result of research for the preparation of compound feed with a dissipating force, with significant savings in energy consumption and investment, has an annual efficiency of 1547.3 AZN = 789.76 EUR when used on a farm containing only 100 dairy cows.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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