RESEARCH IN MILKING MACHINE OF PAIRWISE COMBINED TYPE

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Abstract. It is known that improving the process and means of milking can increase the productivity of cows by 25-30%. Perfection of the design, interaction of the parameters and mode of operation of the milking machine have a special impact on the health, productivity of cows and milk quality. Parameters and modes of operation must correspond to the physiological characteristics of the process of milk production. Modern milking machines with a pair of milking cups ensure a stable flow of milk from pairs of teats into the collector chamber, doubling the irritation, which also has a synchronous uniform irritation of teats and udder halves. Milking machines with single action have high stability of milk supply to the collector chamber. Such devices also have much lower intensity of milk production. Improving the milking machine by changing the parameters in the milk cup by changing the operation of the control element (pulsator) will ensure asynchronous operation of the milking cups and increase the number of stimulating teats and udders during milking. A milking machine with paired-combined action is proposed, in which phases alternate during a certain cycle: simultaneous sucking phase in both pairs of milking cups, sucking phase in one when compressed in another pair of cups (milk is excreted in these phases) and simultaneous compression phase in both pairs (in this phase there is udder massage). The rational difference in pulsation frequency in pairs of milking cups is in the range from 0.1 to 0.2 Hz. The proposed mode of the milking machine increases the amount of milk produced during machine milking by 13.9% and its total yield by 8.2%, as well as reduces the duration of machine milking by 1.9… 2.1 times.

Keywords: milking machine; collector; pulsation frequency; pairwise combined mode.

Introduction

Existing milking machines [1-3] with simultaneous action of milking glasses are characterized by a high intensity of milk output and its uneven flow into the milk collection chamber of the cluster. Teat and udder irritation is generally uniform and synchronous throughout the milking period.

Modern milking machines with a pair action [4-7] of milking cups ensure a stable flow of milk into the collector chamber and have twice as many irritations. Irritation of the teats and halves of the udder is also synchronous and monotonous. Pair-action milking machines have a lower intensity of milk output compared to simultaneous-action machines.

Improvement [8; 9] of the pneumomembrane pulsator of the paired milking machine with the possibility of independently changing the duration of the sucking stroke in one of the pairs of the udder quarters corresponds to the physiological characteristics of cows and provides the mode of paired milking, based on the nodes of the unified synchronous pulsator.

Milking machines [10; 11] with quarter-by-quarter action of milking machines have a high stability of milk flow into the collector chamber. They create stimulating monotonous-synchronous irritations of the udder. Such devices also have a significantly lower milk excretion rate.

Therefore, it is advisable to improve the parameters and mode of operation of the milking machine. The problem posed can be solved by connecting the control links – pulsators at different pulsation frequencies for each of the two pairs of mammary glands grouped together, which makes it possible to provide non-synchronous (asynchronous) stimulation of the udder, milk output and change the nature of the milk flow to the milk collection chamber.

Improving the block of pulsators with different pulsation frequencies will allow combining the main advantages with high intensity of milk output of the milking machine with the simultaneous mode of milk output and stable flow of milk into the collector chamber with the paired action of the teat cups. Improving the completeness of milk excretion within the limits of zootechnical requirements is possible due to asymmetric irritations [12-14]. Reducing the vacuum pressure drop in the milk collecting chamber of the collector depending on the portion, with an even flow of milk, flow-controlled vacuum [15] increased peak milk flowrate by 12% and increased average milk flowrate by 4% [13].

Materials and methods

A characteristic design feature of the pulsator block (Fig. 1) is the presence of a common chamber of constant atmospheric pressure, an underwater line with a constant vacuum pressure, separate variable pressure control chambers with controlled throttling holes and corresponding variable pressure chambers. Due to this solution, an operating mode is created between pairs of udder dies with asynchronous stimulation of the udder, a combination of advantages in pairwise and simultaneous milk withdrawal (pairwise-combined mode) and milk flow into the milk collection chamber of the collector for each pulse from a pair of pines (Fig. 2).

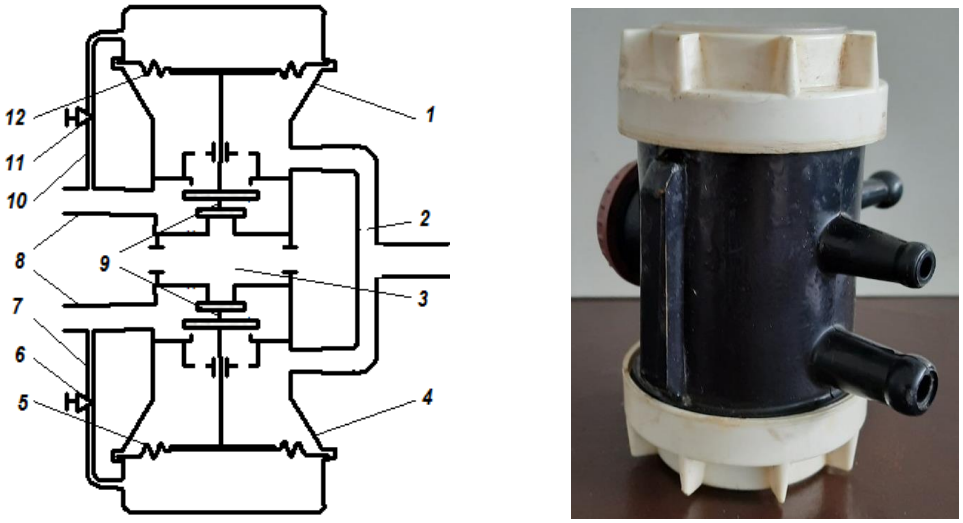

Fig. 1. **Scheme of the developed block of pulsators of the milking machine and general view:** 1, 4 – chambers of constant vacuum pressure; 2 – vacuum inlet; 3 – chamber of constant atmospheric pressure; 5, 12 – membrane; 6, 11 – throttle holes; 7, 10 – controlled channel; 8 – controlled pressure outlets; 9 – blocks of control valves

The pairwise-combined mode has recurring periods, the components of which are characteristic features:

- simultaneous operation of both paired pairs of teat cups in the sucking phase;
- operation of one pair of teat cups in the sucking phase, and the other in the compression phase;
- simultaneous operation of both pairs of teat cups in the compression (massage) phase.

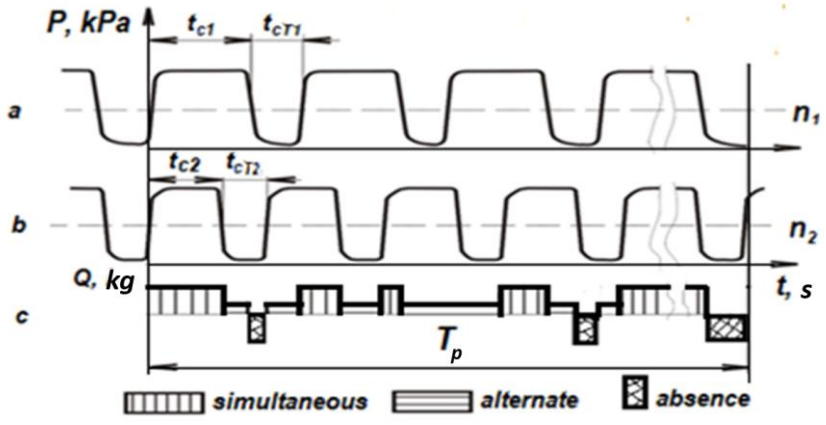

Fig. 2. **Cyclograms of changes in vacuum pressure in the interwall spaces of individual pairs (a, b) of milking cups and the nature of the change in the mode of milk inflow into the milk collecting chamber of the collector (c) with a pairwise combined mode of operation of the milking machine**

The pairwise-combined version, in terms of the intensity of milk removal, approaches the simultaneous operation of teat cups while maintaining the uniformity of the milk flow entering the

collector. The latter contributes to the stabilization of the level of vacuum pressure in the underside spaces of the teat cups.

The operation of the milking machine is determined by the well-known parameters:

- pulse duration –

$$t_p = t_c + t_{ct}, \tag{1}$$

- pulse rate –

$$n = \frac{1}{t_n}, \tag{2}$$

- ratio pulses –

$$\lambda = \frac{t_c}{t_{ct}}, \tag{3}$$

where t_c – duration of the sucking phase, s;
t_{ct} – duration of the compression phase, s.

The pairwise combined mode of operation of the teat cups is provided by the condition:

$$t_{n_1} \neq t_{n_2}, \tag{4}$$

where t_{n1} and t_{n2} – pulse duration, respectively, for the first and second pairs of teat cups.

According to the above condition (4), the duration of the pulses is not equal and can vary within the zootechnical requirements for the parameters of the milking machine. Then $n_1 > n_2$, can be denoted as the difference:

$$\Delta n = n_1 - n_2. \tag{5}$$

With the passage of pulses in each pair of teat cups, there comes a moment when the beginning of the stroke (sucking) in pairs of teat cups will coincide, and a new period T_c will begin. Then, in the period in each pair of teat cups, the number of pulses is repeated, respectively, several times k_1 and k_2 (multiplicity of pulses).

$$\left.\begin{aligned} k_1 &= \frac{t_{n_2}}{\Delta t}, k_1 \in Z \\ k_2 &= \frac{t_{n_1}}{\Delta t}, k_2 \in Z \end{aligned}\right\}. \tag{6}$$

The duration of the period is determined:

$$T_p = k_1 t_{n_1} = k_2 t_{n_2}. \tag{7}$$

During the operation of the milking machine with a pairwise combined mode, a cyclic repetition of periods occurs. During the passage of periods, asynchronous stimulation of the halves of the udder occurs according to a certain algorithm, determined by the multiplicity of pulses. The simultaneous withdrawal of milk by the indicated milking machine differs in the number of pairs of pines involved in the sucking stroke and the receipt of these portions in the milk collecting chamber of the collector. The flow of milk into the collection chamber of the collector approaches a continuous flow, which reduces the fluctuation of the vacuum pressure in the chamber.

The determination of the cycle duration T_p for the mode of operation of the pairwise-combined type milking machine was determined by the graphical-analytical method (Fig. 3) by processing the indicator diagrams of vacuum pressure fluctuations in the pairs of milking cups and the collector chamber. The durations of paired, simultaneous and compression milking were determined as the sum of the corresponding durations.

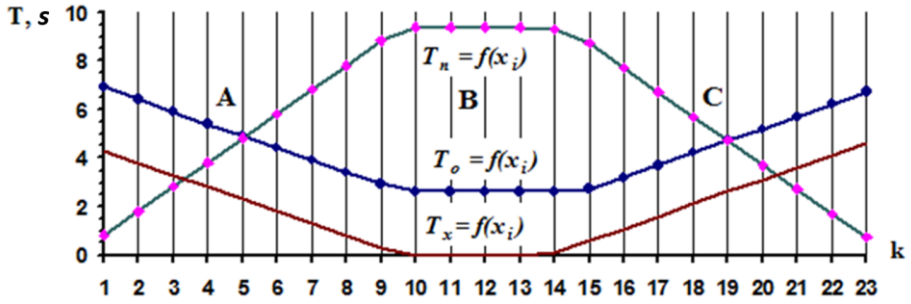

Fig. 3. **Dependences of the duration of periods (T_p) on the frequency of pulses for the first (k_1) and second pairs of teat cups (k_2)**

Then:

$$T_o = \sum_{i=1}^{i=k_1} t_{o_i} ; \tag{8}$$

$$T_n = \sum_{i=1}^{i=k_1} t_{n_i} ; \tag{9}$$

$$T_x = \sum_{i=1}^{i=k_1} t_{x_i} , \tag{10}$$

where t_{oi} – duration of the period of simultaneous operation of both pairs of teat cups in the sucking phase, s;
t_{ni} – duration of the period of operation of one pair of glasses in the sucking mode, and the other in the compression stroke, s;
t_{xi} – duration of the period of simultaneous operation of both pairs of glasses in the compression mode, s.

The graphic dependence of duration of the periods - simultaneous, pairwise, and idle periods of work is a curve that has three straight sections, and three zones (A, B, C) can be conventionally distinguished. The curve of the simultaneous and idle periods has the same slope, but different initial ordinates. The change in these curves in the sections has the same character, which determines the duration of one cycle and its repeatability.

The curve of the period of pairwise work has the character of an inverse curve of the simultaneous and idle periods, as well as other angular and initial ordinates. Since the values t_{oi}, t_{ni}, t_{xi} are variable within one cycle, the duration of the latter can be represented as:

$$T_P = f_o(x_i) + f_n(x_i) + f_x(x_i), \tag{11}$$

where $f_o(x_i)$, $f_n(x_i)$, $f_x(x_i)$ – functions of respectively simultaneous, pairwise and idle durations for the i-th period of the cycle, straight sections (A, B, C);
x_i – parameter under study, on which the specified function depends.

The basis for creation of the pilot plant was the use of the components of the experimental stand – for testing milking machines, in particular: a flow meter for a milk ejection simulator, a milk pipeline, an artificial udder, a vacuum installation with a vacuum line, vacuum gauges, strain gauges of vacuum pressure. The general view of the installation is shown in Fig. 4, and the constructive-functional scheme of the stand in Fig. 5.

This installation allows to conduct experiments on removing the parameters of the milking machine for different modes of operation.:

- change the intensity of milking and suction capacity in combination of paired and simultaneous modes of operation of the milking machine;
- control of the value of the vacuum pressure in the collection chamber of the collector;
- measurement of the pulsation frequency in each pair of teat cups.

To determine the influence of the factors (changes in pressure in the interwall chambers P_e and P_a and pulsation frequency n_1, n_2) on the amplitude of vacuum pressure fluctuations and the flow of milk into the milk collection chamber of the collector in the sucking and compression strokes in simultaneous, paired, and combined modes of operation, taking into account the duration of the period, movements of the milking cups of the hanging part of the apparatus, a sifting factorial experiment was carried out.

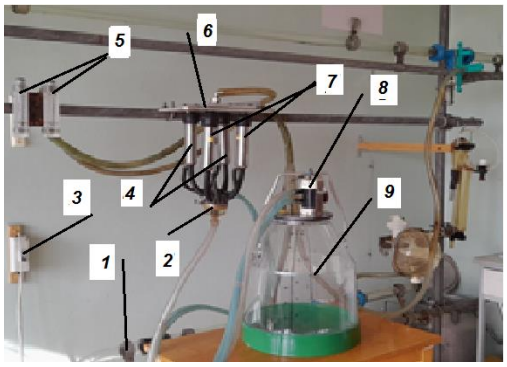

Fig. 4. **General view of the setup for the experimental research:** 1– vacuum gauge installation; 2 – cluster; 3 – installation switch; 4, 7 – pairs of milking cups; 5 – milk simulator flowmeters; 6 – artificial udder; 8 – block of pulsators; 9 – milking bucket

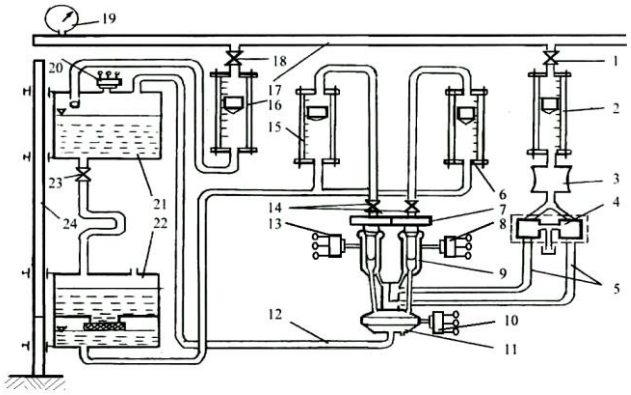

Fig. 5. **Structural and functional scheme of the stand for the study of operating modes of milking machines:** 1,14,18,23 – valves; 2,6,15,16 – rotameters; 3 – receiver; 4 – block of pulsators; 5 – air hoses; 7 – artificial udder; 8,10,13,20 – pressure sensors; 9 – milking cups; 11 – cluster; 12 – milking hose; 17 – vacuum pipe; 19 – pressure gauge; 21 – milk tank; 22 – feeder; 24 – stand

The studies were carried out according to the standards ISO 6690:2004 and SOU 74.3-37-273:2005 with a threefold repeatability.

The intensity of milk flow was changed in the range from 0.2 l/min to 3.8 l/min using a liquid supply control valve, control was carried out with PC-5 rotameters for the corresponding pair of glasses. Pressure fluctuations in the milk collection chamber of the collector, taking into account the time, were produced using an analog-to-digital converter. The studies were carried out at a pressure of 50 ± 2 kPa, which corresponds to the zootechnically accepted optimal indicators from 48 to 52 kPa for milking cows of different stiffness.

During the experiment, pressure changes were determined in the milk collection chamber of the collector and the interwall chambers of the milking cups.

Results and discussion

The equations obtained as a result of the analysis of the experimental data:

$$T_p = 0.1062\,P - 98.5880\Delta n + 205.2200\,\Delta n^2 - 0.2500P\cdot\Delta n + 12.7862 \quad (12)$$

where P – vacuum pressure value. kPa;
Δn – pulsation frequency difference, pulses per min.

Analysis of the graphical model (Fig. 6) indicates that the dependences are in the nature of a graph of a hyperbolic function. A decrease in the pulsation frequency difference ($\Delta n < 0.1$ Hz) leads to a geometric increase in the cycle duration, and its increase at $\Delta n > 0.25$ Hz leads to insignificant changes in the latter. The uniform change in the response function is located within the difference in the pulse frequency ($n = 0.1$ to 0.2 Hz). Depending on the value of the vacuum pressure (Fig. 7), the duration of the cycle changes insignificantly in a linear manner.

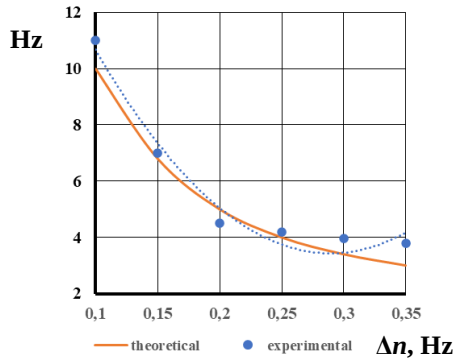

Fig. 6. **Dependence of the duration of the cycle on the difference in the frequency of pulsation in the pairs of milking machines at a vacuum pressure value P_v = 50 kPa**

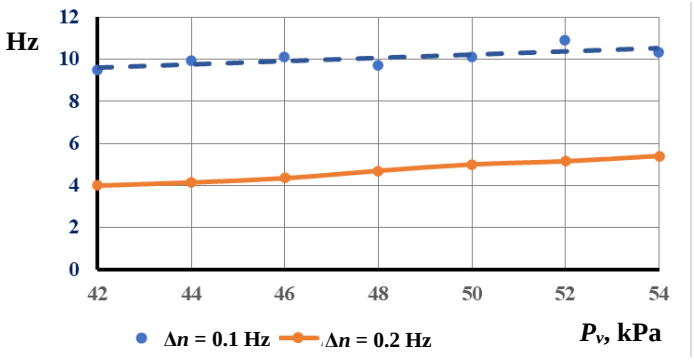

Fig. 7. **Experimental dependence of the cycle duration on the value of the vacuum pressure with a difference in the frequency of pulsation in the teat cups**

On the indicated graphical model it is possible to single out the main zones of the configuration in terms of the size and its growth. The maximum value of the duration and its change is reached in the zone (A) Δn = 0…0.05 Hz, which approaches the simultaneous action of the teat cups. An insignificant change in the duration of the cycle until its corresponding increase is in the zone Δn = 0.3 ... 0.5 Hz, which is characterized by a change in the duration of the cycle in the interval of two or three cycles, which creates insignificant stimulating irritation. Given that under production conditions membrane pulsators have an error in the pulse frequency of ± 0.08 Hz, to ensure the specified mode, we selected a zone with a change in the parameters of the apparatus within Δn = 0.1 ... 0.3 Hz. In this zone, the change in the duration of the cycle and its increase is significantly uniform.

The studies were carried out using the method of planning multifactorial experiments of Box-Behnken at three levels and three times. The verification of the adequacy of mathematical models was carried out using the elements of dispersion analysis according to the Fisher criterion at a confidence level of 0.95; the assessment of the significance of the regression coefficient is determined by the Student's criterion for the selected level of significance.

From the analysis of dependencies, we can conclude that the rational condition under which the pairwise-combined mode of operation of the improved milking machine will be provided by changing the difference in the frequency of pulsation between pairs of cups of the machine is within Δn = 0.2 ± 0.1 Hz.

Conclusions

1. It has been established that due to the change in the frequency of pulsation in pairs of teat cups a pairwise combined mode of operation of the apparatus occurs. The parameter that characterizes the specified mode is the difference in the pulse rate, the multiplicity of repetitions of changes in the cycle. The duration of the cycle has characteristic periods, the duration of which varies and depends on the difference in the frequency of pulsations between pairs of milkings. Cyclic repetitions cause additional irritation between pairs of milkings.
2. Mathematical models have been obtained for changing the duration of cycles between pairs of teat cups in the pairwise-combined mode of operation of the milking machine. The obtained dependencies indicate that the longest cycle of the pairwise-combined mode of operation of the milking machine is within 10-14 multiple repetitions.

Author contributions

All the authors have contributed equally to creation of this article.

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