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THEORETICAL STUDIES OF THE PROCESS OF MACHINE MILKING OF COWS WITH AN APPARATUS WITH MILKING RUBBER VARIABLE THICKNESS

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Over the last decade, the conditions of dairy farming have undergone significant changes. A decrease in the number of livestock and the production of dairy products was allowed. Despite measures taken at the state level, the number of dairy cattle is decreasing. The decrease in the volume of milk production is sharply reflected in the level of consumption of dairy food products.

At the current stage of the country's economic development, in order for domestic dairy farming to be profitable, competitive and ensure food independence, it must be highly productive. For this purpose, it is necessary to speed up the introduction of advanced milk production technologies into dairy farming based on the creation and use of competitive domestic equipment.

Despite the large number of known technical solutions, the task of creating a design of a milking machine that combines high productivity and stimulation of the reflex action on the animal remains relevant. Designs of milking equipment are currently being improved mainly in two directions:

- *development of milking machines that provide regulation of working parameters depending on the level of milk yield;*
- *development of designs of mechanisms of milking machines that stimulate the milking reflex without causing negative effects to the animal.*

During manual milking and sucking of a cow, the udder is vigorously massaged by the calves, while with machine milking, such a massage is often absent. Milking under high vacuum often leads to negative effects on cows' udders. After analyzing the designs of existing milking machines, we chose the direction of research with the development of milking rubber of variable cross-section for them. The efficiency of machine milking of cows is affected by the technical parameters of the process, the genetic parameters of the udder and milk yield, and the peculiarities of the organization of the process. As a result of the research, a new type of milking rubber is proposed for the most widely used devices of double action. This will reduce the vacuum load on the cow's udder and the shock effect of the rubber on the teat during machine milking of cows.

Achieving the set goal will improve the biotechnical process of machine milking of cows.

Key words: *machine milking of cows, milking apparatus, milking rubber, milk yield, simulation of milk ejection, vibration - oscillatory movements of milking rubber.*

Eq. 19. Fig. 2. Table. 2. Ref. 6.

1. Problem formulation

To ensure the country's food independence at the current stage of economic development, domestic dairy farming must be highly productive and, as a result, profitable and competitive. For this, it is necessary to speed up the introduction of the latest milk production technologies into dairy farming. They must use competitively developed technology and equipment. In this regard, the direction of work on the improvement

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of milking facilities is quite multifaceted. This is, first of all, increasing the capacity of milking equipment and minimizing the harmful effect on the organs of animals.

The nature of the effect of teat rubber on a cow's udder depends on many factors: the pressure drop in the interwall and sub-teat spaces of the milking cup; physical and mechanical properties and structural parameters of milking rubber; its tension in the sleeve of the glass and the elasticity of the milk.

One of the types of harmful effects of the teat tube on the teat during stroke is compression in the form of a "clap". During one machine milking, the milking machine can "issue" up to 400-600 such "oscillating blows" [2, 4].

In the process of operation of milking machines, especially at the beginning and at the end of milking cows, the frequency of oscillatory-vibration movements of the milking rubber does not coincide with milk output at optimal vacuum pressure. This often causes mastitis in animals, which leads to their culling.

Thus, the task of creating new executive working bodies of milking equipment, namely milking rubber, which will improve the biotechnical process of machine milking of cows, remains relevant at the moment.

2. Analysis of recent research and publications

Initially, researchers believed that milk is extracted from the mammary gland due to the liquefaction that occurs in the calf's oral cavity [2].

Later, an opinion appeared in which the denial of constant rarefaction in the sucking stroke was expressed. The sucking stroke in calves consists of two phases: squeezing (sucking) and rest. These phases are characterized by maximum positive and maximum negative pressures.

The maximum rarefaction in the calf's oral cavity is 30.6…33.25 kPa, and the number of suckings ranges from 100 to 120 per minute. The average amount of rarefaction created in the calf's oral cavity during a constant sucking process is 17.2 kPa. The average pressure caused by calves on the teat is within 110.7…112.7 kPa.

Together with the magnitude of the compression force on the teat, the tempo (the number of compressions of the teat per unit of time) and the rhythm of milking are of great importance. The pace of milking should ensure maximum emptying of the udder from milk before the end of the active period of milk yield. 80.. 140 compressions per minute are considered physiologically normal [2, 5].

During machine milking of cows, milk is removed from the udder due to the action of a working vacuum (dilution) created under the teat, which is 1.5…2.5 times higher than in the calf's oral cavity during sucking.

The analysis of modern trends in the design of milking machines shows the classic way of their development - the expansion of the adaptation capabilities of the equipment and at the same time its sharp complication. Despite constant improvement, existing milking machines have shortcomings both from a technical and physiological point of view. Stimulation of milk production of an animal is a complex of physical and physiological factors, and different groups of receptors are involved in the regulation of excretory and secretory activity of the mammary gland and related systems [3, 5].

The nature of the effect of teat rubber on a cow's udder depends on many factors: pressure drop in the interwall and inframammary spaces of the milking cup; physical and mechanical properties and structural parameters of teat rubber; its tension in the sleeve of the glass and the elasticity of the milk.

This impact is calculated by several methods.

However, in our opinion, it is most rational to use the classical theory of shells. At the same time, geometric linear equations for solving the problem of stability of the cylindrical shell were obtained. Knowing the boundary conditions for solving the system of differential linear equations, the authors obtained the formula for the critical pressure g (kPa) on the milk tissue:

$$q = \overline{q}E\left(\frac{h}{R}\right)^2, \tag{1}$$

where – $\overline{q}$ is the dimensionless coefficient of the critical load obtained experimentally; E – modulus of elasticity of the rubber material, H/cm^2; h – wall thickness, cm; R – is the rubber radius, see [1].

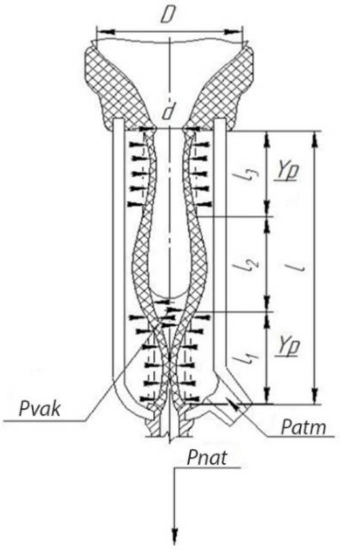
3. The purpose of the article

Theoretical studies and substantiation of the parameters of the main executive mechanism of the milking machine, which is in direct contact with the cow's udder - the milking (teat) rubber.

4. Results of the researches

Theoretical studies of the parameters of rubber of variable cross-section

In the mode of operation of the double action milking machine, the sucking and massage strokes are the main ones in the working cycle.



D – outer diameter of the suction cup, m;
d – internal diameter of the suction cup, m;
l_1, l_3– working length of rubber without change in thickness, m;
l_2 – working thickened length of rubber, m;
l – common working length of rubber, m;
P_{atm} – atmospheric pressure acting on rubber, kPa;
P_{vak} – vacuum metric pressure, kPa;
P_{nat} – rubber tension force, N;
Y_p – transverse deformation of rubber under the influence of Δp, m;
ΔP – pressure drop in the interwall and sub-cup space of the milking cup, kPa;
h – the value of the change in the diameter of the milk during the compression stroke, m.

Fig. 1. Scheme of the action of forces on the milking rubber and the tissue of the udder in the experimental executive mechanism of the milking apparatus of pair action during the compression stroke.

In these studies, the determining parameter in the operation of the milking rubber is the change in the diameter of the teat during the compression stroke

$$h = \frac{(Y_p \cdot l_1)+(Y_p \cdot l_2)+(Y_p \cdot l_3)}{d} = \frac{Y_p(l_1+l_2+l_3)}{d}, \tag{2}$$

where – l_1, l_2, l_3 can be conditionally taken as equal to 0.04 m.

During the compression stroke, the transverse deformation of the rubber of variable cross-section allows it to be practically absent in the l_2 section and reduced in the l_3 section.

Based on this assumption, expression (2) will take the form:

$$h = \frac{Y_p \cdot l_1 + Y_p \cdot l_3}{d} = \frac{Y_p(l_1+l_3)}{d}, \tag{3}$$

Teat rubber, which affects the teat of an animal, can be represented in the form of a beam lying on an elastic base. According to the theory of E. N. Furss, the magnitude of the reaction to the beam is proportional to its deflection. Therefore, it can be assumed that the pressure exerted by the teat rubber on the teat P_d is proportional to the deformation of the tube in the cross section, i.e.:

$$P_d = \mathrm{C} Y_p \tag{4}$$

where C is the total coefficient of elasticity of udder rubber and animal udder tissues:

$$C = C_{rubbers} + \mathrm{C}_{teat}, \frac{H^3}{m}$$

From formula (4), we determine Y_p:

$$Y_p = \frac{P_d}{\mathrm{C}_{rubbers}+\mathrm{C}_{teat}}, \tag{5}$$

we take $P = \Delta P$; $\Delta P = P_{at\text{м}} - P_{vak}$.

Substitute the value of Y_p into formula (3), we get:

$$h = \frac{\left(\frac{\Delta P}{\mathrm{C}_{ser}+\mathrm{C}_{teat}}\right) \cdot l_1 + \left(\frac{\Delta P}{\mathrm{C}_{rubbers}+\mathrm{C}_{teat}}\right) \cdot l_3}{1{,}33\, d} \tag{6}$$

Taking into account that the upper part l_3 of the rubber does not close completely during the compression stroke. The coefficient (1.33) is introduced into the obtained formula (6), which takes this circumstance into account.

Analysis of formula 6 shows that the experimental milk tube reduces the "cotton" effect on the animal's udder tissues by 30% due to the reduction of the pressure difference in the udder and in the sub-udder space.

Mathematical modeling of the process of milk removal by a milking machine of a pair action with a milking rubber of variable cross-section.

The initial performance of the milking machine is influenced by the technical and design parameters, the vacuum mode of its operation, as well as the physiological state of the mammary gland of the animal's udder. The conducted research is related to the solution of extreme tasks, which are aimed at finding optimal conditions for the flow of the work process of machine milking of cows. Taking into account the fact that the conduct of experiments is associated with a large amount of labor, the study was carried out using the optimal planning of the experiment, a cybernetic approach to the experimental study of systems with incomplete knowledge of the mechanism of the process.

The purpose of this study is to obtain a mathematical model that can be used to automatically determine the optimal operating modes of the equipment during machine milking of cows.

Selection of the optimization criterion.

When planning an experiment, it is very important to determine the criterion to be optimized. The optimization criterion is a response to the influence of factors that determine the behavior of the feedback system.

The criterion must be quantitative and specified in numbers. It should be measured for any possible combination of inverse factor levels.

As an optimization criterion, we choose (Q_c) – the output mass of milk in one cycle of the milking machine.

The selection of factors is a very important stage in preparation for planning an experiment. Factors are variables that correspond to the methods of influence of the external environment on the object. They determine both the object itself and its state. Requirements for factors: controllability and unambiguity. According to the theory of system analysis, we present the research object in the form of a complex multidimensional cybernetic system (Fig. 2).

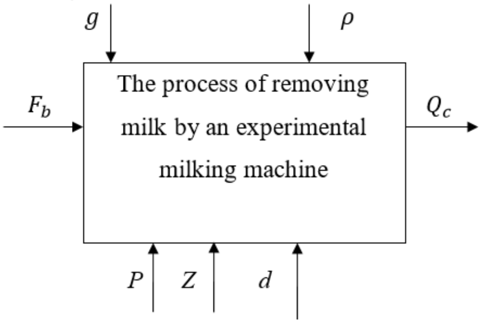


Fig. 2. Structural diagram of the milking process of the milking apparatus with an experimental milking tube

According to the structural diagram (Fig. 2), we will present the indicators that characterize the process of the milking machine in the form of functional dependence:

$$Y(Q_c, F_b, P, Z, d, g, \rho) = 0 \tag{7}$$

All parameters when planning experiments and processing experimental data must be expressed in the same system of measurement units.

Table 1

Factors that characterize the process of milk production from the cow's udder

Size	**Dimension formula**	**Units**
Length	L	m
Mass	M	kg
Time	T	s
Input parameters		
Factors	Dimension formula	Units
The strength of milk flow from the teat canal - (F_b)	LMT^2	H
Platform installation height - (P)	L	m
The inner diameter of the rubber tube - (d)	L	m
The stiffness of the closure of the rubber - (Z)	$L^{-1}MT^{-2}$	H/m^2,Pa
Density milk - (ρ)	$L^{-3}M$	kg/m^3
Acceleration of gravity -(g)	LT^{-2}	m/s^2
Output parameters		
Size	Dimension formula	Units
The mass of milk produced of milk per cycle- (Q_c)	M	kg

The output parameter Q is a function of four variables F_b, P, d and Z:

$$Q_c = f(F_b, P, d, Z) \tag{8}$$

To carry out a full factorial experiment of the first order when changing factors at two levels, it is necessary to conduct 2 experiments.

In our case, the number of necessary experiments is $2^4 = 16$. To reduce the number of necessary experiments, we use dimensionless complexes (similarity criteria), introducing additional constants g and ρ.

Similarity criteria can be obtained by choosing any three parameters from among the primary basic units - meter, kilogram, second, for which the determinant is not equal to zero Δ≠0. Accepting them as the main ones, you can move on to dimensionless complexes (similarity criteria). If we represent the indicators of equation (7) in terms of basic quantities, we will get the dependence in relative:

$$\frac{\Upsilon(Q_C;F_b;P;Z;d;\rho;g)}{d^{\tau}\rho^{\lambda}g^{\mu}} = 0 \tag{9}$$

Such basic parameters can be g, ρ and d:

$$[g] = [M][L]^1[T]^{-2}, [\rho] = [M]^1[L]^{-3}[T]^0, d = [M]^0[L]^1[T]^0$$

Since for them the determinant is not equal to zero:

$$\Delta = \begin{vmatrix} \mu_1 & \lambda_1 & \tau_1 \\ \mu_2 & \lambda_2 & \tau_2 \\ \mu_3 & \lambda_3 & \tau_3 \end{vmatrix} = \begin{vmatrix} 0 & 1 & -2 \\ 1 & -3 & 0 \\ 0 & 1 & 0 \end{vmatrix}$$

$$= \mu_1\lambda_2\tau_3 + \mu_3\lambda_1\tau_2 + \mu_2\lambda_3\tau_1 - \mu_3\lambda_2\tau_1 - \mu_1\lambda_3\tau_2 - \mu_2\lambda_1\tau_3$$

$$= (0 - 3 + 0) + (0 + 1 + 0) + (1 + 1 - 2) - (0 - 3 - 2) - (0 + 1 - 0)$$

$$- (1 + 1 + 0) = -2$$

The value of $\mu_i\lambda_i\tau_i$ determined from the equation under the condition that the complexes are dimensionless quantities. Each of the remaining parameters is divided by the product of three and equated to one.

$$\frac{P}{(g^{\mu}\ \rho^{\lambda}\ d^{\tau})} = 1;\ \frac{[L]^1}{([L]^1[T]^{-2})^{\mu}}([M][L]^{-3})^{\lambda}([L]^{\tau}) = 1$$

$$[L]^{1-\mu+3\lambda-r}[M]^{-\lambda}[T]^{2\mu} = 1$$

The fourth dimensionless complex $-\ y = \frac{Q_c}{\rho} \cdot d^3$

The fourth complex is a function of the first three - $y = f(X_1; X_2; X_3)$

The total number of all similarity criteria can be found using the formula

$$t = n - m$$

where n – is the number of values relevant for the process, $n = 7$; m – is the number of quantities with independent dimensions of primary quantities, $m = 3$.

Then the number of dimensionless complexes will be determined $t = 7 - 3 = 4$.

In empirical formulas of dimensions, the right and left parts, as a rule, do not coincide. If you look for the dependency, you can see:

$$\mathrm{y} = \mathrm{f}\left(\frac{P}{d}; \frac{F_b}{g \cdot \rho \cdot d^3}; \frac{\mathrm{Z}}{\mathrm{g} \cdot \rho \cdot \mathrm{d}}\right) \tag{10}$$

Based on experimental and calculated data in the first approximation of the dependence are linear:

$$\pi_1 = \left(\frac{P}{d}\right);\ \pi_2 = \left(\frac{F_b}{g\rho d^3}\right); \pi_3 = \left(\frac{Z}{g\rho d}\right); \tag{11}$$

The transition to a dimensionless form does not change the nature of these dependencies. Denoting the dimensionless complexes by y, X_1, X_2, X_3, the Q_c function can be written using a polynomial of the first degree:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{1,2}X_1X_2 + b_{2,3}X_2X_3 + b_{1,3}X_1X_3 + b_{1,2,3}X_1X_2X_3$$

where b_i – i is the regression coefficient; $X_i -$ factors that affect the process.

The coefficients of this dependence are constant values for selected cybernetic systems and can be determined by processing the results of experimental studies.

Selection of intervals of variation of factors.

It is necessary to choose two levels of variation in the experiment for each factor. The interval of variation is a certain amount, the addition of which to the main level gives the upper level, and the subtraction - the lower level of factors.

Before starting the experiment, the factors are coded. When coding the factors, a linear transformation of the factor space is carried out with the transfer of the origin of the coordinates to the center of the experiment and the selection of the scale along the axes in the units of factor variation.

To simplify the recording of experimental conditions and processing of experimental data, the scales along the coordinate axes are selected in such a way that the upper level of the factor corresponds to (+1), the lower one to (-1), and the main one to -0.

Coding of factors is carried out according to the formula:

$$\widehat{X_\iota} = \frac{X_i - X_{0i}}{\Delta X_i} \qquad (12)$$

$\widehat{X_\iota}$ – coding value of the factor; X_i – natural value of the factor; X_{0i} – is the natural value of the factor at the basic level; ΔX_i – is the interval of factor variation.

$$\Delta X_i = \frac{X_i^B - X_i^{\text{H}}}{2} \qquad (13)$$

The regression coefficients B_0, B_1, B_2, B_3 are determined by the formulas, independently of each other, due to their orthogonality:

$$b_0 = \frac{\sum_{u=1}^{n} \overline{y_u}}{n}\ ; \quad b_i = \frac{\sum_{u=1}^{n} X_{iu} \overline{y_u}}{n}\ ; \quad b_y = \frac{\sum_{u=1}^{n} X_{iu} X_{ju} \overline{y_u}}{n}\ ; \qquad (14)$$

To determine the coefficients $B_{1,2}, B_{1,3}, B_{2,3}$ – double effects interaction and in1,2,3 – the effect of triple interaction, it is necessary to expand the working matrix to the plan - the matrix presented in table 2.

Table 2.

Plan-matrix of the PFE 2 experiment

№ experiment	X_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	$X_1X_2X_3$	$У$
1	+1	+1	+ 1	+1	+1	+1	+1	+1	$У_1$
2	+1	-1	+ 1	+1	-1	-1	+1	-1	$У_2$
3	+1	+1	-1	+1	-1	+1	-1	-1	$У_3$
4	+1	-1	-1	+1	+1	-1	-1	+1	$У_4$
5	+1	+1	+ 1	-1	+1	-1	-1	-1	$У_5$
6	+1	-1	+ 1	-1	-1	+1	-1	+1	$У_6$
7	+1	+1	-1	-1	-1	-1	+1	+1	$У_7$
8	+1	-1	-1	-1	+1	+1	+1	-1	$У_8$

Checking the adequacy and reproducibility of the mathematical model.

After determining the coefficients of the model, it is checked for suitability, that is, for the conformity of the description of the object of the obtained model with the results of the experiment. Such a check is called a model adequacy check.

The residual sum of squares is quite suitable for characterizing the average spread in relation to the regression line.

The residual sum of squares divided by the number of degrees of freedom is called the residual variance or adequacy variance.

$$A_{ad}^2 = \frac{\sum_{i=1}^{n} \Delta y_i^2}{f}; \qquad (15)$$

where *f* is the number of degrees of freedom – the difference between the number of experiments and the number of coefficients of the full factorial experiment 2^3 and the determination of the linear regression equation, the number of degrees of freedom is determined:

$$f = N - (k + l); \quad f = 8 - (3 + l) = 4.$$

$$\mathrm{S}_{ad}^2 = \frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} \left(y_{\text{cp}.u} - \widehat{y_u}\right)^2}{\mathrm{f}} \qquad (16)$$

where $y_{\text{cp}.u}$ – is the average value of the optimization parameter and in the *u-th* experiment at *m* repetitions; y_u – is the value of the optimization parameter, calculated from the regression equation for the condition of the *u-th* experiment.

The variance, which characterizes the errors of experiments in the plan matrix, determined by the formula:

$$\mathrm{S}_{\mathrm{y}}^2 = \frac{\sum_{\mathrm{u}=1}^{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{M}} (y_{iu} - \bar{y})^2}{\mathrm{N(m-1)}}\ , \qquad (17)$$

where *m* – is the number of repetitions of one experiment.

The homogeneity of variances is checked using various statistical criteria. One of the simplest is Fisher's test, which is used to compare two variances. Fisher's criterion (F-criterion) is the ratio of a larger variance to a smaller one. The obtained value is compared with the table value of the F-criterion. If the numerical value of the ratio is greater than that given in the table for the corresponding degrees of freedom and the selected level of significance, it means that the variances are significantly different from each other, that is, they are heterogeneous.

We check the adequacy of the model using Fisher's F-test.

$$F = \frac{S_{ad}^2}{S^2(y)}. \tag{18}$$

The error of the experiment, which is called in statistics the dispersion of reproducibility, serves as the basis for judging the quality of the model and its elements.

It is necessary to know whether the errors in different regions of the factor space are close, or whether the variances of the optimization parameter are the same at different points. Homogeneity of variances is one of the requirements of regression analysis. Dispersions of parallel experiments at the points of the plan should be comparable with each other, i.e.:

$$\sigma^2\{y_1\} = \sigma^2\{y_2\} = \cdots \sigma^2\{y_n\}.$$

The homogeneity of variances with the same number of parallel experiments is assessed using the Cochrane test.

$$G_{max} = \frac{S_{y\,max}^2}{\sum_{u=1}^{N} S_u^2}. \tag{19}$$

5. Conclusions

The existing methods of calculating the effect of teat rubber on an animal's udder are analyzed.

The analytical dependence of the influence of the tube of variable stiffness on the tissues of the udders of cows is derived.

It was established that the milking rubber of variable cross-section of the studied milking apparatus of pair action reduces the vacuum effect on the tissues of the udder by an average of 30%.

As a result of the application of the theory of similarity and dimensions together with the theory of experiment planning, mathematical models of the process of removing milk from the udder of cows with an experimental milking machine equipped with a teat rubber of variable cross-section were obtained.

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ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ПРОЦЕСУ МАШИННОГО ДОЇННЯ КОРІВ АПАРАТОМ З ДОЇЛЬНОЮ ГУМОЮ ЗМІННОЇ ТОВЩИНИ

За останнє десятиліття умови ведення галузі молочного скотарства зазнали значні зміни. Допущено зниження поголів'я худоби і виробництво молочної продукції. Незважаючи на заходи, які приймаються на державному рівні, поголів'я дійного стада великої рогатої худоби зменшується. Зниження обсягу виробництва молока різко відбивається на рівні споживання молочних продуктів харчування.

На сучасному етапі економічного розвитку країни, щоб вітчизняне молочне тваринництво було рентабельним, конкурентоздатним і забезпечувало продовольчу незалежність, воно має бути високопродуктивним. Для цього необхідно прискорити впровадження в молочне тваринництво *прогресивних технологій виробництва молока на базі створення і використання конкурентоздатної вітчизняної техніки.*

Незважаючи на велику кількість відомих технічних рішень, актуальним залишається завдання створення конструкції доїльного апарату, що поєднує високу продуктивність і стимулювання рефлекторної дії на тварину. Конструкції доїльного обладнання зараз удосконалюються в основному в двох напрямах:

- розробка доїльних апаратів, що забезпечують регулювання робочих параметрів залежно від рівня молоковіддачі;

- розробка конструкцій механізмів доїльних апаратів які стимулюють рефлекс молоковіддачі не наносячи тварині негативного впливу.

При ручному доїнні і смоктанні корови телям енергійно масажується дійка вимені, а при машинному такий масаж часто відсутній. Доїння при високому вакуумі часто призводить до негативного впливу на дійки корів. Після аналізу конструкцій існуючих доїльних апаратів ми вибрали напрям досліджень з розробкою для них доїльної гуми перемінного перерізу. На ефективність машинного доїння корів впливають технічні показники процесу, генетичні показники вимені і молоковіддача та особливості організації процесу. В результаті досліджень пропонується новий тип доїльної гуми для найбільш широко використовуваних апаратів попарної дії. Це зменшить вакуумне навантаження на вим'я корови та ударну дію гуми на дійку при машинному доїнні корів.

Досягнення поставленої мети покращить біотехнічний процес машинного доїння корів.

Ключові слова: *машинне доїння корів, доїльний апарат, доїльна гума, молоковіддача, моделювання молоковиведення, переиінний переріз доїльної гуми.*

Ф. 19. Рис. 2. Табл. 2. Літ. 6.

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