Results of studies of a suction-type milking machine with squeezing effect

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Abstract. An important measure in dairy farming is to increase the rate of milk production by increasing the milk productivity of cows. The use of modern milking equipment that meets the requirements of animal physiology will help to increase the milk production of animals. Due to the analysis of device constructions it has been revealed that the most essential disadvantage is their extremely hard influence on teat receptors and consequently inhibition of milking reflex. This leads to a reduction in the milk yield and the milking intensity of the cow. One of the items of the Federal Scientific and Technical Programme for Agricultural Development 2017-2025, in accordance with the Decree of the President of the Russian Federation of 21 July 2016 №350 "On Measures to Implement the State Scientific and Technical Policy for Agricultural Development" and the Decree of the Government of the Russian Federation of 25 August 2017 №996 "On Approving the Federal Scientific and Technical Programme for Agricultural Development 2017-2025" is technical and technological modernization of the agricultural sector, without which, with the equipment used, it is impossible to fully ensure import substitution with competitive products and increase the economic security of the country. Based on the above, it can be concluded that the work on improving milking machines is an urgent task and is of practical interest to farms.

1. Introduction
Based on the generalized data, the design scheme and construction of the milking machine with the squeezing effect in the compression stroke are proposed [1...8]. The technical solution is to increase the intensity of milking and reduce the amount of residual milk in the cow's udder (increase the completeness of milking), due to the fact that the working part of the teat tube is made decreasing in thickness to the suction cup, where the cylindrical part (or cone-shaped part with a smaller diameter at the tail part) formed by the connection of the suction cup and the tail part is taken as the working part of the teat tube. It will allow transforming the 'compression' tact into a 'compression with squeezing effect' tact at certain ratios of pressure values in the teat and interstitial chambers, and to soften the periodic impact of teat tubes on the udder of the animal.

The milking machine with teat tube (Figure 1) contains a pulsator 15, a collector 9, milk hoses and four milking cups, each consisting of a teat tube 1 located in a sleeve 2. The milking machine works as follows (Figure 1). At "sucking" stroke (Figure 1, a) vacuum pressure from vacuum tube 17 via chamber 15A of pulsator 15 comes to chamber 15B and further via distributor 9B of manifold 9 to interwall chamber 3 of milking cups [3]. Simultaneously constant vacuum pressure \( P_{vac} \) is delivered from milk pipeline through the milk hose through the chamber 9A of the collector 9 into teat chambers 8 of milking cups. The teat tube 1 is not deformed under the same vacuum pressure in both chambers, i.e. there is no
deflection. The teat sphincter is open, the milk is freely sucked first into the chamber 9A of the collector 9 and then through the milk hoses into the milk pipe (milking bucket).

Gradually, in chamber 15Г of the pulsator 15, vacuum pressure is applied through the calibrated channel 12 (Figure 1, b). The air causes the diaphragm 14 with the valve 13 to move downwards. As a result, the vacuum pressure from chamber 15A of the pulsator stops flowing into chamber 15Б. The air from chamber 15B flows to chamber 15Б of the pulsator, and then through chamber 9Б of the collector into the interwall chambers 3 of the milking cups. Due to the pressure difference in the interwall chamber 3 and suction chamber 8, the walls of the teat tube 1 begin to bend, initially with the smallest value of wall thickness (at the suction cup), thus blocking the channel connecting the milk section of the udder cistern with teat section 6, thereby minimizing such negative factor as reverse milk outflow. The residual milk in the teat section of the cistern 6 and the teat canal 7 is then completely squeezed out. Thus at the end of the "compression with squeezing effect" tact (Figure 1, c) the stepped teat tube 1 is completely compressed, covering the lower part of the teat. The sphincter 8 closes, the flow of milk stops, the udder teat is completely isolated from the action of the excessive vacuum and blood circulation in the animal is restored.

The pressure from chamber 15Б through the calibrated channel 12 is created in chamber 15Г of the pulsator. Through the diaphragm 14 it overcomes the force acting on the valve 13 from above. This is possible because the working area of the valve 13 is considerably smaller than that of the diaphragm 14. The valve 13 moves upwards again, thereby preventing chamber 15Б from communicating with chamber 15B. Vacuum pressure from chamber 15A through chamber 15Б of the pulsator enters chamber 9B of the manifold 9 and then into the interstitial space 3 of the milking cups. By turning the adjusting screw 16, it is possible to adjust the pulsation frequency of the milking machine. The sucking stroke occurs and the work cycle is repeated until the milking process is completed [3].

![Figure 1](image-url). Scheme of the milking process when using a milking machine with a teat tube: a) "sucking" stroke; b) "compression with squeezing effect (start)" stroke; c) "compression with squeezing effect (end)" stroke: → – milk; ← – air; 1 - teat tube; 2 - sleeve; 3 - interwall chamber; 4 - milk cistern; 5 - teat section; 6 - teat channel; 7 - sphincter; 8 - teat chamber; 9 - collector; 10 - rubber valve; 11 - milk hose; 12 - calibrated channel; 13 - valve; 14 - diaphragm; 15 - adjusting screw; 17 - vacuum guide.

2. Methods and Materials

To conduct the research, the peak milking rate was adopted as the optimization criterion. It is an indicator that evaluates the technological process of milking a simulator by a milking machine with teat tubes. A solution of H2O+NaCl, with a density of 1027 kg/m³, which is close to milk, was taken as a milk simulator [1...8].
In the studies, the peak milking rate was determined as follows:

\[ Q_{\text{max}}^\text{peak} = \frac{V}{t}, \text{l/min} \]  

(1)

where \( V \) – volume of the milk simulator milked, l; \( t \) – the time of milking, min.

To determine the peak milking intensity of a milking machine with a squeezing effect, a milking time of 5 minutes was taken in the experiments. This time interval expresses the maximum duration of milking of an animal and the action of the hormone oxytocin, which promotes milk production, milk yield and milk yield in general.

As a result of exploratory studies and theoretical evaluation of milking intensity and justification of design and technological parameters of the milking machine, the factors that have the greatest impact on the process were identified and their levels of variation were determined (Table 1). The other factors did not change and were fixed at constant levels [3...5].

**Table 1.** Factors and their variation levels in a three-factor experiment.

| Factor                                     | Unit of measure | Designation code | Variation levels |
|---------------------------------------------|-----------------|------------------|-----------------|
| Vacuum pressure \( p_{\text{vac}} \)        | kPa             | \( x_1 \)        | 40 45 50        |
| The ratio of the height of the working part element of the teat tube to its thickness | H/h             | \( x_2 \)        | 5 15 25         |

The other factors did not change in the studies and were fixed at constant levels: milk density of at least 1027 kg/m^3; temperature \( t= 40 \) Co. In order to optimise the quantitative and qualitative criteria for assessing the performance of any device, it is necessary to carry out laboratory research.

To conduct laboratory research on determining the main design and technological parameters of milking machines, a laboratory unit for the study of milking machines was made (Figure 2), consisting of three main parts.

![Figure 2](image)  

**Figure 2.** General view of the laboratory set-up for investigating the milking machine with stepped teat tubes: 1 - buffer tank; 2 - circulating pump OASIS CN-25; 3 - automatic switch-off; 4 - Vesper E-8300; 5 - tap of forced stop of liquid supply; 6 - artificial udder; 7 - milking machine with stepped teat tubes; 8 - individual milking unit AID-2; 9 - milking bucket with a scale for milk simulator level recording.

The first part is a registering part and includes a milking bucket with a milk simulator level scale and a vacuum gauge, with which the AID-2 individual milking unit is fitted as standard. The second part is
the control mechanism. It consists of an automatic unit 3 - of IEK type, a frequency converter 4 - Vesper E-8300 according to GOST R 51318.11-99 and a tap 5. The third part is an execution mechanism. It includes a circulation pump 1 - of OASIS CN-25/4 type, an artificial udder 6 and teat imitators, a milking machine with teat tubes 7 and an individual milking unit 8 - AID-2. There is a recording part for determining the volume of simulated milk produced per unit of time.

In order to set the required udder pressure, an artificial udder 6 (Figure 2) imitating an animal udder containing overlapping and communicating vessels with a total height of 0.7 m, with four teat cups in the lower part (Figure 3), is used.

![Figure 3. Udder teat simulators: a) - general view; b) - design scheme: 1 - ball valve; 2 - spring; 3 - adjusting screw; 4 - channel; 5 - teat; 6 - insert-simulator of resilience.](image)

At the end of each udder teat simulator there is a ball valve 1 (Figure 3, b) that simulates teat tightness by means of an adjustment screw 3 and a spring 2, thus creating desired value of sphincter tone (vacuum pressure value of valve opening was taken as \( P_{\text{vac}} = 30 \text{ kPa} \), which corresponds to standard vacuum value, at which the sphincter is ajar). Substitution of insert-simulators 6 will allow for the elasticity of the nipple of different animals to be taken into account.

Before carrying out the work, the following must be done. The stand must be connected to the mains. The simulated milk should be poured into the container. Then, by pressing the "start" button, apply voltage to the electric motor windings of the OASIS CN-25/4 circulation pump. Then, the milking machine must be connected to the vacuum source, and then the milking cups must be connected to the artificial teats. The frequency converter should be used to set the required value. Then the height of the liquid column has to be adjusted by means of the forced disconnection tap. The test station is needed to check the milking intensity of the milking machine. In order to make experimental tests there was made a set of teat tubes with changed height of the working part of teat tube to create wave effect of squeezing from sucker to diverter in the "squeeze" stroke. The nipple tubes were manufactured by moulding.

Based on the condition that the marginal error in all experiments is approximately equal to the largest possible statistical error, and given the reliability of the studies (\( p=0.95 \)), a threefold repetition of experiments was chosen. According to the two-factor experiment matrix presented (Table 2), a set of teat tubes with different heights of the working part in the "compression" stroke were produced.

Mathematical processing of the results was carried out using Statistica 6.0, MathCAD 2001 RUS, Microsoft Excel on a PC. The matrix of the two-factor experiment is presented in Table 1. The data were statistically processed using Statistica 6.0 Multiple Regression module and Nonlinear Estimation module. The multiple correlation coefficient and F-test were used to determine the adequacy of the model. For definition of optimum values of factors the program MathCAD 2001 RUS was used.
To establish milking machine performance and to compare it with the result of the full-factor experiment, the performance of the milking machine with the squeezing effect was tested under production conditions.

3. Results

Adequate mathematical dependencies of peak milking intensity of cow milking machine on design and technological parameters are obtained in coded form with multiple correlation coefficient \( R = 0.99 \) and convergence of calculated and experimental data F-test = 0.99:

\[
Q_{\text{mil}} = 3.25 + 0.235 \cdot x_1 + 0.378 \cdot x_2 - 0.228 \cdot x_1^2 - 0.218 \cdot x_2^2 \text{ l/min}; \quad (2)
\]

To determine optimal parameters of milking machine with four-stage teat tubes by peak milking intensity, the data were processed in MathCAD program to find the extremum of mathematical dependence (2). For this purpose the obtained mathematical dependence (2) was differentiated by variables \( x_1, x_2 \), and a system of equations was obtained:

\[
\begin{align*}
0.235 - 0.456 \cdot x_1 &= 0 \\
0.378 - 0.436 \cdot x_2 &= 0
\end{align*} \quad (3)
\]

By solving the system of equations (3), the optimum parameter values for the milking machine were determined in a coded form:

\[
\begin{align*}
x_1 &= 0.515 \\
x_2 &= 0.867
\end{align*} \quad (4)
\]

At the optimum values of the parameters (22), the peak milking intensity of the milking machine (2) is \( Q_{\text{mil}}^{\text{max}} = 3.474 \text{ l/min}. \)

On the basis of the mathematical dependence (3) a two-dimensional cross section of response surface of peak milking intensity by milking machine in dependence of vacuum pressure \( x_1 \) and tact ratio \( x_2 \) was built (Figure 4). It is possible to conclude from the analysis that the found parameter values correspond to the extremum of mathematical relation (3) and determine maximal milking peak intensity of the milking unit.

Table 2 shows coded and decoded values of milking machine parameters. The decoding was done taking into account the system of equations (4) and Table 3 by interpolation method.

**Table 3.** Optimal values for the factors under study.

| Factor name                                      | Unit of measure | Designation | Optimum factor value |
|-------------------------------------------------|-----------------|-------------|----------------------|
| Vacuum pressure                                 | kPa             | \( p_{\text{vac}} \) | \( x_1 \) | \( x_2 \) |
| The ratio of the height of the working part     |                 |             | 0.515               | 0.867    |
| element of the teat tube to its thickness       |                 |             | 47.6                | 23.7     |
The ratio of the height of the element of the working part of the teat tube to its thickness is \( \frac{H_1}{h} = 23.7 \), which is feasible when the element height of the working part of the nipple tube is \( H_1 = 0.028 \text{ m} \) and its thickness is \( h = 0.0012 \text{ m} \). As shown in Table 4, the experimental milking machine has a higher peak milking rate and completeness compared to the commercially available ADU-1.

Table 4. Milking machine research results in a production environment/

| № | Parameter name                        | Milking machine with squeezing effect | ADU-1 |
|---|--------------------------------------|--------------------------------------|-------|
| 1 | Peak milking intensity, l/min         | 3.250                                | 2.580 |
| 2 | Time to peak milking intensity, s     | 50                                   | 50    |
| 3 | Timed milk yield, l:                 |                                       |       |
|    | for 1 minute                          | 2.970                                | 2.353 |
|    | for 3 minutes                         | 7.132                                | 6.654 |
| 4 | Single milk yield, l.                 | 7.695                                | 7.236 |
| 5 | Milking time, s                       | 207                                  | 230   |
| 6 | Average milking intensity, l/min      | 2.112                                | 1.677 |
| 7 | Stripping, l                         | 0.118                                | 0.210 |
| 8 | Milking completeness, %               | 98.4                                 | 97.1  |

Based on the results of production studies of the milking intensity of the milking machine and the commercially available ADU-1, a graph of the dependence of the milking intensity \( Q_{\text{max}} \) on the time of milking \( t_{\text{mil}} \) was drawn (Figure 5).

Figure 4. Two-dimensional cross-section of the response surface of the milking intensity of the milking machine as a function of vacuum pressure \( x_1 \) and the ratio of the height of the teat tube element to its thickness \( x_2 \)

Figure 5. Graph of the dependence of the milking intensity \( Q_{\text{max}} \) on the time of milking \( t_{\text{mil}} \): 1 – commercially available ADU-1; 2 – milking machine with squeezing effect
Compared to the commercially available ADU-1, the milking intensity of the milking machine with squeezing effect is 20.06% higher than that of the commercially available one.

4. Conclusion
According to the results of research it was found that in the production conditions the milking machine with squeezing effect has a higher peak of milking intensity $Q_{\text{max}} = 3.250$ l/min in comparison with the commercially available ADU-1 where the same indicator is $Q_{\text{max}} = 2.580$ l/min, that is 20% higher in percentage terms. In addition, more complete milking per unit time (for 1 and 3 min.) is provided, which consequently reduces the total duration of milking from 230 s to 207 s for the commercially available ADU-1 and the milking machine with squeezing effect. In this regard, higher average milking intensity index, which is 2.112 l/min for the milking machine with squeezing effect, and for the commercially available ADU-1 is 1.677 l/min respectively, which is 20.6% higher.

The completeness of milking was 98.4% and 97.1% for the milking machine with squeezing effect and for the ADU-1, respectively. The milking efficiency of the developed design is 1.3% higher compared to its analogue, while the amount of residual milk does not exceed the requirements. As a result of comparison of results of theoretical and experimental data it is revealed that discrepancy of peak milking intensity of the milking machine with squeezing effect does not exceed 1.2% when comparing results of theoretical researches and those under production conditions.

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