The working process of the device for combined massage of the udder of heifers

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Abstract. The article discusses the concept of a unified approach to the development of pneumomechanical massage devices and milking machines. The practical implementation of this approach is considered. An improved pneumomechanical massage device is proposed. The main function is assigned to reduced pressure (vacuum) when performing technological operations of udder massage. The mechanical component of the device fulfills auxiliary function. The presence of an independent element in the suggested structural scheme of the device for the combined massage of heifers' udders is substantiated. The change of pressure is fulfilled by a principle of counter-phase in a massage bell. This technical solution allows to increase efficiency of unloading cycle and to provide full restoration of blood circulation in the udder of an animal. The analysis of working process of the massage devices is carried out. An analysis of pressure changes in massage devices was made, a diagram of pressure changes in a massage bell and in a massage element of the device is drawn. The proposed design will eliminate the disadvantages of the device for pneumatic massage of the udder of heifers. The device allows regulation of pneumatic massage parameters for massage bell and massage element in limits of 20-25 and 40-48 kPa respectively.

1. Introduction

One of the most energy-intensive and technologically demanding processes in milk production is machine milking of cows. This is demonstrated by the fact that for the milking of, for example, 100 cows a vacuum pump drive of 3-4 kW should be operated for 6-8 hours per day.

Technological complexity of machine milking lies in the necessity of interaction of mechanization of the process (milking machine) with relatively constant working parameters with a biological object, which in a relatively short period of time significantly changes its requirements for quality of service. For example, in the period of accustoming first-calf cows to a milking machine, when their body has not yet recovered from the physiological stress (calving), the animals are forced to adapt to another stress - the technological one.

An option to solve this problem is to accustom the animals to the milking machine at an early stage of life. And also with a relatively mild mammary gland exposure option. For this purpose, heifers are prepared for future lactation with the help of special technical means 2-3 months prior to calving. These technical aids ensure that the animals are more easily accustomed to the milking equipment at the right period and also promote the growth and development of their mammary gland.

Despite numerous studies that have been done in the field of udder massage for heifers, acceptable results for real production have still not been obtained.
The analysis of the works performed to date [1, 2, 3] indicates the relevance of the scientific concept based on a unified approach to the development of massage devices and milking machines in terms of pneumomechanical action on the mammary gland of animals.

Technological audit of massage devices with combined principle of pneumatic massage indicates significant and not fully used reserves of this group of equipment [4, 5, 6].

Its practical implementation implies that the main role in performing technologically necessary operations in udder massage of animals is assigned to reduced pressure (vacuum), while the mechanical component should perform an auxiliary function.

It is known that a device for pneumatic udder massage of heifers is a rigid construction in the form of a hemisphere (bell), the size and shape of which take into account the configuration of the mammary gland. A polyethylene spring-loaded grid with protrusions is mounted inside the hemisphere. During operation of the device, a certain volume of air is periodically pumped out and supplied into the cavity of the hemisphere by means of a pulsator.

At the moment of creation of reduced pressure in the hemisphere of the device for pneumatic massage of the udder of heifers, the pneumatic impact on mammary gland of heifer is produced, and by means of spring-loaded grid the mechanical massage, designed to restore blood circulation in udder of the animal, disturbed under the influence of vacuum, is made. The intensity of mechanical massage is limited by the value of working vacuum in the cavity of the hemisphere, which usually does not exceed 15-17 kPa. A diagram of pressure changes in the hemisphere (bell) of the device for pneumatic udder massage (Figure 1) clearly demonstrates its disadvantages, which in general case are reduced to small amplitude of working vacuum change ($P_2 - P_1$) in the massage stroke and absence of proper rest of udder tissues from action of reduced pressure ($P_1$) in the unloading stroke.

![Figure 1. Diagram of air pressure changes in the massage bell: $P_1$, $P_2$ - maximum and minimum value of working vacuum, kPa; $P_A$ - atmospheric pressure, kPa.](image)

The presence of a residual vacuum in the massage bell during the unloading stroke is an important characteristic when evaluating the pressure diagram. This drawback is unavoidable for the given structural scheme of the device for pneumatic massage of the udder of heifers. The residual vacuum in the massage bell serves to hold the device on the animal's udder in the unloading cycle. And it does not allow to restore normal blood circulation in the tissues of the udder, disturbed during the massage.

The experience of massage devices modernization developed on the basis of a device for pneumatic massage of the udder of heifers indicates a possible solution to this problem by introducing an independent element into the structure, in which the pressure change will be performed in antiphase with respect to the massage bell. A similar principle is realized, for example, in milking machines equipped with a pair milking pulsator [7]. Such a pulsator provides a change in the atmospheric air pressure in the inter-wall chambers of the teat cups to a reduced pressure (vacuum), in antiphase for two pairs of cups, put on two front and two rear nipples of the udder of animals [8]. Currently, several massage devices have been developed and patented, the workflow of which is based on a similar principle [9].

The aim of the study is to substantiate the working process of a pneumatic massage device with a more effective unloading tact that ensures full restoration of blood circulation in the udder of the animal.
2. Materials and Methods
The object of the research was a device for combined (pneumomechanical) massage of the udder of animals of a two-chamber type. The methods implemented in the research have made it possible to obtain a diagram of the pressure change in the massage bell and the massage element of the device. The studies were conducted using a laboratory installation consisting of an artificial udder of a cow, a vacuum system of a milking installation, as well as measuring and recording equipment.

The conversion of air pressure in the massage device into electrical signals and their recording was performed using two small-sized pressure sensors MDD-1-1000 and a high-speed recorder N3031-4.

The advantages of sensors of the MDD type include their insignificant inertia, as well as a linear relationship between the resistance of the potentiometer and the deformation of the membrane.

The principle of operation of the sensor is as follows. A vacuum is diffused through a tap nozzle in a sealed cylinder (housing).

The vacuum causes the diaphragm to deform, moving a system of levers with a sliding contact. By moving the potentiometer, the contact changes the resistance of the arms of the bridge circuit into which the sensor is connected.

The wiring diagram for connecting the sensor was made according to generally accepted bridge circuitry and mounted on a separate panel. The wiring diagram allows the sensor to be used with practically any type of recording equipment.

3. Results and Discussion
To carry out the research, a massage device was made, the design and technological scheme of which is shown in Figure 2.

The operating process of the device is based on interaction of two working bodies designed to perform pneumatic massage on two different areas of the heifer's mammary gland by air currents, the pressures of which are in antiphase to each other.

The basis of the device is a massage bell 1 (Figure 2), equipped with a rubber seal 4 and a power pneumochamber 10. In the lower part of the chamber a socket 8 is fixed with the possibility of moving a rod 9 in it, at the end of which a rubber massage element 3, made in the form of a hemisphere is mounted. The socket is equipped with a spring-loaded double-arm retainer 6. One end of the lever is designed as a button, and the other end acts on the indentations on the stem by means of a through hole in the socket. By pressing the lever lock, the rod 9 moves upwards and the massage element together with the bell is pressed to the udder and the device is put into working condition.

![Figure 2](image-url)
The massage bell and the massage element are connected to two nozzles of the pulsator 5 using hoses. The pulsator 5 is used to convert a constant value of reduced pressure in the main vacuum line into a variable one. The cavity of the bell 1 and the pulsator 5 is connected using connecting hose 4. The pulsator 5 and hollow stem 9 are connected using connecting hose 7. The alternating pressure is supplied to the massage element 3 from the pulsator 5 through the hose 7 and the hollow stem 9.

The working process of the massage device is implemented according to the principle of two steps in the following sequence. With the help of the main hose, the pulsator is connected to the vacuum system and alternately supplies and evacuates air in the massage bell and the massage element.

When air is evacuated from the cavity of the massage bell, the walls of the power chamber 10 are deformed and the stem with the massage element is moved upwards. At the same time, a certain volume of air is supplied to the massage element and the pressure in it increases to atmospheric level.

Thus, the part of the animal's mammary gland, limited by the massage bell, is pneumatically massaged, while the other part of it, which is affected by the massage element, is mechanically massaged. This restores normal blood circulation in the part of the udder limited by the hemisphere of the massage element.

During the next work stroke of the massage device, air is pumped into the cavity of the massage bell and the power pneumatic chamber (due to the elastic properties of the material which it is made of) restores its initial shape. At the same time, the pulsator lowers the pressure (vacuum) in the cavity of the massage element. The massage element grabs onto the udder's tissue and holds the entire device on it. At the same time, the part of the udder that is restricted by the massage element is subjected to a pneumatic massage.

In the part of the udder that interacts with the massage bell, normal blood circulation is restored under the influence of atmospheric pressure in this stroke. Thus, both parts of the mammary gland that are affected by the massage bell and the massage element are fully relieved from the effects of the reduced pressure and are able to restore the blood circulation that has been impaired by the action of the vacuum. Elimination of residual vacuum in the massage bell during the unloading cycle allows intensifying the process of udder massage by slightly increasing the working vacuum. Figure 3 shows the diagram of air pressure change in the elements of suggested massage device depending on the frequency of the pulsator pulsation.

![Diagram of air pressure change in the suggested massage device.](image)

Figure 3. Diagram of air pressure change in the suggested massage device.

The analysis of the diagram shows that the vacuum value acting on the heifer mammary gland tissue differs significantly for the massage bell and the massage element.
In the massage element with standard for this type of pulsator frequency of 60 pulsations per minute, working pressure (vacuum) coincides with the value of this parameter in the main hose of the vacuum system - 48 kPa. Reducing the frequency to 50 pulsations per minute reduces the working vacuum to 40 kPa.

When the pulsator frequency decreases from 60 to 50 pulsations per minute, a different picture is observed in the massage bell: the working vacuum increases slightly. The pulsator in normal operation is designed to pump out air from two inter-wall chambers of teat cups, the volume of which does not exceed 0.4 dm$^3$. The volume of the massage bell free from the udder is approximately 2 dm$^3$. In this regard, a decrease in the frequency of operating cycles of the pulsator contributed to an increase in the vacuum in it. In the normal operating mode of the pulsator, the increased volume of the massage bell does not allow the pumping and air supply to be completely completed. That is typical for milking machines in a similar mode.

It should be noted that the higher vacuum in the massage element compared to the massage bell is due to the need to keep the massage device on the animal's udder in the unloading cycle when the pressure in the bell is increased to atmospheric pressure. Theoretically, reduction of vacuum load on the area of a heifer's mammary gland, interacting with the massage element, is possible in case of smaller mass of the device or increase of the surface area of the massage element. Meanwhile, the expediency of one or another variant is not obvious, as the mechanical component of the massage device ensures restoration of normal blood circulation on this, relatively small part of the animal's mammary gland.

4. Conclusion
The design of the pneumomechanical massage device is generally more efficient than the prototype. The claimed efficiency is achieved by a rational pressure variation diagram in the massage bell and the massage element. The use of this device provides adjustable parameters of pneumatic mode for the massage bell and massage element in the range of 20-25 kPa and 40-48 kPa respectively.

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