ISSN 2083-1587; e-ISSN 2449-5999
2022,Vol. 26,No.1, pp.243-252
Agricultural Engineering
www.wir.ptir.org
DOI: 10.2478/agriceng-2022-0019

SIMULATION OF DESIGN PARAMETERS OF A MILKING CUP WITH AN EXTENDED SERVICE LIFE

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ARTICLE INFO

Article history:
Received: September 2022
Received in the revised form: November 2022
Accepted: November 2022

ABSTRACT

Modern milking machines need some additional studies to meet the requirements as to milking equipment. An imperfect design of a teatcup results in an incomplete milking of cows. The availability of devices for milk flow stimulation promotes an increase in a cow milk yielding capacity. But here arises a problem of an un-

Keywords:
milking,
teatcup,
cow,
milk

controlled axial motion of a teatcup on a teat. As a result, a full milkflow is reduced, particularly at the final stages of milking. There is an effect of an increase in an inner diameter of a liner barrel, which causes that teatcups fall down. A scientific problem of the mitigation of some negative developments with the view to improve the efficiency of a teatcup arises. In a teatcup shell a liner is in a detended position during milking and resting periods. Thus, it under constant stretching. It results in a loss of elasticity irrespective of the material, as well as in reduction ofthe period of service maintenance. The use of a device for supporting a liner which is in a stretched state only during the milkflow, will result in an increase of a teatcup efficiency. The suggested automatic pneumatic mechanism releases a liner from the load during the resting period. The dependence of a tension force of a liner from the surface area of an annular membrane has been established. It has been proven that the membrane surface of 0.00065 m^2 provides tension for a mechanism performance irrespective of operating vacuum pressure. The regression equation which connects geometrical parameters of an operating system with the efforts directed at the opening of a leading membrane has been received. A suitability of operation of using a pneumatic tightening device has been substantiated. An insignificant axial motion of a liner during a cycle of milking creates a stimulating effect. As a result, a completeness of miliking increases by 3-8%.

Introduction

A teatcup is the most important part of a milking machine as it provides a direct contact with an animal. Therefore, a teatcup design has a significant impact on the effectiveness of cow milking. A teatcup design from leading manufactures of milking equipment has a one type two-chamber structure. As considered (Reinemann, 2019; Penry et al., 2018), a two-chamber teatcup provides a high rate of milking. An adaptation of a liner to the parts of an udder, which are different by size, is a positive characteristic of such a design (Reinemann, 2019). It facilitates a free opening of a teat sphincter that ensures full milking (Besier and Bruckmaier, 2016; Gutsol et al., 2019). It has been established that the last portions of milk are of the highest fat content, which improves the final product quality (Besier and Bruckmaier, 2016; Upton et al., 2016).

A simplicity of a construction design results in a wide use of two-chamber milking machines (Peychev and Dineva, 2020). Besides, they are characterised by simplicity of operation and service. But there are some shortcomings of a two-chamber teatcup, which are caused by a design simplicity. Thus, there is an effect of an increase in an inner diameter of a liner caused by a violation of an operating mode of a milking machine. An axial motion of a teatcup, which slows down the milking process, can be observed at the final stage of machine milking.

A liner is the main operating element of a teatcup. The use of modern materials provides some comfort to cows during milking. The milking cup overall duration depends on the preservation of the elastic properties of liner material. A fixed state of a liner in a teatcup muff speeds up the loss of its elastic properties. Thus, the effectiveness of machine milking reduces and the cow teats get injured. An extended service life of a liner will reduce the amount of service actions as well as the operating costs of a milking machine.

While studying the negative properties of a two-chamber teatcup, the researchers (Gleeson et al., 2004**)** suggested their own design. The purpose of the invention is to avoid an axial motion along the cow's teat. The positive effect can be caused by using an additional inner cylinder. The suggested decision can be considered acceptable, because a full milking can be achieved without additional service actions. A complicated design as to machine operation and service is the main shortcoming. Besides, there is no mechanism of stimulating the transformations and change settings.

The researchers (Patent 95214 Ukraine, 2011) suggest the design of a teatcup with a mechanism of changing the liner position. During the cow milking the liner is fixed in an operating state. After milking the retainer is removed and the liner is in a free state. A free state of a liner between the periods of cow milking helps to extend the term of its use. It happens due to preservation of the elastic properties of the liner material. But the mechanism is put into action by a milking machine operator. Some additional time is spent and it levels the received positive effect (Holst et al., 2021; Esin, 2021).

The search for possible ways of improving the teatcup indicates relevance of the given issues. The developing of a mechanism of an automatic regulation of liner elasticity in order to increase the interservice life of a teatcup is an unsolved scientific problem. In this case a positive effect is achieved together with a simultaneous reduction of the operating costs (Kiktev et al., 2021; Khort et al., 2022).

Materials and methods

The authors of the research developed a design of a teatcup (Fig. 1) with an automatic mechanism of changing the liner position. Thus, during the milking process the liner is in a working state and during the rest of the time it is in a free state. Therefore, the liner elasticity is maintained longer. Besides, you can get rid of an axial motion of a teatcup at the final stages of cows machine milking.

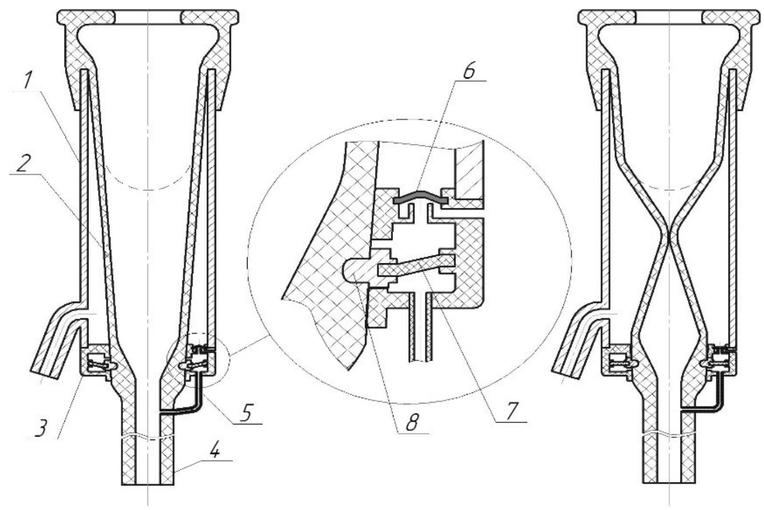

Figure 1. Scheme of the developed teatcup: 1 – shell; 2 – liner barrel; 3 – the proposed mechanism; 4 – shot milk tube; 5 – thin tube; 6 – control membrane; 7 – annular membrane; 8 – ring (authors research)

The main purpose of studying the developed adjusting mechanism of a teatcup is to determine the geometric parameters and the technological modes of the operation. So, it is necessary to perform the simulation of the impact of the working pressure dynamics and to set power characteristics of the working elements of a developed mechanism.

The research was conducted using the known theories of mathematic simulation when using some provisions of an integral and differential calculus, pneumatics and technical mechanics. The structural and functional diagrams of a control mechanism of a teatcup are the objects of the research.

A suggested design solution requires solving some scientific problems. First of all it is necessary to substantiate the design and the technological parameters as well as the dynamic characteristics of a developed mechanism.

Results and discussion

The force, which directs the liner down, acts on an annular membrane during the suckling stroke (Fig. 2a). This force is formed due to the effects of pressures in an upper chamber p_u and under an annular membrane p_n.

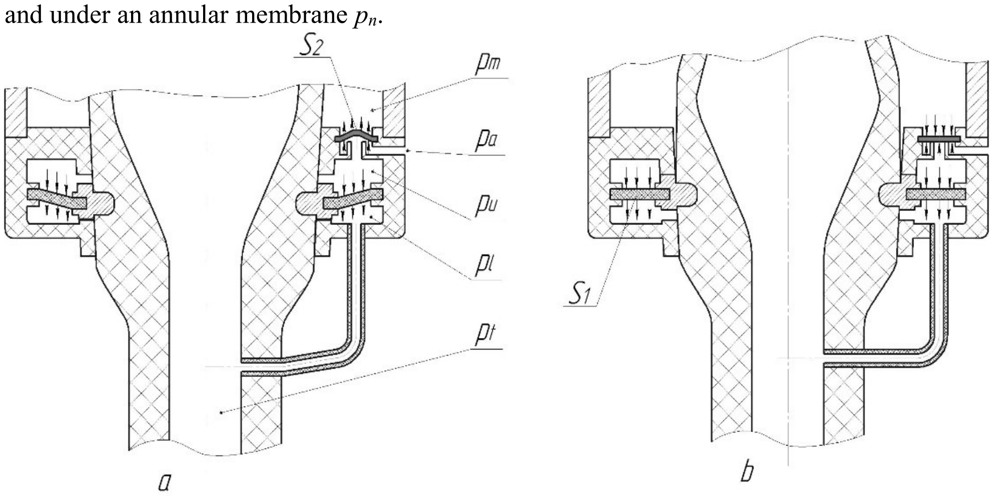

Figure 2. Force analysis of a developed device: p_a – atmospheric pressure; p_m – pressure in the space between a shell and the liner barrel; p_t – pressure in the space under the teat; p_u – pressure over the an annular membrane; p_l – pressure under the annular membrane (authors' own research)

The force which bends an annular membrane down, equals:

$$F_1 = F_u + F_l, \tag{1}$$

where:

F_u – the force which acts on the membrane from the upper chamber, (H)

F_l – the force which acts on the membrane from the lower chamber, (H)

Taking into account that the force is determined as a result of multiplication of pressure by the area of action of this pressure (Medvedskyi et al., 2018; Penry et al., 2018), the equation (1) is as follows:

$$F_1 = S_1 \cdot (p_u + p_l), \tag{2}$$

where:
S_l – the area of an annular membrane, (m^2)
p_l – pressure under an annular membrane, (Pa)
p_u – pressure above an annular membrane, (Pa)

According to the equation (2) a graphic dependence of the effects of geometric parameters of a membrane on the pressure force (Fig. 3) have been received.

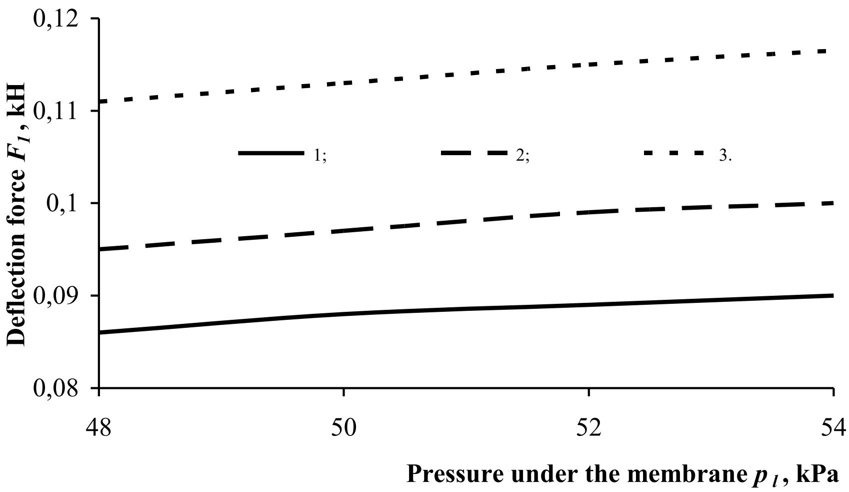

Figure 3. Magnitude of deflection force F_l according to pressure under the membrane p_l provided its working area: 1 – S_l=0.00055 m^2; 2 – S_l=0.00065 m^2; 3 – S_l=0.00075 m^2 (authors' own research)

The analysis of graphic dependences (Fig. 3) shows an increase in the deflection force of an annular membrane F_l alongside the increase in its area S_l. When pressure under the membrane p_l increases, a slight increase in pressure force can be noticed, which is essential for further studies. The force of elasticity of the material from which an annular membrane is made of, prevents its deflection. The force, which directs the membrane upword, can be determined taking into account the recommendations (Holst et al., 2021):

$$F_2 = S_1 \cdot p_u \cdot \lambda_1, \tag{3}$$

where:

λ_1 – the coefficient, which takes into account the elastic properties of a membrane, is detrmined by the formula (Golub et. al., 2018):

$$\lambda_1 = \frac{\frac{1}{3} + \frac{d_u}{d_l} + \left(\frac{d_u}{d_l}\right)^2}{1 + \frac{2d_u}{d_l} + (\frac{d_u}{d_l})^2}, \tag{4}$$

where:

d_u – upper diameter of an annular membrane, (m)
d_l – lower diameter of an annular membrane, (m)

Providing the diameters are equal, the correlation $d_u/d_l=1$ is received, at which the coefficient of elasticity of a membrane material equals $\lambda_1=0.583$ (Reinemann, 2019). If the correlation of diameters is more than one, the elasticity coefficient will increase, and if it is less than one – it will decrease. Thus, the deflection force of a membrane is determined by its geometric parameters.

Liner tension force during a suckling stroke can be determined by the formula:

$$F_b = F_u + F_l - F_2. \tag{5}$$

If we substitute the values of the equation (2) and (3) into the equation (5), we will receive a graphic dependence (Fig. 4) and a complete record of the quation:

$$F_b = S_1 \cdot \left[\left(p_u + p_l \right) - p_u \cdot \lambda_1 \right]. \tag{6}$$

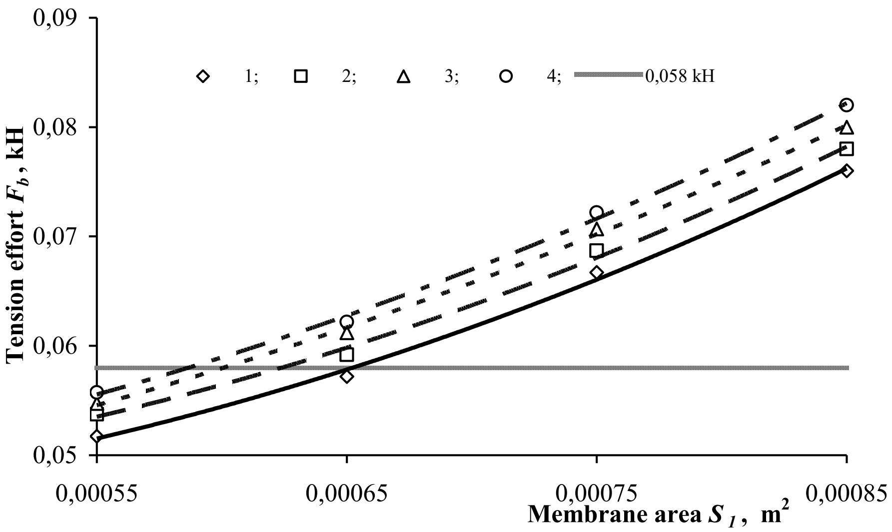

Figure 4. The effect of an annular membrane area S_1 on tension effort F_b of a liner under condition of a minimum permissible force 0.058 kH and the pressure under the membrane: 1 – p_l=47 kPa; 2 – p_l=50 kPa; 3 – p_l=52 kPa; 4 – p_l=54 kPa (authors research)

Tension forces F_b of a liner must exceed a minimal permissible efforts of overcoming the resistance of tension forces of a liner which equals 0.058 kH. When the membrane area increases from 0.00055 m^2 to 0.00075 m^2, the impact efforts on a liner increases by 46-47%, which can be considered as a control factor of the research. When the working pressure equals 54 kPa, a minimal permissible area of an annular membrane must be not less than S_l=0.00058 m^2 (Fig. 4).

When milk is flowing, a control membrane S_2 (Fig. 2a) is in an open state. The force which keeps the membrane S_2 in an open state depends on its geometric parameters (Fig. 5) and can be determined by establishing the equilibrium equation:

$$F_3 = 0,785 \cdot d_{S2}^2 \cdot \left[\left(p_m + p_a \right) - P_m \cdot \lambda_2 \right], \tag{7}$$

where:

- p_m – pressure in the space between the muff and the liner, (Pa)
- d_{S2} – diameter of a control membrane, (m)
- p_a – pressure under a control membrane, (Pa)
- λ_2 – coefficient which takes into account elastic properties of a control membrane material (Reinemann, 2019).

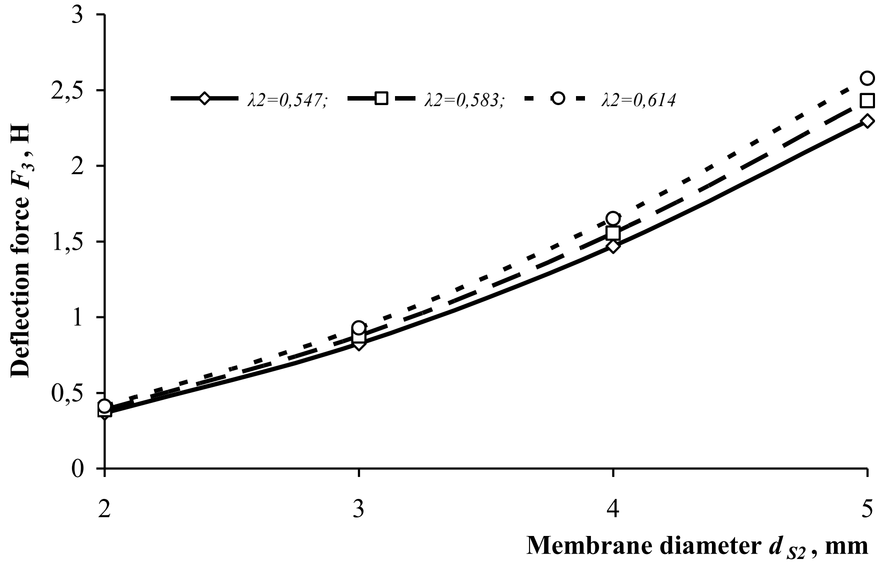

Figure 5. Dependence of a deflection force F_3 of a control membrane on its diameter d_{S2} under the operating pressure of 54 kPa at different coefficient values λ_2 (authors' own research)

Under different coefficient values λ_2 (Fig. 5), the force F_3 of a membrane opening is proportional to an increase in its diameter d_{S2} in the direction of a lower space of a control membrane.

As follows from the research results, a received regression equation, which characterises the relationship between the geometric parameters of a control membrane and the force of its deflection, is as follows:

$$F_3 = 0,0972 \cdot d_{S2}^2 + 0,194 \cdot d_{S2} + 0,0978. \quad (8)$$

Equation (8) has a high approximation index R^2=0.999, that testifies to the reliability of the received results.

When no milk is flowing (Fig. 2b) a control membrane S_2 bends down with a force which equals 0.38 H. In this case an air access into the space above an annular membrane is stopped. A control membrane S_2 will be closed when no milk is flowing, and an annular membrane S_1 will take a horizontal position. In the moment when milk will start to flow, a control membrane will open and the process will repeat again. When a milking machine is disconnected from a vacuum source, the same external pressure will act on both sides of an annular membrane. Under such conditions a liner will be in a free state, that will promote to an extension of its service life.

Conclusions

1. Serial milking machines are equipped with teatcups which do not ensure the compliance with some requirements as to cows milking regulations. It is, first of all, axial motion which requires some additional service actions after milking process completion. A fixed state of a liner in a teatcup muff is typical for modern milking machines designs. In this case a liner is constantly under tension and stretch. As a result, a liner loses its elasticity untimely, that results in reduction of its service life. The known scientific research do not allow to solve the problem of extending the service life of a liner.
2. The authors' research has established the need for a teatcup improvement. For this purpose, a pneumatic device of an automatic tension of a liner has been developed. A positive effect is achieved due to the reduction of the periods of validity of tensile forces. A liner is in an operating state only during a cow machine milking. On the completion of a machine milking process, all tensile forces are taken off from a liner. A suggested decision can solve the problem of extending the operational resource of the material, of which the liner is made.
3. The research has established the relationship between the geometric parameters of a developed mechanism and power characteristics of the operating elements. It has been proven that the area of an annular membrane of a developed mechanism must be not less than 0.00065 m^2. In this case the working vacuum pressure level will not affect the efficiency of a device operation. The regression equation, which connects the geometric parameters of a control system with a force characteristics of the operating elements, has been received. It has been established that an insignificant axial motion of a teatcup during a suckling stroke creates an additional stimulating effect. As a result, a more complete excretion of milk from the cow udder can be achieved.

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SYMULACJA PARAMETRÓW PROJEKTOWYCH KUBKA UDOJOWEGO O PRZEDŁUŻONEJ ŻYWOTNOŚCI

Streszczenie. Współczesne maszyny udojowe wymagają prowadzenia dalszych badań, aby sprostać wymaganiom sprzętu udojowego. Nieidealny project kubka udojowego wpływa na niezupełny wydój krów. Dostępność urządzeń do stymulacji przepływu mleka zwiększa wydajność udoju. Jednak, pojawia się problem niekontrolowanego ruchu osiowego kubka udojowego na strzyku krowy. W rezultacie, przepływ mleka jest zmniejszony, szczególnie na końcowych etapach udoju. Dochodzi do zwiększenia wewnętrznej średnicy gumy strzykowej co powoduje odpadanie kubków udojowych. Pojawia się kwestia złagodzenia niektórych negatywnych skutków aby ulepszyć wydajność kubków udojowych. W kubku udojowym, guma strzykowa znajduje się w pozycji odprężenia podczas dojenia i spoczynku. Dlatego podlega ciągłemu rozciąganiu. Powoduje to zmniejszenie elastyczności bez względu na materiał a także skrócenie okresu serwisowego. Zastosowanie urządzenia do potrzymania gumy, która znajduje się w stanie rozciągnięcia tylko podczas przepływu mleka, spowoduje zwiększenie wydajności kubka udojowego. Zaproponowany automatyczny mechanizm pneumatyczny zwalnia gumę od obciążenia podczas okresu spoczynku. Ustalono zależność siły napięcia gumy od powierzchni membrany pierścieniowej. Udowodniono, że powierzchnia membrany 0.00065 m^2 dostarcza napięcia mechanizmowi bez względu na podciśnienie robocze. Otrzymano równanie regresji, które łączy parametry geometryczne systemu roboczego z wysiłkiem skierowanym na otwarcie membrany. Potwierdzono odpowiedniość działania przy zastosowaniu pneumatycznego urządzenia zacieśniającego. Nieznaczący ruch osiowy gumy podczas dojenia stwarza efekt stymulujący. W rezultacie kompletność udoju zwiększa się o 3-8%.

Słowa kluczowe: dojenie, kubek udojowy, krowa, mleko