

EXPERIMENTAL PULSE GENERATOR COMBINED  
WITH THE MILKING MACHINE COLLECTOR  
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ЕКСПЕРИМЕНТАЛЬНИЙ ГЕНЕРАТОР ІМПУЛЬСІВ СУМІЩЕНИЙ  
ІЗ КОЛЕКТОРОМ ДОЇЛЬНОГО АПАРАТА

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## ABSTRACT

Factors affecting the milk ejection intensity and power consumption of the pulse generator combined with the milking machine collector have been analyzed. The main factors and limits of their variation, as well as the results of experimental studies are given. The matrices of a multivariate planned experimental study of a pulse generator with a combined collector (pneumatic-electromagnetic pulsator-collector) have been developed. According to the results of experimental studies, the coded and natural values of the regression equation are derived. The equations characterize the dependence of the milk ejection intensity on the pulsation frequency, the ratio between the strokes and the vacuum pressure in the under teats space of the teat cup. The dependence of the power consumption of the pulse generator on the pulse rate and the ratio between the strokes are derived. Graphical models of interpretation of regression dependencies according to the experimental data are constructed. Student's t-test, Fisher and Cochran criteria are calculated. These indicators show the adequacy and reproducibility of the models obtained during the studies using an experimental pulse generator combined with a milking machine collector.

## РЕЗЮМЕ

Проаналізовано фактори, які впливають на інтенсивність молоковіддачі і споживану потужність генератора імпульсів із суміщеним колектором доїльного апарата. Наведено основні фактори і межі їх варіювання, розроблено матриці багатфакторного планованого експерименту генератора імпульсів суміщеного із колектором (пневмоелектромагнітний пульсоколектор), а також результати експериментальних досліджень. За результатами експериментальних досліджень виведено рівняння регресії у кодованих і натуральних значеннях, які характеризують залежність інтенсивності молоковіддачі від частоти пульсації, співвідношення між тактами та вакуумметричного тиску у піддійковому просторі доїльного стакана, та залежність споживаної потужності генератора імпульсів від частоти пульсації і співвідношення між тактами. Побудовано графічні моделі інтерпретації регресійних залежностей за експериментальними даними. Розраховано t-критерій Стьюдента, критерії Фішера і Кохрена, які показують адекватність і відтворюваність отриманих моделей технологічного процесу з використанням експериментального генератора імпульсів суміщеного із колектором доїльного апарата.

## INTRODUCTION

Robotization of the milking process provides a complete adaptation of the technical system to the physiology of the cow and is an urgent task of today. The automatic milking system is a technology of labour saving (Floridi et al., 2013). Today's ensuring of adaptive milking is one of the major innovations of dairy farms worldwide (De Koning, 2010).

However, attention should be paid to the automation of individual milking operations, which is part of the overall milking system. Automatic milking is quite favourable for the cow (Pastell et al., 2006). The design and its components are the main elements that influence the servicing characteristics of the milking machine (Spencer et al., 2004). There are many factors that determine the quality of the process. However, it is important to observe the appropriate operating parameters, as not adjusting the unit to a particular animal may result in injury and disease to the udder of the cow.

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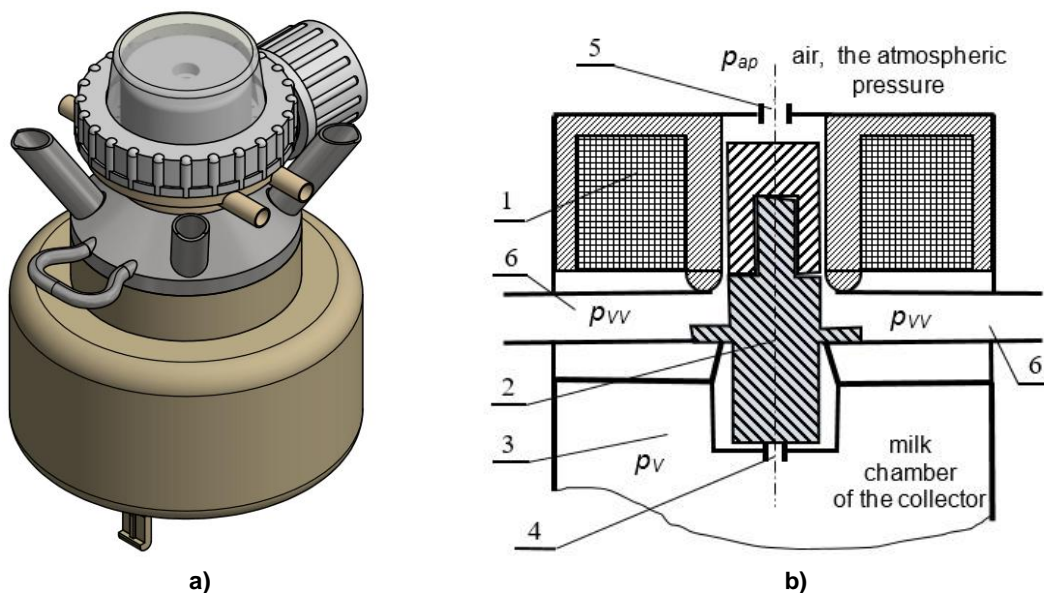
Pulse rate and vacuum also affect the cow's adaptation of the system and determine the softness and speed of milking (Penry *et al.*, 2016). Changing the ratio between strokes from 50:50 to 70:30 with a steady pulse rate of 60 pulses/min and the 42 kPa vacuum pressure level in the system reduces the duration of the milking time to 25%, but at the 51 kPa vacuum pressure in the system the milking time is reduced by only 5% (Thomas *et al.*, 1993). The results of research by scientists (Spencer *et al.*, 2007) showed that the maximum amount of milk was at the vacuum pressure of 43.9 kPa.

This confirms that the level of vacuum, the frequency of pulsations and the stroke ratio create a dominant influence on the intensity of milk production (Mein Graeme *et al.*, 2007).

Therefore, the development and research of an adaptive pulse generator combined with a collector is relevant.

## MATERIALS AND METHODS

The purpose of the work was to study the characteristics of an experimental pulse generator combined with the milking machine collector, depending on the parameters of the process of machine milking of cows. The general view and scheme of the experimental pulse generator combined with the milking machine collector is shown in Fig. 1.



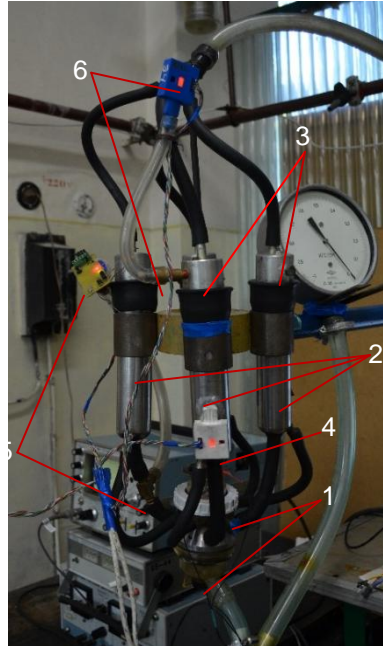
**Fig. 1 - The general view (a) and scheme (b) of experimental pulse generator combined with milking machine collector**

1 – electromagnet; 2 – keeper (armature) valve; 3 – milk chamber of collector; 4 – drain port of vacuum pressure; 5 – drain port of atmospheric pressure; 6 – chamber of variable pressure (engaging the inter wall chamber of teat cups)

An experimental pulse generator combined with a collector (Fig. 1b) ensures the movement of the (2) armature valve by electric current feed with a given frequency to the (1) electromagnet. The (2) armature valve moves and with a given frequency closes the (4) and (5) drain ports by turn. When an electric current is applied to the electromagnet (1), the electromagnetic force arises and raises the (2) armature valve upwards and closes the (5) drain ports of the atmospheric pressure access. Then, through the drain ports of (4), the vacuum pressure  $p_v$  from the (3) collector milk chamber enters into the (6) chamber of variable vacuum pressure, from where the  $p_{vv}$  variable vacuum pressure enters into the inter wall chamber of teat cups. It is a stroke of sucking. In the absence of electric current on the (1) electromagnet, the armature valve moves down, closes the (4) drain port and opens the drain port of (5). Then, through the (5) drain port, the atmospheric pressure  $p_{ap}$  enters into the (6) chamber of variable pressure, from where the  $p_{vv}$  atmospheric pressure enters into the inter wall chamber of teat cups. This corresponds to a compression stroke.

The nature of the armature valve switching and the influence on this process of technological operation parameters of the milking machine with the experimental pulse generator combined with the collector were investigated using a full-scale planned experiment. The technique of the experiment was taken as the basis of (Dmytriv *et al.*, 2019), taking into account the weight of each factor and decoding the elements of the regression dependence into the coefficients of the equation for the natural values of the factors.

The general view of connection of the pulse generator combined with the collector is shown in Fig. 2. To measure the pressures (Fig. 2) in the inter wall chamber of teat cups, in the under teats space and milk chamber of artificial udder of the cow (3) the intelligent pressure sensors are activated for (4), (5) and (6) respectively. To simulate the diagram of the cow's milk ejection intensity simulator, developed by the authors, was used (Dmytriv V. T. and Dmytriv I. V., 2013).



**Fig. 2 - The general view of connection of experimental pulse generator combined with collector**

1 – pulse generator combined with collector; 2 – teat cups; 3 – artificial udder of cow;  
4 – sensor of pressure of the inter wall chamber of teat cup; 5 – sensor of pressure of under teat space of the teat cup;  
6 – sensor of pressure in “milk chamber” of artificial udder of cow

Response criteria were the  $q$  [g/sec] intensity of milk ejection and  $N$  [W] power consumption. The factors were the ripple frequency of  $n$  [imp./min] –  $x_1$ , the ratio between the strokes of  $t/T$  –  $x_2$  and the vacuum gauge pressure in the under teat space of the teat cup of  $p_n$  [kPa] –  $x_3$ . The values of the vacuum gauge pressure in the under teat space of the teat cup were 26, 32 and 38 kPa, the  $n$  ripple frequency was at levels of 40, 60 and 80 imp/min, and the ratio between the strokes was 40:60, 60:40 and 70:30.

The coding factors, according to the theory of experiment planning, are given in Table. 1.

**Table 1**

**Levels of variation of factors and their code values in the planned experiment**

Factors	Designation	Dimension	Levels of factors			Variation interval
			upper	null	lower	
			Code values			
			+ 1	0	- 1	
Ripple frequency, $n$	$x_1$	[imp./min] [Hz]	40 0.67	60 1.0	80 1.33	20 0.33
Ratio between the strokes, $t/T$	$x_2$		40:60 = 0.667	60:40 = 1.5	70:30 = 2.333	0.833
Vacuum gauge pressure in the under teat space of the teat cup, $p_n$	$x_3$	[kPa]	26	32	38	6

## RESULTS

Taking into account the real operational modes mentioned above, we have applied a second-order polynomial, which is easily systematized and investigated as to the extremum. To make the planned experiment of the milk ejection dependence on the following factors - the ripple frequency, the ratio between the stroke and the vacuum pressure in the under teat space of the teat cup we have selected an orthogonal central composite plan (Table 2). Such factors correspond to the technological parameters of the milking machine. Column 11 is an orthogonal matrix of the planning, and column 12 is the value of the experiment response criterion.

The values of the factors for the planned experiment of the study of power consumption by an experimental pulse generator combined with a collector are given in Table. 3. The main factors were the ripple frequency and the ratio between the strokes. The pressure was constant during the planned experiment.

Table 2

**Extended matrix of orthogonal experiment planning for a three-factor model of the second order for milk ejection dependence on factors**

Experi- ment №	$x_1$	$x_2$	$x_3$	$x_1 \cdot x_2$	$x_1 \cdot x_3$	$x_2 \cdot x_3$	$(x'_1)^2$	$(x'_2)^2$	$(x'_3)^2$	$x_1 \cdot x_2 \cdot x_3$	$y(q),$ [g/sec]
1	+1	+1	+1	+1	+1	+1	0.3333	0.3333	0.3333	+1	40
2	0	+1	+1	0	0	+1	-0.6667	0.3333	0.3333	0	46.110
3	-1	+1	+1	-1	-1	+1	0.3333	0.3333	0.3333	-1	47.333
4	+1	+1	-1	+1	-1	-1	0.3333	0.3333	0.3333	-1	42.443
5	0	+1	-1	0	0	-1	-0.6667	0.3333	0.3333	0	43.333
6	-1	+1	-1	-1	+1	-1	0.3333	0.3333	0.3333	+1	43.333
7	+1	+1	0	+1	0	0	0.3333	0.3333	-0.6667	0	40
8	0	+1	0	0	0	0	-0.6667	0.3333	-0.6667	0	39.553
9	-1	+1	0	-1	0	0	0.3333	0.3333	-0.6667	0	41.553
10	+1	-1	+1	-1	+1	-1	0.3333	0.3333	0.3333	-1	38
11	0	-1	+1	0	0	-1	-0.6667	0.3333	0.3333	0	38.667
12	-1	-1	+1	+1	-1	-1	0.3333	0.3333	0.3333	+1	36.557
13	+1	-1	-1	-1	-1	+1	0.3333	0.3333	0.3333	+1	23.330
14	0	-1	-1	0	0	+1	-0.6667	0.3333	0.3333	0	25.443
15	-1	-1	-1	+1	+1	+1	0.3333	0.3333	0.3333	-1	26.447
16	+1	-1	0	-1	0	0	0.3333	0.3333	-0.6667	0	37.667
17	0	-1	0	0	0	0	-0.6667	0.3333	-0.6667	0	40.890
18	-1	-1	0	+1	0	0	0.3333	0.3333	-0.6667	0	39.777
19	+1	0	+1	0	+1	0	0.3333	-0.6667	0.3333	0	42.667
20	0	0	+1	0	0	0	-0.6667	-0.6667	0.3333	0	44.447
21	-1	0	+1	0	-1	0	0.3333	-0.6667	0.3333	0	43.777
22	+1	0	-1	0	-1	0	0.3333	-0.6667	0.3333	0	26.223
23	0	0	-1	0	0	0	-0.6667	-0.6667	0.3333	0	30
24	-1	0	-1	0	+1	0	0.3333	-0.6667	0.3333	0	32.557
25	+1	0	0	0	0	0	0.3333	-0.6667	-0.6667	0	40
26	0	0	0	0	0	0	-0.6667	-0.6667	-0.6667	0	41.557
27	-1	0	0	0	0	0	0.3333	-0.6667	-0.6667	0	40.667
$\Sigma$	18	18	18	12	12	12	-	-	-	8	-

Table 3

**Extended matrix of orthogonal experiment planning for a two-factor model of the second order for power consumption dependence on factors**

Experiment №	$x_1$	$x_2$	$x_1 \cdot x_2$	$(x'_1)^2$	$(x'_2)^2$	$y(M),$ [W]
1	+1	+1	+1	0.3333	0.3333	3.51
2	0	+1	0	-0.6667	0.3333	4.60
3	-1	+1	-1	0.3333	0.3333	6.77
4	+1	-1	-1	0.3333	0.3333	2.09
5	0	-1	0	-0.6667	0.3333	2.7
6	-1	-1	+1	0.3333	0.3333	3.743
7	+1	0	0	0.3333	-0.6667	3.13
8	0	0	0	-0.6667	-0.6667	3.98
9	-1	0	0	0.3333	-0.6667	5.77
$\Sigma$	6	6	4	-	-	-

According to the data in table 2 as to the established procedure (Dmytriv et al., 2019), the results of calculations of the coded and natural values of the regression equation coefficients are given in Table 4, and for the data in the Table 3 results of calculations of the coded and natural values of the regression equation coefficients are given in Table 5.

Table 4

**Results of calculating the coefficients of the regression equation of the milk ejection dependence on factors**

Coefficient of the regression equation	Coded coefficient	Real coefficient
$b_0$	40.593	-78.231
$b_1$	-1.204	-30.726
$b_2$	4.271	-3.771
$b_3$	4.691	6.360
$b_{12}$	-0.499	26.67
$b_{13}$	0.278	1.508
$b_{23}$	-2.806	0.289
$b_{11}$	-0.982	-8.837
$b_{22}$	0.369	0.536
$b_{33}$	-2.926	-0.097
$b_{123}$	-1.375	-0.904

The regression equation that models the change in the intensity of cow's milk ejection in natural factors will look like:

$$q = -78.231 - 30.726 \cdot n - 3.771 \cdot (t/T) + 6.360 \cdot p_n + 26.67 \cdot n \cdot (t/T) + 1.508 \cdot n \cdot p_{II} + 0.289 \cdot (t/T) \cdot p_n - 8.837 \cdot n^2 + 0.536 \cdot (t/T)^2 - 0.097 \cdot p_{II}^2 - 0.904 \cdot n \cdot (t/T) \cdot p_{II} \quad (1)$$

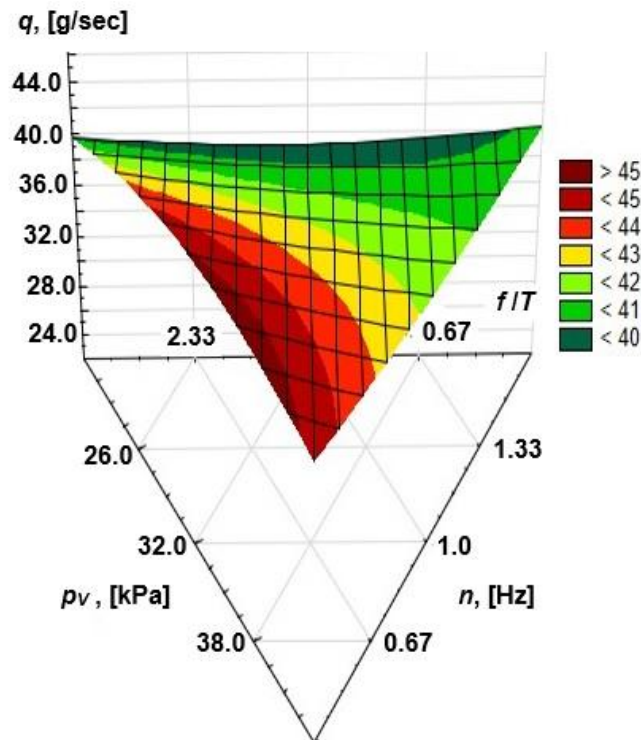
where  $q$  – the milk ejection. [g/sec];

$n$  – the ripple frequency. [Hz];

$t/T$  – the ratio of strokes (compression stroke to suction stroke);

$p_n$  – the vacuum gauge pressure in the under teat space of the teat cup. [kPa];

The graphical representation of (1) dependence is shown in Fig. 3.



**Fig. 3 - The dependence of the  $q$  intensity of the milking machine milk ejection on the technological process parameters**

$n$  – the ripple frequency;  $t/T$  – the ratio between strokes;  $p_v$  - the vacuum gauge pressure in the under teat space of the teat cup



Table 5

Results of calculating the regression equation coefficients of the power consumption by factors

Coefficient of the regression equation	Coded coefficient	Real coefficient
$b_0$	4.02	6.205
$b_1$	-0.839	-9.12
$b_2$	0.706	4.434
$b_{12}$	-0.403	-1.47
$b_{11}$	0.409	3.755
$b_{22}$	-0.388	-0.563

The regression equation that models the change in the  $N$  power consumption in natural factors will look like:

$$N = 6.205 - 9.12 \cdot n + 4.434 \cdot \left(\frac{t}{T}\right) - 1.47 \cdot n \cdot \left(\frac{t}{T}\right) + 3.755 \cdot n^2 - 0.563 \left(\frac{t}{T}\right)^2 \quad (2)$$

The graphical representation of (2) dependence is shown in Fig. 4.

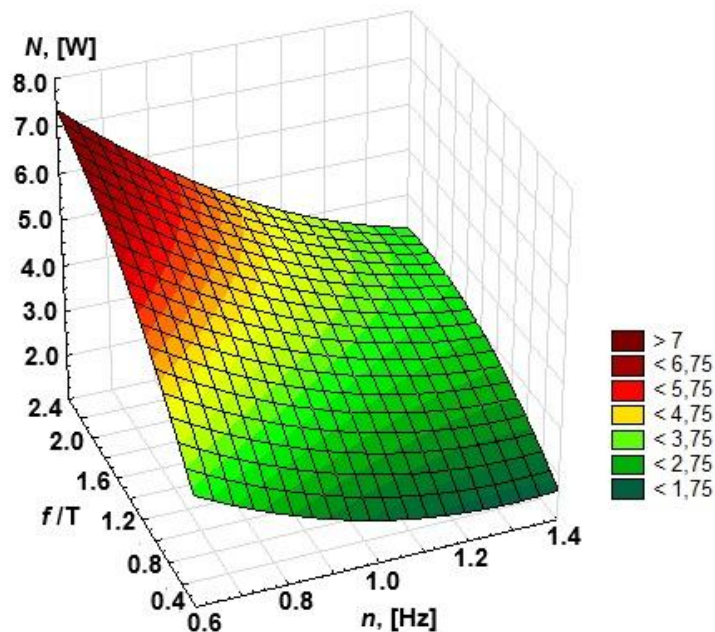


Fig. 4 - The dependence of the  $N$  power consumption by the experimental pulse generator combined with a collector on the technological process parameters

$n$  – the ripple frequency;  $t/T$  – the ratio between strokes

The results of the analysis of the experimental data on the reproducibility of the experiments by the Cochran criterion, on the significance of the regression equations' coefficients by the Student's  $t$ -test and on the evaluation of the models adequacy by the Fisher  $F$ -test showed the following.

To confirm the reproducibility of the experiments (measurements) according to the (1) dependence of the milk ejection intensity, the calculated value of the Cochran criterion is 0.1136, being less than the table value, which is 0.198.

To estimate the significance of the regression coefficients the mean variance of  $S^2$  was determined as  $S^2 = 523.019/27 = 19.371$ .

The variance in the determination of the regression coefficients (Dmytriv et al., 2019) is calculated by the dependence:

$$S_A^2 = S^2 / (k \cdot m_k) \quad (3)$$

where  $k$  – the number of experiments;  $m_k$  - the number of reinvestigation.

$$S_A^2 = \frac{19.371}{27 \cdot 3} = 0.239$$

To compare each regression coefficient with the  $S_A \cdot t$  expression, the Student's  $t$ -test is determined for the significance level of 0.95, so the degree of freedom is calculated by the dependence:

$$\begin{aligned}fn &= k \cdot (m_k - 1). \\fn &= 27 \cdot (3 - 1) = 54.\end{aligned}\quad (4)$$

Accordingly, the tabular value of the  $t$ -criterion is  $t = 2.004$ .

The value of the  $S_A^2 \cdot t = 0.479$  expression is compared with the coefficients of (1) equation. The  $|b_i| > S_A^2 \cdot t$  condition is fulfilled except the coefficients of  $b_{23}$  and  $b_{33}$ . We can conclude that the other coefficients of (1) equation are significant.

The suitability of the (1) regression equation for a characteristic description of the optimization criterion dependence on factors by the known method (Dmytriv *et al.*, 2019) is checked and the Fisher criterion ( $F$ -criterion) is determined.

The  $S_{ao}^2$  variance of adequacy and the calculated value of the  $F$ -criterion  $F_p$  are  $S_{ao}^2 = 29.057$  and respectively  $F_p = 1.5$ .

The table value of the  $F$ -criterion is  $F_T = 1.95$  for the calculated degrees of freedom of the main variance of  $f_1 = 18$  and the variance of adequacy of  $f_n = 54$ .

The model adequacy is estimated by the  $F_p \leq F_T$  condition, respectively at the  $1.5 \leq 1.95$  the model described by (1) equation is adequate.

To confirm the reproducibility of the experiments according to the (2) dependence of the power consumption, the calculated value of the Cochran criterion is 0.32, being less than the table value, which is 0.4775.

To estimate the significance of the regression coefficients the  $S^2$  mean variance was determined as  $S^2 = 0.53954/9 = 0.05995$ .

The variance in the determination of the regression coefficients (Dmytriv V.T. *et al.*, 2019) is calculated by the (3) formula:

$$S_A^2 = \frac{0.05995}{9 \cdot 3} = 0.00222$$

To compare each regression coefficient with the  $S_A \cdot t$  expression, the Student's  $t$ -test is determined for the significance level of 0.95, so the degree of freedom is calculated by the (4) formula:

$$fn = 9 \cdot (3 - 1) = 18$$

Accordingly, the tabular value of the  $t$ -criterion is  $t = 2.10$ .

The value of the  $S_A^2 \cdot t = 4.663 \cdot 10^{-3}$  expression is compared with the coefficients of (2) equation. The  $|b_i| > S_A^2 \cdot t$  condition is fulfilled. We can conclude that all coefficients of (2) equation are significant.

The suitability of the (2) regression equation for a characteristic description of the optimization criterion dependence on factors is checked by the known method (Dmytriv *et al.*, 2019) and the Fisher criterion ( $F$ -criterion) is determined.

The  $S_{ao}^2$  variance of adequacy and the calculated value of the  $F$ -criterion  $F_p$  are  $S_{ao}^2 = 0.1798$  and respectively  $F_p = 3$ .

The table value of the  $F$ -criterion is  $F_T = 4.58$  for the calculated degrees of freedom of the main variance of  $f_1 = 3$  and the variance of adequacy of  $f_n = 18$ .

The model adequacy is estimated by the  $F_p \leq F_T$  condition, respectively at the  $3 \leq 4.58$  the model described by (2) equation is adequate.

## CONCLUSIONS

The regression model of studied factors (the dependence of the milk ejection intensity from the pulsation frequency, the ratio between the stroke and the vacuum pressure) approaches to linear form. With the increase of the vacuum gauge pressure and the ratio between strokes and the pulse rate decrease, the milking machine intensity of milking was increased. The maximum milk ejection is 49 g/sec at a vacuum gauge pressure of 38 kPa, a ripple frequency of 0.67 Hz and the 2.33 ratio between the suction and compression strokes.

With increasing the ripple frequency and decreasing the duration of the suction stroke, the power consumption decreased. The maximum power consumption is 7 W at a ripple frequency of 0.67 Hz and the 2.33 ratio between the suction and compression strokes accordingly.

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