Experimental studies of duration of air pumping out from the "TEAT CUP - PULSATOR" system

Valeriy Adamchuk¹, Vasyl Dmytriv², Ihor Dmytriv²

1. National Scientific Centre "IAEE"
2. Lviv National Agrarian University, e-mail: dmytriv_ihor@ukr.net

Received July 07 2015: accepted November 10 2015

Abstract. The article analyzes the results of experimental studies of duration of air pumping out from chambers of the variable vacuum-gauge pressure in the "teat cup - pulsator" system.

The study of impact of structurally-technological parameters of milking units on the process of milk ejection and time characteristics of the operating mode was analyzed.

The methods of conducting experimental studies of transitive time characteristics of pulsator operating modes based on differentiated study of transitive processes by high-frequency scanning of vacuum-gauge pressure changes while pumping air out from the "teat cup - pulsator" system are given.

Results of the study of impact of vacuum pressure and the overflow hole diameter on the duration of air pumping out from chambers of the variable vacuum-gauge pressure system are provided. Results of experimental data are compared with theoretical ones. The analysis of results of experimental studies showed that the pulsator overflow hole diameter has the greatest effect on the duration of air pumping. By reducing the diameter, the duration of air pumping increases nonlinearly.

Due to results of comparison of theoretical and experimental studies it was found the deviation of experimental data from the theoretical modeling of the duration of air pumping out from chambers of the variable vacuum-gauge pressure in the "teat cup - pulsator" system.

The coefficient of coordination of theoretical dependencies on experimental data to calculate the duration of air pumping was calculated.

The analysis of the obtained dependencies of the duration of air pumping out from the system "teat cup - pulsator" system allowed to recommend the most rational options of the pneumatic and electromagnetic pulsator, provided that it will be provision of the mode of smooth shockless opening of milking cup teat rubber at 48 kPa vacuum pressure and the volume of variable vacuum-gauge pressure chambers of the system "teat cup - pulsator" 10⁻⁴ m³.

Key words: milking unit, pulsator, vacuum-gauge pressure, pumping duration, isolines.

INTRODUCTION

One of the problem concerning machine milking today is the disparity of operating parameters of milking units in physiological characteristics of milk ejection. This prevents rapid and complete milking. Today most advanced technical means to ensure "clean" machine milking (hand milking - not exceeding 100 g), do not provide whole cows milking (about 3 liters of alveolar milk is left in the udder)[1].

Therefore, the question of milking units improving remains an urgent problem.

One of the important components of the technological process of machine milking is a milking unit, which has a direct impact on labour productivity and intensity of milk ejection and animal health. Largely, parameters and characteristics of milking unit operation depend on the pulsator technical level.

In automated (robotic) systems milking pulsator is crucial for the realization of adaptive milking process control algorithm [2]. Thanks to these, you can achieve the regime of milking in a function from the intensity of milk ejection for each cow udder quarter by choosing the operation algorithm for functional pulsator adaptation to each teat.

Defining of reasonable pulsator structurally-technological parameters allows to control regime milking unit characteristics and stimulate milk ejection, to increase productivity and prevent the harmful effects of machine milking on a cow.

The given problem is solved provided that the adaptive pneumatic and electromagnetic pulsator, which is installed directly on the milking cup that provides adaptive mode of the teat cup of each individual udder quarter, is applied. The aim of the experimental research was checking of conclusions rightness made during theoretical [3; 4] researches.
THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Works of many researchers are dedicated to the study of the impact of structurally-technological parameters of milking units on the process of milk ejection [1-15].

In particular, A.I. Fenenko investigated changes of vacuum-gauge pressure for the milking unit DA-F-50 if the speed of milk ejection was 0-4 kg/min and there were structural sizes of operating mechanisms[5, 6].

The proposed by L.A. Kiriavtsev schematic diagram of the milking unit, which ensures the independence of milking cups operation apart with regulators of milk ejection, enables automatic change of operating mode of each milking cup of milk depending on milk ejection of the corresponding quarter of the udder and better adaptation of the milking unit to physiological requirements of milk ejection [7].

Investigating the operating process of modern automated milking units, V.T. Dmytriv developed the system of milk unit self-setting parameters according to the physiology of cow’s milk ejection [9-11]. The block diagram of the automated milking unit, which allows implementing the algorithm of self-setting parameters, is shown in (Fig. 1).

![Fig. 1. The block diagram of the automated milking unit: 1 – single chip computer; 2 – thermoanemometric indicator of milk ejection intensity; 3 – electronic pulsator; 4 – complex indicator of milk parameters (pH, temperature); 5 – milking (teat) cup; 6 – pressure sensor; 7 – multiplexer interface of digital information coding / decoding; 8 – unit of stabilized voltage; 9 – information display unit.](image)

The implementation of such a system improves the performance of both technical and biological systems and optimization of technological process of machine milking in general, by milking unit parameters setting according to cows milk ejection, which solves the problem of subsystem "machine-animal" adapting and ensures the implementation of the system of "exact livestock raising" [9-14].

V.F. Uzhyk and A.A. Belokobylyskyy while developing and justifying structural and operational parameters of milking units with controlled operating mode studied changes of vacuum-gauge pressure in the governing chamber according to the time when switching from the stimulating milking mode to the nominal one depending on the diameter of the calibration hole, the air flow through the calibration hole of the governing chamber valve and the pressure drop on it [15-17].

After analyzing the study, we should note that despite of considerable extension of pneumatic and electromagnetic pulsators of milking units, improving their constructive and technological characteristics, issues on adaptation of constructive and technological parameters to milk ejection of a cow remain unexplored and unresolved.

OBJECTIVES

The purpose is to study the duration of air pumping out from chambers of variable vacuum-gauge pressure of the system "teat cup - pulsator" for providing the shockless closing and opening of the teat cup rubber.

METHODS

According to the developed methods[18] it was conducted the planned experiment of studying of duration of air pumping in the "teat cup - pulsator" system. The main factors affecting the pumping duration are the vacuum-gauge pressure \( P_0 \), the diameter of the hole \( d_{nwp} \) through which the space of chambers of variable vacuum-gauge pressure of the system is filled with air, and the volume of chambers of variable vacuum-gauge pressure remained unchanged. To obtain the mathematical model of the experiment the noncompositional Box-Behnken design of the second order on three levels with five times repeatability of experiments was conducted. Selection of factors limits were done on the basis of real operating modes of a milking unit and according to the results of theoretical studies [19, 20]. Thus, the vacuum-gauge pressure varied from 40 kPa on the lower level to 48 kPa at the upper level with a variation interval of 4 kPa, the diameter of the overflow hole \( d_{nwp} \) - from 2 mm on the lower level to 4 mm on the upper level with a variation interval of 1 mm.

Coefficients of the regression equation were calculated and given for natural values of factors. The regression equation describing the dependence of duration \( t \) of air pumping out of chambers of the variable vacuum-gauge pressure on vacuum-gauge pressure \( P_t \) and the diameter of the overflow hole \( d_{nwp} \) in natural values is:

\[
\begin{align*}
t & = 1,8184 - 0,0752 \cdot P_t - 0,03 \cdot d_{nwp} - \\
& - 0,00135 \cdot P_t \cdot d_{nwp} + 0,001 \cdot P_t^2 + 0,0014 \cdot d_{nwp}^2
\end{align*}
\]  

Checking of reproducibility of experiments was done by comparing tabular \( G_f \) and calculation \( G_f \) values of the Cochran’s test. As the condition \( G_f \geq G_f \) was fulfilled [18; 21] – the experiments were reproducible.

The significance of the regression coefficients were tested due to Student’s t test (t-test) for the selected index of significance (0.95) and the degree of freedom [21]. After comparing each factor, it was concluded that all coefficients were significant.

Regression equation suitability to describe the real
depending of the optimization criterion on factors was performed by using the Fisher’s test (F-test) according to known methods [21-23] of conditions (2).

\[ F_p \leq F_T \; \text{– the adequate model;} \]

\[ F_p \geq F_T \; \text{– the model is not adequate, } (2) \]

where: \( F_T \) – tabular value of the F-test for the degree of freedom of the main dispersion \( f_1 = 3 \) and dispersion adequacy \( f_2 = 36 \) is \( F_T = 2.9 \) [21; 22; 23]; \( F_p \) – the calculation value of the Fisher's test will be equal \( F_p = 0.1163 \).

Taking into account that \( F_p \leq F_T \), we can state with 95% probability that this model is adequate.

Graphically, the regression equation is represented as a three-dimensional plane and shown in (Fig. 2).

It was important to assess the impact of vacuum-gauge pressure \( P_t \) and the diameter of the overflow hole \( d_{\text{up}} \) on the duration of air pumping out of chambers of the variable vacuum-gauge pressure of the "teat cup-pulsator" system.

![Fig. 2. Dependence of the duration \( t \) of air pumping out from chambers of the variable vacuum-gauge pressure of the "teat cup-pulsator" system on the diameter of the overflow hole \( d_{\text{up}} \) and the vacuum-gauge pressure \( P_t \).](image)

To build isolines on the factor plane \((x_1, x_2)\), the regression equation was solved (1) as a quadratic equation. Building of isolines was done using the following algorithm:

a) we chose several sections of the factor space (usually 6 sections are sufficient if \( x_1 = 0; \; x_1 = \pm 1; \; x_2 = 0; \; x_2 = \pm 1 \));

b) by substituting into the equation the functions of values recall \( 0, \pm 1 \) for one of the factors \( x_j \) \((j = 1, 2)\) were found for each intersection of the equation after bringing similar terms:

\[ y(x_j) = b_0 + b'_1 \cdot x_j + b'_2 \cdot x_j^2 \; (i = 1, 2). \]  \( (3) \)

a) we found a solution to this equation:

\[ x_j(x_i) = \frac{-b'}{2b''} \pm \frac{1}{b''} \left( y(x_i) - \frac{b'_0 - \frac{b'^2}{4b''}}{b''} \right). \]  \( (4) \)

d) we substituted the values \( y(x_i) \) for a given isoline in the equation of the intersection, and determined the coordinates of the appropriate intersection points with the intersection \( x_i \).

### THE MAIN RESULTS OF THE RESEARCH

Results of construction of two-dimensional sections of the response function are shown in (Fig. 3).

![Fig. 3. The impact of vacuum-gauge pressure \( P_t \) and the diameter of the overflow hole \( d_{\text{up}} \) on the duration \( t \) of air pumping out from chambers of the variable vacuum-gauge pressure of the "teat cup-pulsator" system.](image)

Analysis of the obtained surfaces showed that the diameter of the overflow hole had the greatest impact on the duration of air pumping. If we reduce it, the duration of air pumping increases nonlinearly.

When comparing the theoretical and experimental results of the research (Fig. 4), some deviation was detected.

![Fig. 4. Dependence of the duration \( t \) of air pumping out from chambers of the variable vacuum-gauge pressure on the vacuum-gauge pressure \( P_t \) and the diameter of the overflow hole \( d_{\text{up}} \).](image)

Thus, the deviation of experimental data from the theoretical modeling [3] of duration of air pumping out from chambers of the variable vacuum-gauge pressure of the "teat cup-pulsator" system is in the range from 0.2% to 26.4%. When the vacuum-gauge pressure was \( P_t = 40 \) kPa and the diameter of the overflow hole \( d_{\text{up}} = 2 \) mm, the deviation of theoretical data from experimental ones was 22.4%. When the vacuum-gauge pressure was \( P_t = 48 \) kPa and the diameter of the overflow hole \( d_{\text{up}} = 2 - 4 \) mm, the deviation of theoretical data from experimental ones was 13 - 17.8%.

This is because when calculating the duration of air pumping with the use of the mathematical model while modeling the speed coefficient, the mode of air flow through the overflow hole was chosen approximately and the pressure loss coefficient was calculated with deviations, which led to the deviations of theoretical data from experimental ones.
To coordinate theoretical dependences with experimental data we enter the coefficient 1.18 into the equation of modeling of duration of air pumping out from chambers of the variable vacuum-gauge pressure of the "teat cup-pulsator" system.

CONCLUSIONS

The results of experimental studies confirmed the theoretical studies. It was established that duration of air pumping out from chambers of the variable vacuum-gauge pressure of the "teat cup-pulsator" system increased with reducing of the diameter of the pulsator overflow hole \( d_{\text{sup}} \) and with increasing of vacuum-gauge pressure.

Analysis of the obtained dependencies enables to recommend rational parameters of pneumatic and electromagnetic pulsator providing the shockless smooth closing and opening of a teat cup rubber at the vacuum-gauge pressure \( P = 48 \text{ kPa} \) and the volume of chambers of variable vacuum-gauge pressure of the "teat cup-pulsator" system \( V = 10^{-3} \text{ m}^3 \).

For the duration \( t \) of air pumping out from chambers of the variable vacuum-gauge pressure set in the range of 0.16 to 0.17 s, the diameter of the pulsator overflow hole must be within \( d_{\text{sup}} = 3-3.2 \text{ mm} \).

REFERENCES


