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An Experimental Stimulating Milking Machine

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Abstract: *This paper describes machines and equipment to study an experimental stimulating milking machine and compare it with serial milking machines (similar devices), identifying the advantages of this milking machine and its vacuum effect on the animal's teat.*
The authors propose a method for calculating and substantiating the operation of the teat cup liner and optimizing the process of removing milk from the cows' udder with an experimental stimulating milking machine based on mathematical processing of the data obtained.

Keywords: *milking machine, atmospheric and vacuum pressures, oscillograms, milk flow intensity, vacuum load on the animal's teat.*

I. INTRODUCTION

Dairy farming is one of the leading branches of agriculture in Russia. At the present stage of Russia's economic development, for domestic dairy farming to be profitable, competitive, and ensure food independence, it must be highly productive. For this, it is necessary to accelerate the introduction of progressive milk production technologies into dairy farming based on the creation and use of competitive technology.

Studies carried out by many researchers [1]-[3] indicate that the stimulation of animal milk flow is a complex of factorsю In the regulation of the excretory and secretory activity of the mammary gland and related systems, the participation of various groups of receptors has been found and confirmed.

As noted by many authors [3], all serial production milking machines have the following disadvantages:

– single-mode milking;

– intermittency of the milk stream and its reverse outflow during the squeeze phase;

– impact on the teat during cyclical pulsations of the teat cup liner;

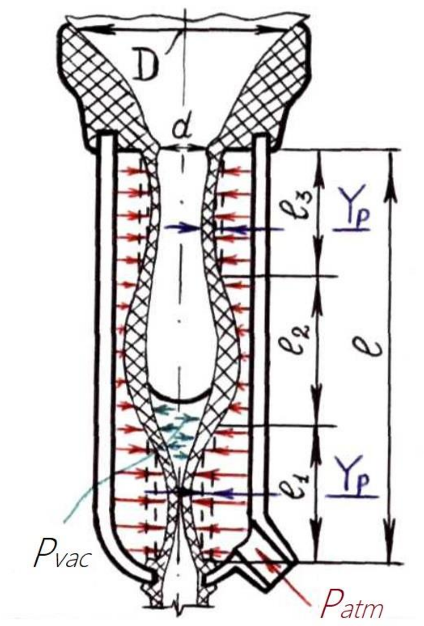
– weak stimulating ability;

– formation of aerosols in the under-teat spaces that promote the penetration of pathogenic microbes into the cavities of the milk tanks of the animals' udder.

The nature of the impact of the teat cup liner on the animal's teat depends on many factors: pressure drop in the inter-wall and under-teat spaces of the teat cup; physical and mechanical properties and design parameters of teat cup liner; its tension in the sleeve of the teat cup and the elasticity of the teat.

In the operating mode of the experimental stimulating milking machine, the suction and massage phases are the main ones in the working cycle.

Definitions (Fig. 1):



D is the external diameter of the suction cup, m;
d is the internal diameter of the suction cup, m;
l_1, l_3 is the working length of the teat cup liner without changing the thickness, m;
l_2 is the working thickened length of the teat cup liner, m;
l is the total working length of the teat cup liner, m;
P_{atm} is the atmospheric pressure acting on the teat cup liner, kPa;
P_{vac} is the vacuum pressure, kPa;
P_{nat} is the tensile force of the liner rubber, N;
Y_p is the lateral deformation of the teat cup liner under the action of ΔP, m;
Δp is the pressure drop in the inter-wall and under-teat space of the teat cup, kPa;
h is the value of the change in the diameter of the teat during the massage phase, m

Fig. 1 Scheme of the action of forces on the teat cup liner and teat tissue in the experimental stimulating milking machine during the massage phase

Let us determine the amount of change in the diameter of the teat during the massage phase.

$$h = \frac{(Y_p \cdot l_1)+(Y_p \cdot l_2)+(Y_p \cdot l_3)}{d} = \frac{Y_p(l_1+l_2+l_3)}{d}, \qquad (1)$$

l_1, l_2, l_3 are taken as equal to 0.040 m;

During the massage stroke, the lateral deformation of the teat cup liner allows it to be absent in the area l_2 and its reduction in the area l_3 due to the new design of the suction cup chamber (the suction cup).

Then expression (1) will take the following form:

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

The teat tube acting on the animal's teat is represented as a beam lying on an elastic base. According to the theory of E.N. Fuss, the magnitude of the response to the beam is proportional to its deflection. Therefore, we will assume that the pressure exerted by the teat tube on the teat, p_d, is proportional to the amount of deformation [4] of the teat tube in the transverse direction, i.e.:

$$p_д = CY_p, \qquad (3)$$

where C is the total coefficient of elasticity of the teat cup liner and tissue of the animal's teat

$C = C_в + C_t$, N/m^3

From formula (3), we define Y_p as:

$$Y_p = \frac{p_д}{C_в + C_t}, \qquad (4)$$

we accept $p_д = \Delta p$; $\Delta p = p_{atm} - p_{vac}$

Substituting the value Y_p, we obtain the following in formula (2):

$$h = \frac{\left(\frac{\Delta p}{C_в + C_t}\right) \cdot l_1 + \left(\frac{\Delta p}{C_в + C_{ct}}\right) \cdot l_3}{1{,}33\ d}, \qquad (5)$$

Considering that the upper section l_3 of the teat cup liner does not close completely during the massage phase, a coefficient is introduced into the resulting formula (5), taking into account this circumstance.

Analysis of formula 5 shows that the experimental teat tube reduces the "striking" effect on the tissue of the animal's teat by 30% due to a decrease in the pressure difference in the teat and under the teat.

II. DIAGRAM OF THE EXPERIMENTAL STIMULATING MILKING MACHINE

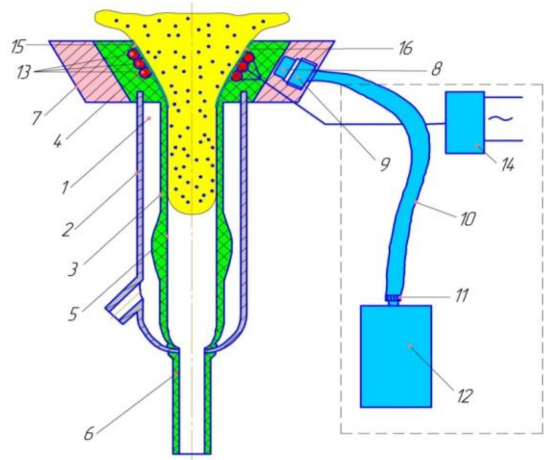
Fig. 2 shows a general view of the experimental stimulating milking machine [3], [5].

The stimulating milking machine (figure omitted) consists of the conventional parts: a collector with a hanging part, a pulsator, and four teat cups. All of these parts are connected using milk, vacuum, main and other hoses.

A distinctive feature of the stimulating milking machine that makes it different from other types of milking machines is the modified teat cups [5].

The modified teat cup (Fig. 1) contains a teat cup 1 with a sleeve 2 and a teat cup 3 installed in the sleeve 2 of a teat cup 1, made of elastic material and consisting of a suction cup 4, a working part 5 and a diverting part 6, while the middle of the working part 5 is thickened, and the lower part has a form of an ellipse. The thickness of the middle of the working part is 3.5-4.0 mm. A laser nozzle is installed on the teat cup 1; the nozzle consists of a tapered ring 7 made of aluminum alloy and performs the function of a heat sink. A monochromatic light emitter is built into the cone-shaped ring 7, in the form of a semiconductor laser 8, secured by a threaded bushing 9, through which a flexible cable 10 is passed, connecting the semiconductor laser 8 through the connector 11 to the battery 12. The laser is selected with an operating range of emitted wavelengths from 0.62 to 1.06 microns [3].

This makes it possible to increase the penetration depth of radiation (the infrared range), which is necessary to improve the therapeutic effect, or to work at a shallower penetration depth of radiation when exposed to the reflexogenic zone to increase milk flow (the red range). In the red range, the required output power of the semiconductor laser 8 can be reduced and, therefore, the power consumption of this laser can be diminished, which makes it possible to increase the time of continuous operation of the laser attachment without recharging the power source. The choice of a pulsed or continuous-wave laser is determined by production and economic considerations. A continuous-wave laser requires a simpler and cheaper power source, but it is expensive. A pulsed laser is cheaper but requires a special power source. Therefore, a device with a pulsed laser has a lower resulting efficiency and higher operating costs. The laser nozzle is put on with a slight interference on the teat cup 1 using a tapered ring 7. A small interference allows rotating it around its axis, removing it from one teat cup and rearranging it to another, which, in combination with a large depth of radiation penetration, allows targeting laser radiation to the affected areas of the udder and achieving not only a preventive but also a therapeutic effect.



1 is the inter-wall chamber of the teat cup; 2 is the teat cup sleeve; 3 is the teat cup liner; 4 is the teat cup suction cup; 5 is the teat cup under-teat chamber; 6 is the milk outlet of the teat cup liner; 7 is the special nozzle; 8 is the upper socket for connecting a laser installation; 9 is the upper connecting contact; 10 is the hose for connecting the laser installation; 11 is the bottom contact for connecting a laser system; 12 is the laser installation; 13 are the electromagnetic contacts; 14 is the electromagnetic generator; 15, 16 are the contact surfaces of the teat cup liner.

Fig. 2 The experimental stimulating milking machine [5]

The design of the stimulating milking machine has a device for massaging the udder, including an oscillation emitter in the form of an inductor with a winding 13 connected to a pulse current source 14. Since the effect of the impact directly on the animal's udder is the same as in the area of the base of the teat, due to the location of the main reflexogenic zone at its base, and the teat cup 1 is the only part of the milking machine that directly interacts with the udder of the cow during milking, the coil 13 of the inductor is placed in the suction cup 4 of teat cup liner 3, while one side 15 of the suction cup 4 of teat cup liner 3, in contact with the base of the teat of the udder, is covered with an elastic diamagnetic film 16, for example, made of fluoroplastic or special types of plastic, covered with a thin layer of diamagnetic metal, for example, copper, aluminum, etc. In this case, the pulse current source 14 is connected to the inductor winding 13 with a flexible cable, which is passed through a channel in a tapered ring 7. Instead of an autonomous power supply from a pulse current source 14 and batteries 12, one can use a centralized stabilized power supply installed in a separate room.

III. THE PRINCIPLE OF OPERATION OF THE EXPERIMENTAL STIMULATING MILKING MACHINE

The stimulating milking machine works as follows [3], [5].

The method of working with a stimulating milking machine is simple and does not require the presence of highly qualified personnel. The operator first turns on the device for massaging the udder and then the laser nozzle, sometime after the start of exposure to the reflexogenic zone at the base of the teat of the udder. The winding 13 (Fig. 2) of the emitter is connected to a pulse current source 14. The oscillation emitter begins to work, on the one hand, like a vibrator since on the side 15 of the suction cup 4 it is covered with a thin film 16, for example, a fluoroplastic film covered with a thin layer of diamagnetic metal, while the effect observed in magnetic pulse installations takes place [6], [7], represented by mechanical pressure transmitted to the reflexogenic zone at the base of the udder teat which can be regulated within a very wide range both in amplitude and frequency. On the other hand, since film 16 is coated with a diamagnetic metal, an electromagnetic pulse from the emitter 14, in this case acting as an emitter of electromagnetic waves, is transmitted to the object, i.e., on the reflexogenic zone at the base of the teat of the udder and has a beneficial effect not only on it but also on the udder and on the body of the animal as a whole, which has been repeatedly noted in various scientific and other publications. Udder massage by affecting the reflexogenic zone at the base of the teat is a preliminary stage of preparation for milking. Having a beneficial effect on the animal's body as a whole, it increases the animal's milk flow reflex.

IV. WORKING METHODS

The operating procedure of the experimental stimulating milking machine with a laser attachment is also simple. The operator turns on the laser attachment after the udder massage is over when the animal's body is ready for the milking process as a result of the increased milk flow reflex. After the end of milking, the laser nozzle is turned off. The capacity of the storage battery is selected sufficient for carrying out morning, afternoon, and evening milking. At the end of the working day, the battery compartments are recharged with low current. When mastitis is detected, the laser nozzle is rearranged onto the teat cup of the milking machine, which milks out the affected portion of the cow's udder, while the laser nozzle is turned so that the laser beam hits the center of the edematous area, if possible. For more severe mastitis, one can fit up to four laser heads per milking machine.

V. PRODUCTION TEST PROGRAM AND METHODS

The purpose of production tests is to determine the performance and effectiveness of the experimental stimulating milking machine. For comparison, the milking machine ADU-1 was chosen under the conditions of economic tests.

The research program provided for comparative tests [8] with the identification of the following characteristics and indicators:

1. Total milking time, s;
2. Duration of machine milking, s;
3. Maximum milk production rate, kg/min;
4. Average milk production rate, kg/min;
5. Duration of machine after-milking, s;
6. Volume of the remaining portion of milk, ml;
7. Milk yield in the morning and evening milking, kg;
8. Recording of machine milking waveforms in various modes;
9. Conducting a dimastin test;
10. Milk quality indicators:
    - 10.1. Milk density, kg/m^3;
    - 10.2. Mass fraction of protein, %;
    - 10.3. Mass fraction of casein, %;
    - 10.4. Fat content of milk, %.

For the experiment, two groups of similar cows were selected: the experimental group and the control group. The cows were milked three times a day.

The density of milk was determined by the calculation method.

To determine the intensity of milk flow, milking was carried out into the milk pipe. A bucket with an electronic scale was installed at the end of the milk pipe. The time per minute for milk release was determined by a mechanical stopwatch.

As a pilot production unit, 3 stalls in two rows were used, using a serial ADM-200 milking installation with an ADU-1 milking machine in the standard configuration.

For comparison, an ADM-200 milking machine was used, which included experimental stimulating milking machines with milking in a milking bucket.

VI. RESULTS OF COMPARATIVE TESTS

Production tests of milking machines were carried out (June to July 2016 and June to July 2017) at the dairy complex of the Sakharovo farm at the Tver State Agricultural Academy [8].

The groups of similar cows had a live weight of about 450 kg, were in 4 ... 5 periods of lactation, with an annual milk yield of 4425 to 4675 liters for the previous lactation.

The main results of production tests are shown in Tables 1 and 2.

TABLE I. RESULTS OF PRODUCTION TESTS OF COUPLED MILKING MACHINES

Name and number of the cow	Preparatory period			Main period		
	Average time of machine milking, s	Average milk flow per second, g/s	Average manual after-milking, ml	Average time of machine milking, s	Average milk flow per second, g/s	Medium manual after-milking, ml
	Control group					
Frosya	435	18.4	106	441	18.2	83
Lavina	474	10.3	109	371	12.0	70
Krasulya	362	9.4	108	330	12.7	75
		Experimental group				
Zayka	337	8.4	86	329	10.5	53
Belochka	397	11.0	103	324	12.0	58
Savinka	335	11.7	101	257	16.3	73

Table 1 shows that for the same time of machine milking in the control and experimental cow groups, in the experimental group, the average second lactation increased by 7.6%.

TABLE II. RESULTS OF PRODUCTION TESTS OF MILKING MACHINES PER EXPERIMENTAL PERIODS

Cow's name	Experimental period								
	Preparatory				Main				
	Milk quantity, kg								
	1st milking	2nd milking	3rd milking	Q	1st milking	2nd milking	3rd milking	Q	Difference, kg
	Control group								
Frosya		6.0	7.0	24.0	5.5	7.0	7.5	20.0	-4.0
Lavina	7.5	4.0	4.0	15.5	4.0	11.5	6.5	21.5	+ 6.0
Krasulya	5.0			11.0	3.0	9.0	5.5	17.5	+6.5
Total				50.5				59.0	+8.5
	Experimental group								
Zayka	4.5	2.5	2.0	9.0	2.0	6.5	8.0	16.5	
Belochka		3.5	3.5	12.5	5.0	4.5	5.0	14.5	+2
Savinka	6.5	4.0	4.5	15	6.0	6.5	8.0	20.5	+5.5
Total				36.5				51.5	+15

As can be seen from Table 2, when milking cows with an experimental stimulating machine, the milk yield throughout the experiment increased in the group by 15 kg in comparison with the preparatory period or by 41.1%. In the control group during the same period, the milk yield increased by 8.5 kg (16.8%), and the difference between the groups was 6.5 kg.

Table 3 shows the results of studies of the composition and quality of milk from the cows in question. The milk of the cows of the experimental group in the main period contained more fat than that of the animals in the preparatory period by 13%.

During the period of the experiment, the content of milk fat in the cows of the control group increased only by 1.6%, which means that in the milk of the cows of the experimental group, the fat content was higher by 11.4% than in the milk of the cows of the control group.

In the milk of cows of the experimental group in the main period, the mass fraction of protein increased by 6.2%.

During the period of the experiment in the milk of cows of the control group, a decrease in the level of total protein by 1.9% was observed.

Analyzing the data on the content of total protein in the milk of different cows, we can say that in the milk of the cows of the experimental group, the protein content increased by 4.3% than in the milk of the control group.

Based on the results of production tests, a graph of the intensity of milk yield of machine milking of cows was built (Fig. 3) for the experimental stimulating machine and the serial milking machine. The graph shows that the intensity of milk output of the experimental stimulating milking machine is higher, and the milking time is lower than that of the serial milking machine ADU-1 [2].

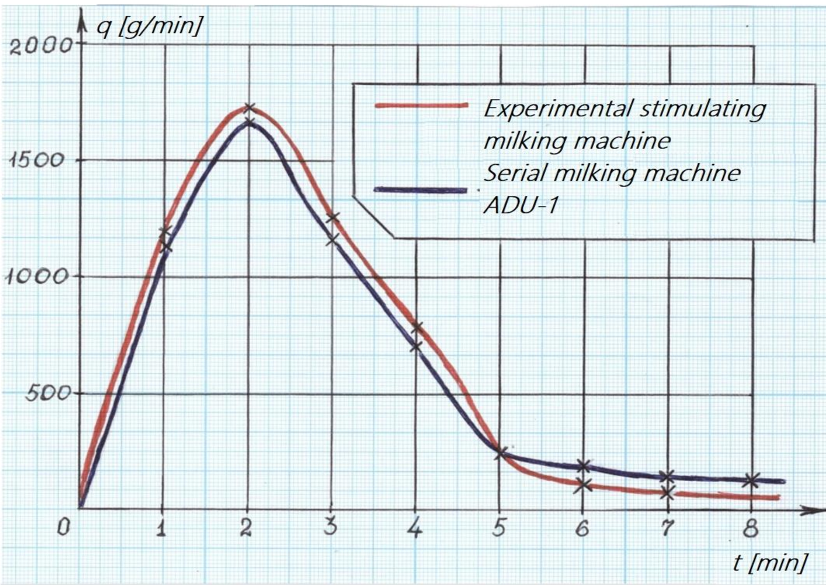


Fig. 3 Graph of the intensity of milk output of machine milking of cows

TABLE III. RESULTS OF STUDIES ON THE COMPOSITION AND QUALITY OF COWS' MILK

Cow's name	Preparatory period				
	Control group				
	Daily milk yield in terms of base fat content, kg	Density, A	Mass fraction of fat, %	Mass fraction of protein, %	Mass fraction of casein, %
Control group					
Frosya	30.4	27.4	4.30	3.72	3.08
Lavina	17.4	27.6	3.82	3.50	2.90
Krasulya	9.9	26.6	3.07	2.46	2.00
TOTAL	57.7				
Average		27.2	3.73	3.23	2.66
± by the preparatory period					
Experimental group					
Zayka	8.7	27.0	3.8	2.40	2.02
Belochka	12.0	28.0	3.88	3.30	2.9
Savinka	16.0	29.2	3.63	3.40	2.96
TOTAL	36.7				
Average		28.1	3.77	3.03	2.63
± by the preparatory period					

TABLE IV. RESULTS OF STUDIES ON THE COMPOSITION AND QUALITY OF COWS' MILK

Cow's name	Main period				
	Control group				
	Daily milk yield in terms of base fat content, kg	Density, A	Mass fraction of fat, %	Mass fraction of protein, %	Mass fraction of casein, %
Control group					
Frosya	24.0	29.0	5.10	3.62	2.88
Lavina	18.5	27.2	2.93	2.70	2.20
Krasulya	17.1	27.8	3.28	3.20	2.60
TOTAL	59.6				
Average		28.0	3.75	3.17	2.56
± by the preparatory period	+ 1.9	+ 0.08	+ 0.02	- 0.06	- 0.10

Experimental group					
Zayka	14.9	28.0	3.52	2.80	2.12
Belochka	16.3	29.2	3.82	3.30	2.84
Savinka	25.9	30.0	4.30	3.55	3.10
TOTAL	51.4				
Average		29.01	3.87	3.22	2.69
± by the preparatory period	+ 20.4	+ 0.97	+ 0.11	+ 0.19	+ 0.06

TABLE V. PRODUCTION TESTS OF THE SERIAL MILKING MACHINE ADU-1

Indicators	Milking machine ADU-1 (average values)					
	50 kPa		60 kPa		70 kPa	
Maximum specific pressure (P_{max}) of the teat cup liner on the teat tissue, kPa	20.0 20.7 17.4	19.4	24.4 20.9 21.6	22.3	35.0 40.3 26.0	33.8
Minute vacuum load (F_m) on udder tissue, N · s	415.8 415.8 356.1	395.9	455.7 410.9 420.8	447.7	654.9 687.2 540.3	627.5
Vacuum load ($F_{e.p.}$) for the full milking period, N · s	2079 2079 1780.5	1980	2278.5 2054.5 2104.0	2145.7	3274.5 3436.0 2701.5	3137.5
Maximum tensile force ($F_{p\,max}$) acting on the teat, N	13.9 13.9 11.9	13.2	15.2 13.7 14.1	14.3	21.8 22.9 18	20.9

TABLE VI. PRODUCTION TESTS OF THE EXPERIMENTAL STIMULATING MILKING MACHINE

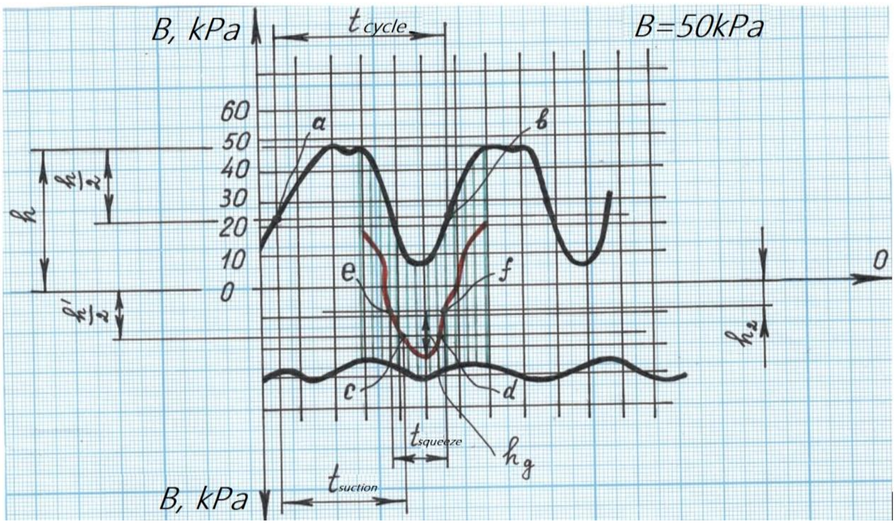
Indicators	Milking machine ADU-1 (average values)					
	50 kPa		60 kPa		70 kPa	
Maximum specific pressure (P_{max}) of the teat cup liner on the teat tissue, kPa	8.7 19.2 17.5	15.1	10.9 27.3 28.5	22.2	16.7 26.9 34.0	25.9
Minute vacuum load (F_m) on udder tissue, N· s	216.6 373.5 373.5	321.2	293.8 476 488	419.3	463.1 597.6 647.4	569.3
Vacuum load ($F_{e.p.}$) for the full milking period, N · s	1083.2 1867.5 1867.5	1606.1	1469.0 2380.0 2440.0	2096.5	2315.5 2988.0 3237.0	2846.8
Maximum tensile force ($F_{p\,max}$) acting on the teat, N	7.2 12.5 12.5	10.7	10.6 16.6 17.0	14.0	15.5 19.9 21.6	19.0

Analyzing the data in Tables 3 and 4, it can be seen that the content of casein in the milk of the experimental animals in the main period increased by 2.3% compared with the preparatory period. In the control group, the casein content in the milk of cows throughout the experiment slightly decreased (3.9%) compared with the preparatory period, and the fat content of milk and the protein content increased from 0.1 to 0.2%.

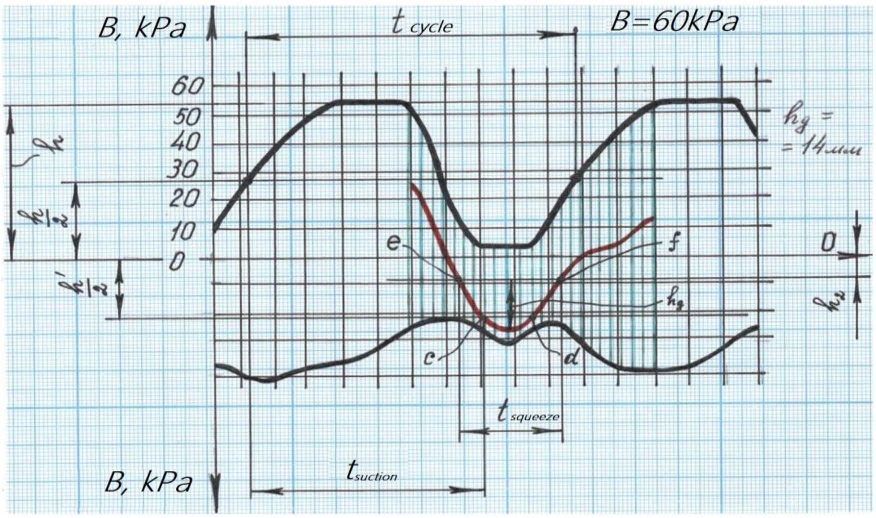
When comparing Tables 5 and 6, all indicators of the vacuum load in the experimental stimulating milking machine in comparison with the serial milking machine ADU-1 tend to decrease. Thus, the maximum specific pressure (at 50 kPa) of teat cup liner on the teat tissue decreases from 19.4 to 15.1 kPa, which is 22.2%. The minute vacuum load (at 50 kPa) on the udder tissue decreases from 395.9 to 321.2 N · s, which is 18.9%. The vacuum load (at 50 kPa.) during the full milking period decreases from 1980 to 1606.1 Ns, which will amount to a decrease of about 19%. The maximum tensile force (at 50 kPa) acting on the teat also decreases its value from 13.2 to 10.7 N, which is about 17.5%.

Thus, the use of an experimental stimulating milking machine makes it possible not only to avoid the harmful effects of vacuum pressure on the cow's teat but also to increase the productivity of the animals while improving the composition of milk.

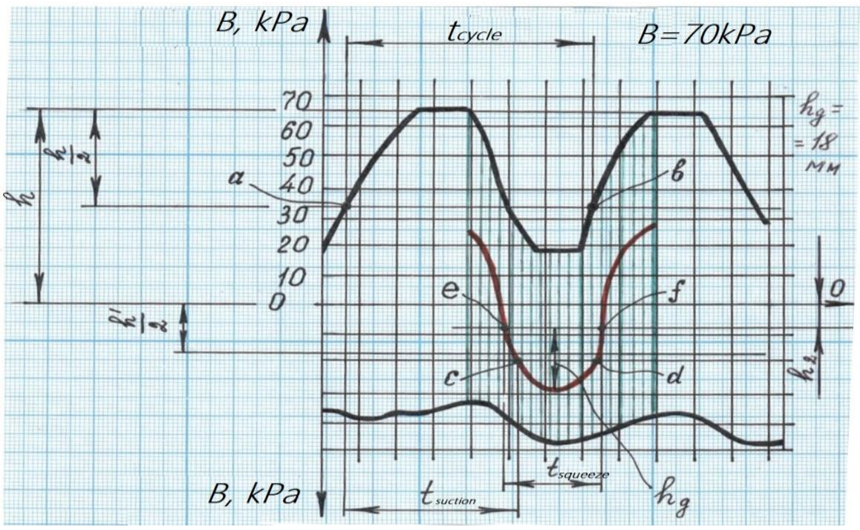
During the main period of comparative production tests of milking machines, oscillograms of machine milking were recorded under various vacuum modes (Figs. 4 and 5) [7].



a) P_{vac} = 50 (kPa)
Fig. 4.1 Cow Lavina

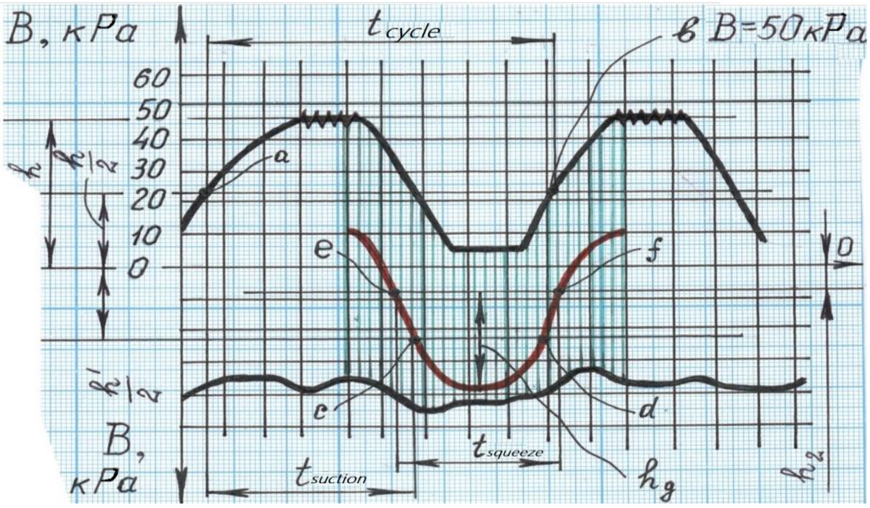


b) P_{vac} = 60 (kPa)
Fig. 4.2 Cow Lavina



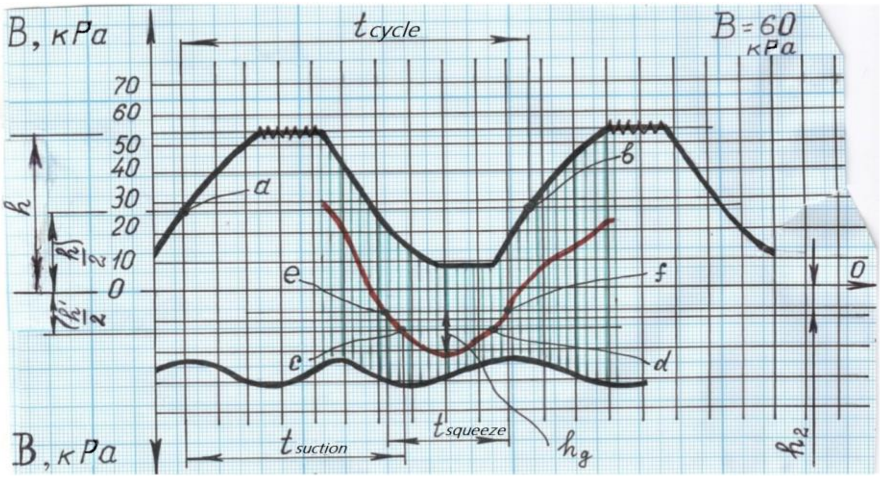
c) P_{vac} = 70 (kPa)
Fig. 4.3 Cow Lavina

Fig. 4 Oscillograms of machine milking of cows on the serial milking machine ADU-1



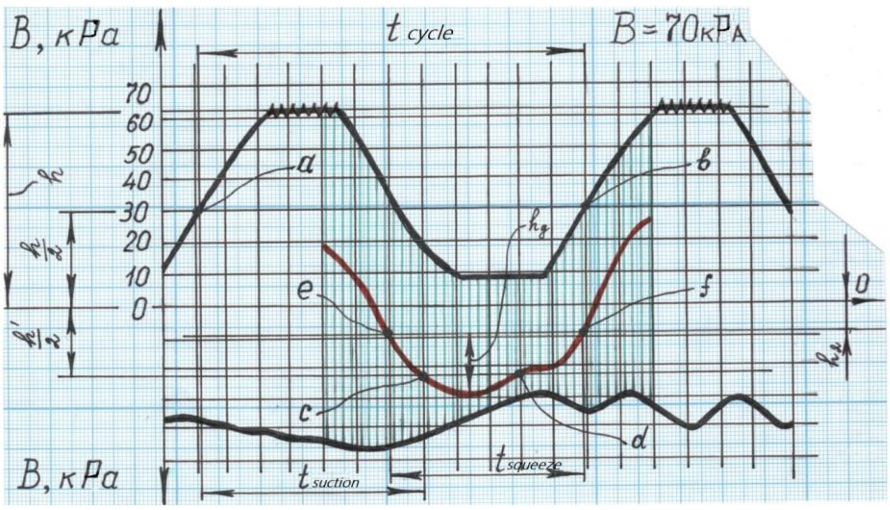
a) P_{vac} = 50 (kPa)

Fig. 5.1 Cow Belochka



b) P_{vac} = 60 (kPa)

Fig 5.2 Cow Belochka



c) P_{vac} = 70 (kPa)

Fig. 5.3 Cow Belochka

Fig. 5 Oscillograms of machine milking of cows on the experimental stimulating milking machine

VII. RESULT ANALYSIS

1. The stimulating milking machine is industrially applicable because it can be manufactured industrially and also is functional, feasible, and reproducible. An industrial prototype of the claimed machine was manufactured, and its laboratory tests were carried out in the laboratory of the MEZh Department of the Tver State Agricultural Academy. The effect of exposure in the area of the base of the teat is the same as directly on the udder of the animal. In both cases, we get an increase in milk yield from each cow by an average of 20-23%, while the fat content of milk will increase by 0.1 ... 0.15%. This circumstance will make it possible not only to simplify the design of the machine but to make it universal and convenient in operation, which allows successfully using the machine for a large group of animals, which is very important in a large livestock complex.

2. Oscillograms processed and decoded [2], [9], and the obtained indicators of vacuum modes are summarized in Table 4. From Table 4, it can be seen that the maximum specific pressure of the experimental teat liner cup on the teat tissue (Pmax) decreased on average by 3.6 kPa, the minute vacuum load decreased at 33.3 kPa by 74.4H · c, and at 50 kPa by 54.2 H · c, which leads to a decrease in the vacuum load during the period of full milking. The maximum tensile force (Fp max) acting on the teat decreased by 2 N from the max value. From the above, it can be concluded that the use of an experimental stimulating milking machine leads to an improvement in the performance of machine milking and contributes to the safe removal of milk from the cows' udder.

3. The oscillograms clearly show the presence of waves during the suction cycle. This suggests that during the suction cycle, the animal's teat is stimulated along the entire length (in the upper, middle, and lower zones).

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