JUSTIFICATION OF MACHINE MILKING PHYSIOLOGICAL PRINCIPLES

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Abstract. The article summarises the world experience of studying the issue of the negative mechanical impact of milking equipment on the health of cows in the process of machine milking. The design, principle of operation and results of experimental studies the special inserts for serial milking cups and teat rubber are presented. Special inserts for liners and milking cups ensure the implementation of physiologically safe principles of machine milking. Compared to a conventional two-chamber teat cup, the teat cup insert ensures pressure equalisation in the teat and interwall spaces during the sucking phase, while the rubber insert reduces the vacuum pressure in the teat space during the compression phase compared to the pressure in the collector chamber. The most common teat liner today has a circular cross-section and is characterised by a sharp transition from the sucking phase to the compression phase, when its cylindrical shell loses stability under the influence of evenly distributed pressure in the intercellular space of the milking cup. In addition, during the compression phase, at the point of closure such a liner has a cross-section in the form of a figure eight, which means that it does not completely disconnect the teat space from the vacuum pressure, which leads to injury to the tip of the teat, especially during dry milking. It was found that when using nipple liners with an insert, the vacuum pressure in the teat spaces of milking cups increases to 17-18 kPa throughout the entire milking period. The pressure in the milk collection chamber of the collector rises to 20-22 kPa. Such indicators largely correspond to the natural suckling of a calf. During production trials over 30 days, the percentage of cows with mastitis decreased by 1.5% and the milk yields increased by 2.2%.

Keywords: milking, phase, vacuum pressure, mastitis decrease.

Introduction

The high level of morbidity and culling of cows due to mastitis is a worldwide problem and is inherent in farms with different levels of technical support. The main prerequisite for the disease mastitis is the intensive mechanical impact of the udder rubber during machine milking, which is due to its design parameters. The presence of constant rarefaction in the udder space is also a significant factor of negative influence, especially at the end of milking when milk production stops. As a result, in the conditions of milk production farms, there is a stock of injured cows with injuries and hyperkeratosis of udders, which contributes to the entry of pathogenic bacteria into the animal's body and the emergence of various diseases. Papers [1; 2] present studies of teat liner suitability for milking at different values of vacuum pressure in the teat space of milking cups. It has been established that wear of the liner occurs faster with more frequent changes in pressure. In works [3-5] the creep of teat liners during milking was studied. Studies have shown that if the operating modes of the milking machine do not match, the milking cups creep onto the teats, which subsequently leads to disease and a loss of milk productivity of up to 9%. In paper [6], the maximum fluctuation of the vacuum pressure in the interwall space of the milking cups was studied, which is 28 kPa at a milk yield intensity of 45 sec^{-1} and a pulsation frequency of 1 Hz. At the same time, the ratio of suction and compression cycles is 0.67. Vacuum fluctuations in the interwall chamber of the milking cups increase with an increase in the frequency of pulsation and a decrease in the duration of the suction stroke. It has been established that due to clinical mastitis, the productivity of cows drops sharply, and milk is excreted as waste within three to four days [7; 8].

For every clinical case of mastitis, there are 20 to 40 subclinical cases, and the decline in productivity is longer and generally leads to significantly greater losses compared to clinical mastitis [9; 10]. Vacuum in the cup chamber indicates the cessation of milk supply flow and serves as an indicator of a decrease in the vacuum at the end of the nipple by a quarter of a level. At the same time, there is a negative effect that contributes to the penetration of pathogenic microorganisms into the milk duct. The use of worn-out rubber leads to a loss of up to 5% of the product [11]. Accordingly, we can draw an unequivocal conclusion that the main reason for the occurrence of various types of mastitis is the negative mechanical impact of milking equipment due to the inconsistency of the structural and technological parameters and modes of operation of the milking equipment to the physiological conditions of milk production.

Materials and methods

According to the results of generalization of the experience of creating physiologically safe equipment for machine milking of cows, it was established that the main factors of negative mechanical impact in the process of machine milking are the impacts of the teat rubber during the transition from the sucking stroke to the compression stroke and the continuation of intensive mechanical impact after stopping the milk yield (“dry milking”). Currently, the backflow of milk from the milk collection chamber of the collector to the teat space, which occurs because of violation of the operation of the milking machine, has a significant impact on the intensity of the spread of mastitis. To minimize the negative impact of vacuum pressure on the tip of the teat after the end of milking, technical means of individual control of the milk flow are created for each teat, and these means also provide differential disconnection of each teat space from the intense impact of vacuum pressure at the end of milking, when there is no milk flow. The most widespread today is the rubber of round cross-section. The peculiarity of its work is the jump-like transition from the suction stroke to the compression stroke, when its cylindrical shell loses stability under the influence of the growth of evenly distributed pressure in the interwall space of the milking cup. In addition, during the compression stroke at the point of closure, such a rubber has a cross-section in the shape of an eight, therefore, it does not ensure a complete disconnection of the teat space from the effect of vacuum pressure, and this leads to hyperaemia of the tip of the teat, especially when “dry milking” takes place. According to zootechnical standards, it is allowed to use rubber with a closing vacuum of 5.3-12 kPa and an elongation of 20-35 mm. The value of the vacuum of its closure depends on the amount of tension of the rubber. The tension of the rubber liner forms the character of the closing - smooth or closing with an impact.

As the analysis of literary sources showed, a feature of the operation of the teat liner of the milking machine is a jump-like transition from the sucking cycle to the compression cycle. The elastic properties of the nipple rubber are characterized by the value of the vacuum closing of its walls during the “compression” cycle, which should be p - 6 ... 11 kPa and depends on the modulus of elasticity of the material from which the nipple rubber is made. The basis for the creation of the experimental installation was the use of elements of the experimental stand intended for testing of milking machines. The stand consists of a milk yield simulator, an artificial udder, means of regulating the intensity of milk output and air flow, a vacuum unit with a vacuum line, vacuum gauges, membrane strain gauges of vacuum gauge pressure. The input parameters of the experiment were: the vacuum pressure in the interwall space of the milking cup of 40, 45 and 50 kPa, the mode of operation of the pulsator (alternate or simultaneous) and the configuration of special inserts. Special inserts for serial milking rubber and for the sleeve of the milking cup, Fig. 1, 2, 3, were developed and researched at IMA APV NAAN.

Fig. 1. **Milking cup with insert**

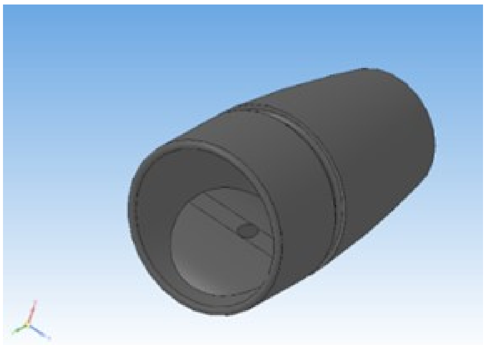

Fig. 2. **3D models of special insert for a milking cup**

One of the simplest technical solutions that can be effective in preventing the mechanical blocking of milk flow at the base of the teat is the use of mechanical teat rubber restrictors. Engineers develop and carry out research on special inserts for serial milking rubber and for the sleeve of the milking cup. Fig. 1 shows a milking cup with an insert. This is a plastic insert that is inserted into the milking cup in the teat. Fig. 2 also shows the insert of the milking cup, which was designed in the AutoCAD system and made on a 3D printer. The theoretical calculations of the insert are protected by a patent for the invention and are not deliberately distributed. Fig. 3 shows an insert for the rubber.

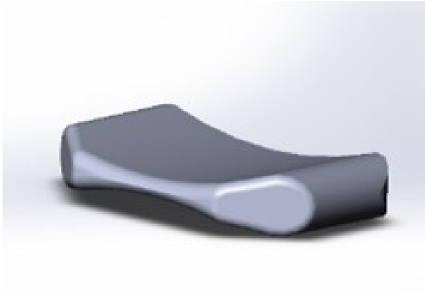

Fig. 3. **3D models of special insert for milking liner**

Theoretical calculations confirm that, compared to a typical two-chamber teat cup, the teat cup sleeve insert provides equalization of pressure in the teat and interwall spaces in the sucking stroke, and the teat rubber insert creates an elliptical cross section of the teat rubber, eliminates the negative effect of the jump to the compression stroke and provides complete separation of the pallet space from the influence of vacuum pressure during the compression stroke.

Results and discussion

The conducted experimental studies confirm the adequacy of theoretical studies. The main control criteria are the pressure in the teat space of the milking cup line 1, the pressure in the milk collection chamber of the collector line 2, and the pressure in the interwall space of the milking cup line 3. Fig. 4 and 5 show comparative diagrams of the pressure dynamics of a typical milking cup and a cup with a milking rubber with an insert, provided that paired pulsators are used. The change in pressure in the spaces of the milking cup when using a pulsator of simultaneous action most closely corresponds to the natural sucking of the calf.

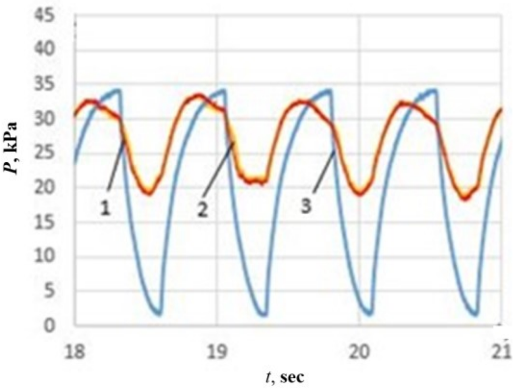

Fig. 4. **Pulsator of simultaneous action. Milking cup with an insert**

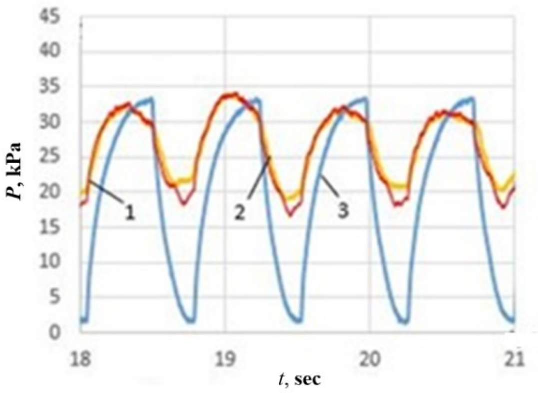

Fig. 5. **Pulsator of simultaneous action. Milking cup without an insert**

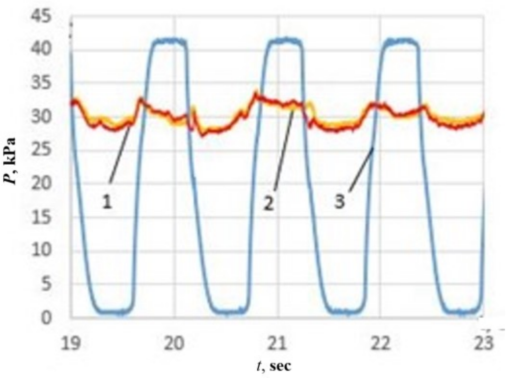

Fig. 7. **Alternate pulsation. Milking cup with an insert**

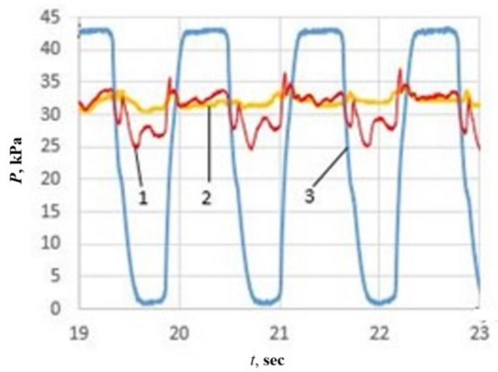

Fig. 8. **Alternate pulsation. Milking cup without an insert**

The main purpose of pulsation is to limit the formation of stagnant phenomena and swelling in teat tissue during machine milking [12]. However, the function of pulsation in the teat cup is to compress the end of the liner, which supports the return flow of blood and lymph through the veins and lymphatics during milking. Thus, vacuum pulsation and the pulsation coefficient are important operating parameters that affect milking performance [13]. However, it is well known that the pulsation coefficient has a significant effect on the milking rate, milking time, and teat condition. Most modern milking equipment manufacturers set their pulsators in a relatively small range of about 60:40 [14] because milking speed has been optimized by keeping the liner open for about 0.5-0.6 s during each cycle [14; 15]. However, the maximum rate of milk flow reaches its maximum at a pulsation ratio in the range from 60:40 to 70:30, depending on the properties of the liners used [14; 16]. In addition, studies have shown that the peak milk flow rate steadily decreases after 70:30 to 80:20. The reason may be insufficient duration of pressure to overcome the load of nipple blockage [15]. It is worth noting that the correct setting of the pulsation factor allows the pulsation chamber to recover to full atmospheric pressure for at least 150 milliseconds (d-phase) (15%) on each cycle. This helps avoid teat clogging when using vacuum milking machines [16]. When using a milking machine with a simultaneous action pulsator, there is a maximum smoothing of the discrepancy in the change of the vacuum pressure compared to a milking machine without an insert. At the same time, the rarefaction pressure in the milking spaces of the milking cups increases to 17-18 kPa during the entire milking period in comparison with a milking machine with a paired pulsator. The pressure in the milk collection chamber of the collector rises to 20-22 kPa.

Conclusions

1. It was established that when using nipple liners with a liner, the pressure of rarefaction in the milking spaces of the milking cups increases to 17-18 kPa during the entire milking period. At the same time, the change in the vacuum pressure in the subdual space changes more smoothly.
2. The pressure in the milk collection chamber of the collector rises to 20-22 kPa. Such indicators largely correspond to the natural sucking of the calf.
3. In general, it has been proven that the operation of the milking machine with a simultaneous pulsator best meets the zootechnical requirements of the operation of the milking machine. The use of special inserts allows to increase the pressure fluctuations during the suction stroke in the interwall and subiliac space to the level of 17-18 kPa.
4. The production tests were carried out for 30 days in the experimental farm. The tests showed a decrease in the incidence of mastitis in cows by 1.5%, while milking yields increased by 2.2%.

Author contributions

Conceptualization, V.T. and V.A.; methodology, V.T. and V.B.; software, O.A.; formal analysis, V.A and O.A..; investigation, V.T., V.B., V.A. and O.A.; writing – original draft preparation, V.T and V.A.; writing – review and editing, V.B. and O.A. All authors have read and agreed to the published version of the manuscript.

References

[1] Shehadeh K., Michael W., Milking Machine Settings and Liner Design Are Important to Improve Milking Efficiency and Lactating Animal Welfare – Technical Note. Agri Engineering, vol.5, 2023, pp. 1314-1326.
[2] Wieland M., Sipka A, Prospective cohort study of the relationship between milking machine liner slip, milking performance, and cow characteristics. J. Dairy Sci. vol. 106, 202, pp. 2044–2053.
[3] Wieland M., Spellman M., Kerry L., Geary C. Comparison of Sensor-Based and Audible Detection of Milking Liner Slips during Machine Milking of Dairy Cows. Sensors. Vol. 24, 2024, pp. 1361.
[4] Yatsunskyi P. The pressure oscillation in the inter-wall chamber of the teat cup. Ukrainian journal of mechanical engineering and materials science. vol. 7, 2021, pp. 3-4.
[5] Aliiev E., Paliy A.. Establishing an interconnection between the technical and technological parameters of milking equipment based on the movement of a milk-air mixture in a milking machine. Eastern-European Journal of Enterprise Technologies. vol. 2/1 (116), 2022.

[6] Schlapbach K., Khatun M., Paulrud C., Bruckmaier R. The mouthpiece chamber vacuum pattern indicates the cessation of milk flow and suits as an indicator to reduce teat end vacuum at a quarter level. J. Dairy Sci. vol. 107, 2021, pp. 1778-1787.
[7] Medvedskyi, O. Achkevych, O. Achkevych, V. Dynamics of the vacuummetric pressure of the dairy chamber of the collector of milking machine. Scientific Horizons, vol. 5, 2019, pp. 51-57.
[8] Stauffer C., Feierabend M., Bruckmaier R. Different vacuum levels, vacuum reduction during low milk flow, and different cluster detachment levels affect milking performance and teat condition in dairy cows. J. Dairy Sci. vol. 103, 2020, pp. 9250-9260.
[9] Holst G., Adrion F., Umstätter C., Bruckmaier R. Type of teat cup liner and cluster ventilation affect vacuum conditions in the liner and milking performance in dairy cows. J. Dairy Sci. vol. 104, 2020, pp. 4775-4786.
[10] Reinemann D., Borne B., Hogeveen H., Wiedemann M., Paulrud C. Effects of flow-controlled vacuum on milking performance and teat condition in a rotary milking parlor. J. Dairy Sci. vol. 104, 2020, pp. 6820-6831.
[11] Tuor M., Jenni B., Wellnitz O., Bruckmaier R. Reduced liner-open phase and vacuum instead of prestimulation increase parlor efficiency in dairy cows. J. Dairy Sci. vol. 105, 2022, pp.1533-1541.
[12] Dmytriv V.T., Dmytriv I.V., Yatsunskyi P.P. Experimental pulse generator combined with the milking machine collector. INMATEH - Agricultural Engineering, 2019, 59 (3), pp. 219-226.
[13] Achkevych O., Achkevych V., Bratishko V., Potapova S. Justification of rational design parameters of milking machine for installations with milk line system. Engineering for Rural Development, 2020, 19, pp. 1313-1318.
[14] Dmytriv I.V. The functional controlability of milk ejection of the adaptive milking system. INMATEH - Agricultural Engineering, 2021, 65 (3), pp. 399-409.
[15] Adriaens I., Huybrechts T., Aernouts B., Geerinckx K., Piepers S., De Ketelaere B., Saeys W. Method for short-term prediction of milk yield at the quarter level to improve udder health monitoring. Journal of Dairy Science, 2018, 101 (11), pp. 10327-10336.
[16] Besier J., Bruckmaier R.M. Vacuum levels and milk-flow-dependent vacuum drops affect machine milking performance and teat condition in dairy cows. Journal of Dairy Science, 2016, 99 (4), pp. 3096-3102.