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DETERMINING THE FORCE PARAMETERS OF THE WORKING PROCESS TO CLEAN THE UDDER NIPPLES OF COWS

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The object of this study is the force parameters of the working process when cleaning the udder nipples of cows from contamination. Failure to provide adequate care for a cow, especially concerning its udder, could lead to significant health and productivity problems. On the other hand, utilizing modern tools, devices, and materials could improve the sanitary and hygienic conditions for milking cows and udder care, thus leading to better overall outcomes. As part of the research, mathematical expressions were derived theoretically, allowing the determination of the force parameters of the working process for cleaning cows' udders from contamination by expanding the range of the device's functional characteristics. Distinctive features of the results regarding the solution to this problem is evaluation of the elasticity force exerted by the lint bundles on the nipple during the rotation of the brush device's drum and the circular force generated by the brush lint. The developed algorithm of the work process aimed at cleaning the nipples and udders of cows made it possible to combine a set of clearly defined and sequentially performed operations into a single whole.

It has been demonstrated that the efforts required to retain different types of contamination on the skin vary significantly. To objectively determine it, a new device has been designed. Its distinctive features are the precision of measurement and simplicity of operation. Following laboratory testing, it was established that the highest contaminant retention forces were exhibited by solid manure (F_{ret}=40±3.21 N), while the lowest values were observed for sawdust (F_{ret}=19±2.17 N) ($p \leq 0.001$). The developments are relevant and could be used at cattle breeding farms of various forms of ownership, the scientific community, and at industrial enterprises manufacturing technological equipment

Keywords: cows, a device for cleaning udders, the process of cleaning cows' udders

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1. Introduction

The production of safe and high-quality milk remains the primary task of the cattle breeding industry. In this context, the sanitary and hygienic condition and functional process of milking cows requires strict compliance with the relevant rules regarding the cleanliness of the udder and nipples [1]. On the other hand, among a significant number of urgent issues in the implementation of measures to improve this process and farm management practices, comfortable keeping of cows, hygiene in the premises for their keeping, control over the condition of milking equipment are extremely important. In particular, work [1] established a clear connection between the hygienic condition of the udder and nipples of Simmental and Holstein cows in Turkey and the content of somatic cells and milk components. Interbreed differences according to these indicators were highly probable and were caused, first of all, by the month of sampling and the hygienic condition of the animals. The expediency of assessing and controlling the hygienic condition of the udder of cows to determine management strategies aimed at reducing problems with milk and improving their welfare is indicated in [2]. Norwegian scientists note that the main risks associated with animal contamination in the 60 researched herds were the lack of cleaning practices, unsatisfactory housing conditions and water consumption [3]. Meanwhile, Iranian scientists believe that one of the effective factors for improving the hygienic condition of cows' udders is drying the udders with a disposable paper towel after immersion in special agents, followed by their treatment and therapy with intramammary ointment with antibiotics [4].

According to [5], a clean floor in the passage of a room for free keeping has a positive effect not only on the cleanliness of the pasture but also on the condition and contamination of the udders and nipples of cows. Whereas the contamination of the animal is a risk of disease and a decrease in the quality of milk. At the same time, with the help of the application before milking of the appropriate devices and methods, it is possible to achieve optimal purity values of the technological process and the product we get.

Study [6] shows that high-quality care of the herd's udders means health care, prevention of mastitis and, as a result, an increase in the quantity and quality of milk. Although the stage of milking significantly affects the accuracy of the assessment of cow hygiene made during milking. A similar opinion is held by specialists in [7]. At the same time, work [8] stated that 49 % of farms in Sweden have dirty livestock, and farmers attribute this to insufficient measures for animal care and the lack of proper means and devices for cleaning them.

It is important to take into account that at the current stage of development of dairy farming, the process of mechanical cleaning of cows' udders is of key interest for obtaining extra grade milk. But it is energy-consuming [9, 10]. At the same time, the leading task set by the practice of operation of such devices is the need to determine the main parameters of their work process, which make it possible to carry out effective diagnostics of the technical condition during operation. Therefore, research on this topic is relevant in terms of intensifying the search for new tools for the practical implementation of this issue.

2. Literature review and problem statement

In work [11], the preparation of cows and equipment for milking is considered to be a determining link of cattle breeding technology, which has a significant effect not only on the speed of milk yield but also on the quality of milk and udder health. But the issue related to determining the impact of working equipment on the efficiency of milking cows remains unresolved. An option to overcome the relevant difficulties is proposed in [12]; an approach that fully reveals the influence of technical and technological parameters of milking equipment on the efficiency of machine milking. At the same time, as stated in [13], cleaning the udders before milking is a key factor in preventing milk contamination. The authors claim that the effectiveness of conventional cleaning of udders is insufficient, as the average purity of a cow is strongly correlated with the level of milk contamination. Similar results are indicated in [14], adding that udder health indicators are related not only to the cow itself but also to the methods of keeping it. Nevertheless, work [15] notes that the most effective method of preparing cows for milking is special mechanized brushes. They clean, stimulate, disinfect, and dry the skin of the udders. The use of mechanized brushes is an example of improving animal welfare [16]. As a result, there is no need to use additional foaming agents for cleaning and disinfecting nipples, as well as dry and wet wipes. Instead, both the cleaning processes and the brushes themselves differ significantly. All this gives reason to assert that it is expedient to conduct a study on the development of the work process for cleaning the udders of cows.

Currently, there is a wide range of production devices for pre-preparation of cow udders for milking. But it is impossible to call them absolute analogs [17]. In terms of technical parameters, the devices have significant differences. They have different speed of rotation of the bristles. At the same time, as noted in works [18, 19], it is not possible to state that the higher their speed, the better. Currently, animals feel discomfort and behave restlessly at the high speed of rotation of the brushes of the devices. Usually, low speed degrades the quality of processing. Therefore, these questions remain finally unsolved.

It should be noted that the unbiased development of technologies under the conditions of wide implementation of innovations is a significant factor in increasing the competitiveness of the production of high-quality dairy products, but it needs to be definitely improved. Now, a device for mechanical cleaning of the udders of cows has been designed and its parameters have been theoretically substantiated, which made it possible to increase the productivity of cows and improve the quality of the obtained products [19]. However, under the modern conditions of milk production, the question of determining the force parameters of the work process of cleaning the nipples of cows' udders remains unresolved. This is related to the assessment of the effect of cleaning elements on the physiological needs of animals and the process of removing pollution against the background of a clear justification of the algorithm of their work process. This necessitates conducting a related study.

3. The aim and objectives of the study

The purpose of our study is to determine the force parameters of the work process of cleaning the udders of cows, which will make it possible to improve the quality of milk.

To achieve the goal, the following tasks were set:

– to justify the interaction parameters of the cleaning elements of the device for cleaning the udders of cows;

– to develop an algorithm of the work process of cleaning the udders of cows;

– to determine the quantitative values of the effort of keeping different types of dirt on the skin.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the force parameters of the work process of cleaning the udders of cows from contamination.

The main hypothesis of the research assumes that the research would contribute to clarifying the force parameters of the work process of effective cleaning of the udders of cows from contamination and could make it possible to improve the quality of milk.

The basis of theoretical research is the methods of multi-criteria analysis, theoretical mechanics, and the theory of mechanisms and machines [20, 21].

Taking into account the given theoretical provisions and the defined conditions of the research object, a program and work methodology for determining the force parameters of the work process of mechanical cleaning of the leather cover of cattle were devised.

First of all, the quality of cleaning (K), which most fully characterizes the efficiency of the device (1), was chosen as a criterion for determination:

$$K=(1-Q_1/Q_0)\times 100, \tag{1}$$

where Q_1 is the final pollution, g/cm^2, Q_0 is the initial pollution, g/cm^2.

4. 2. Research methodology and data processing

The efficiency of cleaning was determined after processing a laboratory sample with contamination. The mass of pollution was applied to a sample with a leather cover and weighed on a scale. Then, after cleaning, the sample was weighed together with the leather covering. The efficiency of the process was determined by the amount of remaining contamination.

Laboratory research methodology included:

– design of a device for determining the retention force of various types of pollution on the skin of an animal;

– determining the effort to retain various types of pollution on the skin of the animal (determination of the pain effect in order to fulfill condition (16).

Laboratory tests of the device for determining the retention effort of various types of pollution on the skin of cows were conducted at the Department of Livestock and Poultry Technologies, the State Biotechnology University (Ukraine). Five cattle skins were used as the processed surface.

The production tests of the device were carried out at the state enterprise of the research farm "Gontarivka", the Institute of Animal Husbandry of the National Academy of Agrarian Sciences of Ukraine, Chuhuiv Region, Kharkiv Oblast, on cows of the Ukrainian black-spotted dairy breed. For the experiment, special sections were allocated in the room and 3 groups of cows, 5 heads in each, were used. The experimental groups were formed taking into account the amount of daily milk yield, the condition of the udder and were kept on a harness. Different bedding materials were used as litter: for group I – sawdust, II – peat, and III – straw. Feeding was carried out with the same rations, which consisted of complete feed, hay, and straw of cereal crops. The repeatability of the experiment is threefold.

The processing of research results was carried out using the Microsoft Excel software package by the method of variational statistics by calculating the average arithmetic values (M), the mean squared error ($\pm m$), and the degree of probability (p). The difference in mean values between the compared samples was considered probable at the significance level of $p<0.05$.

5. Results of studies on the substantiation of parameters of the interaction of the cleaning elements of the device for cleaning the udders of cows

5. 1. Theoretical substantiation of the interaction parameters of the cleaning elements of the device for cleaning the udders of cows

As part of the theoretical studies, the interaction parameters of the cleaning elements of the previously designed device for cleaning udders were substantiated [19]. We assume that during the cleaning of the udders, the following forces act: F_{ce} is the force created by one cleaning element, N; F_{sp} is the effort spent on the separation of a particle of pollution, H; F_f is the frictional force of the contamination cleaning element, N; m – mass of pollution, kg.

The force created by one cleaning element consists of two components: the force of elasticity and the force of separation of a particle of contamination from the surface of the nipple (2):

$$F_{ce}=F_f+F_{sp}. \tag{2}$$

Effective cleaning of cows' udders from contamination (K_e) is a function of four groups of variables: parameters of udders (M_u), brush device parameters (M_{bd}), cleaning modes (M_m), contamination parameters (M_c) (3):

$$K_e=\{M_u, M_{bd}, M_m, M_c\}. \tag{3}$$

In general, the process of preparing the udder of cows for milking is described by a large number of parameters that affect the efficiency of cleaning the udders from contamination (4):

$$K_e=\begin{Bmatrix} L_n, d_n, E_m, D_b, l_b, d_b, n_n, \ {}_r, N_{dd}, \\ \omega, t_{cs}, P_{ce}, t_{cb}, \upsilon_b, m_c, K_{sn}, K_{fn}, \\ K_{mr}, K_{bb}, K_{ma}, K_{lb}, K_{cm}, K_{as}, K_{ac} \end{Bmatrix}, \tag{4}$$

where L_n is the length of nipples, mm; d_n – diameter of the nipple, mm; E_m – modulus of elasticity of milk, kgf/mm^2; D_b – brush diameter, mm; l_b – bristle length, mm; d_b – brush bristle diameter, mm; n_n – the number of bristles in the bundle, pcs; B_r – module of relative stiffness of the bundle of bristles, kgf·cm; N_{dd} – drive power of the brush device, W; ω – angular speed of brush rotation, rad/s; t_{cs} – duration of cleaning the surface of the nipple, s; P_{ce} – circular effort, N; t_{cb} – duration of cleaning the base of the nipple, s; υ_b – linear brush speed, mm/s; m_c – mass of contamination, g; as well as the coefficient that takes into account K_{sn} – the shape of the nipple, K_{fn} – roughness and irregularities (folds) on the surface of the nipple, K_{mr} – the moisture retention of the brush bristle, K_{bb} – the capillarity of the brush bristle, K_{ma} – the intensity of the mechanical action of the bristle bundles per unit length of the nipple, K_{lb} – the location bundles of bristle on the drum of the brush, K_{cm} – physical and mechanical properties of the contamination material, K_{as} – aggregative state of the contamination material; K_{ac} – the area of contamination of the nipple.

We hypothesize that the cleaning of the nipple from contamination occurs by a bunch of bristles, the stiffness B_n of which can be related to the stiffness of individual bristles (5):

$$B_n = K_n E J n_n, \quad (5)$$

where K_n is the coefficient, <1.0; E is the modulus of elasticity of the bristle material (kgf/mm^2), equal to 2.5×10^4; Jn is the moment of inertia of the bristle cross-section, cm^4.

Provided that there are several bundles n_{nn} in the contact zone of the bristle with the cow's udder, then their stiffness B_{nn} is expressed by the total sum (6):

$$B_{nn} = K_n E J n_n n_{nn}. \quad (6)$$

The effect of the bristle on the tip of the nipple depends on the linear and angular speeds of the brushes. At the moment of the first contact of the brush of bristles with the tip of the nipple of the udder, the cow experiences pain. The calculation of the absolute speed of the bristles ϑ_{ab} of the brush is carried out by solving the following expression (7):

$$\vartheta_{ab} = \sqrt{\omega^2\left(l_b + \frac{d_b}{2}\right)^2 + \left(\frac{L_n}{t_{cs}}\right)^2}. \quad (7)$$

The speed of vertical movement of the brushes is limited by the time of preparing the cow for milking and has quite specific values. When cleaning the nipple, it is quite difficult to remove solid impurities. Along with this, the action of the brushes on the nipple is accompanied by blows of bundles of lint, deformations of the contaminated surface of the nipple, dragging of dirt particles by the hairs and their rejection. The total circular force P on the tufts of brush bristle consists of force P_1 for impact and force P_2 for dragging and throwing away dirt particles, etc. (8):

$$P = P_1 + P_2, \text{ N}. \quad (8)$$

In turn, the force P_1 of the impact is determined under the condition of the balance of the momentum of the force P_1 with the change in the amount of movement of the contaminated mass (soil, manure, etc.) (9):

$$P_1 \Delta t = m_3(\vartheta_2 - \vartheta_1), \quad (9)$$

where Δt is the duration of the impact time, s; m^3 – mass of contaminated particles, on which blows are applied, kg; ϑ_2 – velocity of the mass of contamination at the end of the impact, m/s; ϑ_1 is the mass movement speed at the beginning of the impact, m/s.

Based on the provisions about the proportionality of the force P_2 to the total circular force P, i.e., $P_2 = fP$, where f is the proportionality coefficient characterizing the degree of contamination and substituting P_1 and P_1 into expression (8), we calculate (10):

$$P = \frac{m_c \alpha \vartheta_{ab}}{\Delta t(1-f)}, \text{ N}, \quad (10)$$

where α is the proportionality factor.

In this case, the quantitative values of the power required to remove contamination are calculated by multiplying both parts of equation (9) by the circular speed of the brush (11):

$$N_i = \frac{m_c \alpha \vartheta_{ab} \vartheta}{\Delta t(1-f)};\ N_0 = \sum\nolimits_{i=1}^{n} Nt, \text{ W}. \quad (11)$$

The effect of brush bristle on the cow's udder can be both positive, i.e., necessary to remove contamination, and negative, causing damage to the epidermis of the udder's skin, destruction of the barrier for pathogens and pain. The brush device, acting on the contamination of the nipple, should not leave gaps, damage the nipples, and be clogged with impurities. Effective cleaning and a uniform effect on the udder nipple should be facilitated by the placement of bristle bundles, which does not leave untouched strips and overlaps.

To simplify, the intensity of the mechanical action of brushes K_b on the nipple is represented as the ratio of the circular speed of the brush (υ_c) to the linear speed (υ_l) of the vertical movement of the brush device along it. Taking into account the parameters of the device and the cleaning modes of nipples, the calculation formula took the following form (12):

$$K_b = \frac{\left[\frac{\pi n}{60}\left(\frac{d_b}{2} + l_b\right)t_{cs} + L_n\right]}{L_n}. \quad (12)$$

ΔL_a applied to one bundle of bristles indicates the distance (step) through which the next blow of the bundle of bristles will be applied to the epidermis of the cow's skin (13):

$$\Delta L_a = \frac{\Delta L_n}{Z_0} = 1000\frac{\upsilon_l}{n_b} Z_0, \text{ mm}, \quad (13)$$

where Z_0 is the number of bristle bundles along the perimeter of the brush, pcs.; n – brush rotation frequency, min^{-1}.

The step of bundles along the length of the brush drum is calculated by solving expression (14):

$$b_b = d_b + 2l_b \cdot \text{tg}\gamma, \text{ mm}, \quad (14)$$

where d_b is the diameter of the bristle bundle, mm, γ is the deflection angle of the bristles in the bundle, degrees.

The step of bristle bundles along the contour of the brush is equal to (15):

$$a_b = \pi\left(\frac{d_b}{2} + l_b\right) \cdot \frac{d_b}{Z_0 D_b}, \text{ mm}. \quad (15)$$

Therefore, compared to previous studies [19], due to the determination of the elastic force of bristle bundles acting on the nipple when the drum of the brush device for cleaning the nipples of cows' udders is rotated and the evaluation of the circular force formed by the brush bristle, the force parameters of its work process were determined: (1) to (15).

Along with this, in order to avoid pain, it is necessary to fulfill the calculation conditions (16):

$$F_c \le F_d \le F_p, \quad (16)$$

where F_d is the force effect of the mechanical device; F_p is the effort that causes pain; F_c is the contamination containment effort.

5. 2. Development of the work process algorithm for cleaning the udders of cows

On the basis of theoretical studies, an algorithm of the work process of cleaning the udders of cows has been developed (Fig. 1)

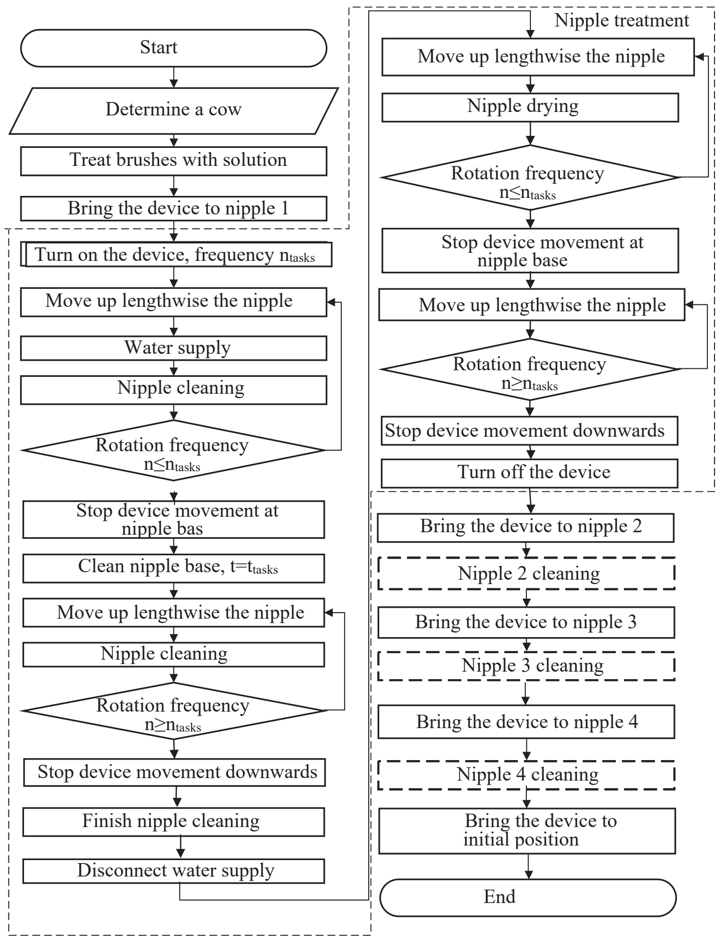

Fig. 1. Algorithm of the work process of cleaning the udders of cows

It is appropriate to note that the application of the proposed algorithm of the work process of cleaning the nipples of the udder of cows ensures consistent wet cleaning of each nipple and the base of the udder with their subsequent drying. This process takes place by controlling the frequency of rotation of the brushes to determine the beginning of the cleaning of the tip of the nipple, the fixed cleaning of its base, and the completion of the cleaning of the cow's nipple and udder.

5. 3. Results of designing the device for determining the quantitative values of the force of retention of various types of dirt on the skin

At this stage of our work, a device was designed to determine the force of retention of various types of contamination on the skin cover of cows, which structurally consists of a fixing element, a dynamometer module, a registration module, and a handle (Fig. 2).

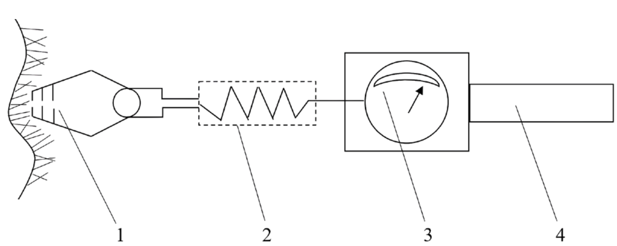

Fig. 2. Device for determining the effort of keeping different types of contamination on a skin cover: 1 – handle; 2 – dynamometric module; 3 – registration module; 4 – handle

The device works as follows: with the help of handle 4, it is installed on the area of the skin. Next, fixing element 1 is contacted with contamination on that part of each cover, on which it is necessary to determine the required amount of effort to hold it. Then the operator makes a pulling movement. The effort spent on holding the force is measured by dynamometric module 2 and recorded using registration module 3. The pulling movement continues until the contamination is completely removed from the animal's skin. According to the readings of the dynamometer, the effort is judged by which the pain threshold of sensitivity of the animal's skin is reached. stability and efficiency of the technological process.

During the testing of the designed device, it was found that the effort to keep different types of contamination on the skin is not the same. In particular, its largest values are characteristic of solid manure, which reach F_{ret}=40±3.21 N, the lowest values are characteristic of contamination of bedding material such as sawdust – F_{ret}=19±2.17 N, which is 2.1 times less ($p \leq 0.001$) (Fig. 3, 4).

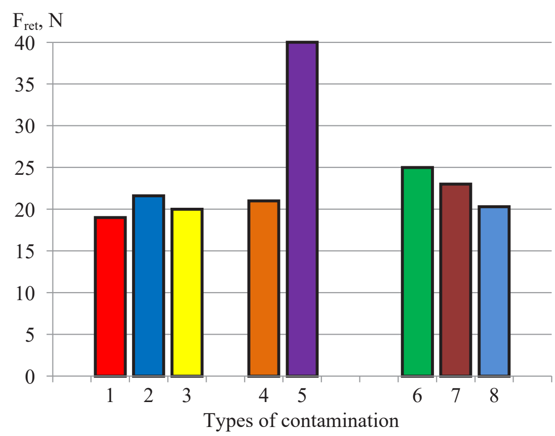

Fig. 3. Laboratory studies of the magnitude of the holding force of various types of contamination on the skin of cows: 1 – sawdust; 2 – peat; 3 – straw; 4 – liquid manure; 5 – solid manure; 6 – compound feed; 7 – hay; 8 – straw

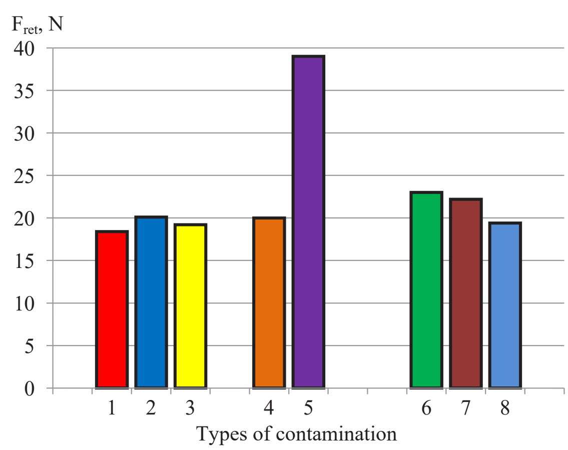

Fig. 4. Production tests of the holding force of various types of contamination on the skin of cows: 1 – sawdust; 2 – peat; 3 – straw; 4 – liquid manure; 5 – solid manure; 6 – compound feed; 7 – hay; 8 – straw

It is worth noting that the data recorded under laboratory conditions differ insignificantly (4.8 %) from the results of the production test. The differences found between them can be explained by the fact that under laboratory conditions the measurements were carried out on samples of recently removed skins from cows. Therefore, the values of the effort to contain various types of contamination were slightly higher than directly under the conditions of production, where natural objects were used.

Our results from using the designed device make it possible to determine the appropriate efforts that take into account the performance conditions (16). That is, under the influence of the cleaning device on the udder nipple, pain sensations can be avoided.

6. Discussion of research results on determining the force parameters of the work process of cleaning the udders of cows

The high concentration of livestock at dairy complexes implies the formation of new approaches to raw milk quality management [22, 23]. However, there are still many unsolved issues related to improving the welfare and ensuring the health of the udder of cows [24, 25]. In order to solve these problems, some authors suggest using various cleaning agents [26, 27]. This fact does not fully align with the results of our own work, which was directed to the development of new objective approaches and devices for effective cleaning of cow udders from various types of contamination. Determining the force parameters of the work process of the previously designed device for cleaning the nipples of cows' udders required the calculation of the elastic force of the bundles of bristles acting on the nipple when the drum of the brush device rotates, and the evaluation of the circular force generated by the bristles of the brushes using formulas (1) to (15) presented in the work. Along with this, in order to avoid pain, it was necessary to fulfill the calculation conditions (16). Within the scope of our research, in contrast to the proposed technical solution [19], the range of functional characteristics has been expanded to determine the force parameters of the work process capable of mechanically cleaning the udders of cows. The work process algorithm developed in parallel during the research, which made it possible to ensure consistent wet cleaning of each nipple and the base of the cow's udder with subsequent drying, deserves special attention.

Our studies are fully consistent with the opinion of the target audience of the authors' collective [15, 17], which demonstrates the need to use mechanical devices for cleaning the udder of cows from various types of contamination.

A feature of the current research was the development of a device for determining the quantitative values of the force of retention of various types of contamination on the skin of cows. The originality of the proposed design of the device is that the effort spent on holding the force of contamination is measured using a dynamometric unit and recorded by a registration unit. As evidenced by the results of laboratory tests (Fig. 3), the designed device demonstrated high accuracy: the largest holding forces on the skin of cows are characteristic of solid manure (F_{ret}=40±3.21 N), the smallest – sawdust (F_{ret}=19±2.17 N, $p \leq 0.01$). The results are also confirmed by their production verification (Fig. 4). However, no technical solutions that would fully match the designed device and ensure the achievement of the obtained result in the available patent literature and scientific and technical sources of information were found.

At the same time, our research has certain limitations due to the field of application of the results, species, features of individual development, physiological state, and stress resistance of the animal. Among the shortcomings, it is worth highlighting the lack of generalized data on extended testing of the designed devices and their significant sensitivity to changing factors, and first of all, the lack of funds for mass production.

Despite this, the main field of application of the developments can be cattle breeding farms of various forms of ownership, the scientific community, and industrial enterprises for the production of technological equipment. A decisive condition for the application of the results is the expediency of designing new devices and determining the force parameters of the work processes of existing devices for cleaning the udders of cows.

The further advancement of the research should be aimed at the development of methods for determining the pain sensitivity of the skin of animals for their keeping under various technological conditions for modern production of high-quality milk.

7. Conclusions

1. The parameters of the interaction of the cleaning elements of the device for cleaning the nipples of cows' udders have been theoretically substantiated, which are represented in the form of mathematical expressions, the distinctive features of which are the assessment of the elasticity of the bundles of bristles acting on the nipple when the drum of this device rotates, and the circular force formed by the bristle of the brushes.

2. An algorithm of the work process of cleaning the udders of cows has been developed as a single integrated set of clearly defined and sequentially performed operations. This makes it possible to ensure consistent wet cleaning of each nipple and the base of the udder, followed by their drying.

3. A device has been designed for determining the quantitative values of the holding force of various types of contamination on the skin of an animal. The proposed device provided high accuracy during the production test, is easy to operate and does not require significant material costs for measurements. It was established that the largest values of holding force on the skin of cows are characteristic of solid manure (F_{ret}=40±3.21 N), the smallest – sawdust (F_{ret}=19±2.17 N, $p \leq 0.01$).

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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This paper is dedicated to the bright memory of the famous scientist, talented organizer of the educational and scientific process, Doctor of Agricultural Sciences, Professor Andrii Paliy.

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