Manipulators adapted for automatic milking

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Abstract. The paper provides a rationale for the relevance of automation in machine milking. It deals with the design and control algorithm of a mobile manipulator adapted for milking machines. The manipulator allows for a change in the milking routine, thus making it possible to regulate the amount of vacuum in a tea cup, subject to a current flow rate separately for each pair of mammary glands. The paper presents the results of theoretical and experimental studies that indicate the way vacuum variations depend on the diameter of a metering orifice of a non-return valve, and how vacuum fluctuations in a teatcup chamber, as a spring-loaded valve opens, depend on the number of coils on a spring and its diameter. The results of a production check on a mobile milking manipulator are presented in the paper.

1. Introduction
To ensure the implementation of industrial safety doctrine, agrarians are challenged to provide the population of Russia with high-quality food, and the industry – with raw materials at affordable prices. Farming can succeed in modern market conditions through high quality products and lower production costs. High quality agricultural produce can be sold under high-end brands at a high purchase price. Production costs can be lowered by reducing operating costs through the introduction of modern technologies and techniques. In dairy husbandry, machine milking has a significant impact on operating costs. Thus, increasing the efficiency of machine milking by means of automated machinery is crucial.

2. Problem statement
One way to address the problem of increasing milk production is to ensure greater efficiency of automatic milking. The need to update machinery used on dairy farms and complexes is due to the fact that in the last 8-10 years they have been replaced with modern equipment by no more than 2.5- 3.0% a year instead of desired 13-15%. In Russia, there are still quite a large number of tied dairy farms, on which obsolete equipment is in place. The labour of livestock raisers on such farms is unproductive, hard, low-paid and unattractive for educated rural youth. On the other hand, tied housing is gentler for cows, which means that animals have up to 5 lactations, and with loose keeping – only 3.0-3.5 lactations [1, 2].

An essential condition for the effective milk production on dairy farms is monitoring the state of dairy cattle, quality of the produce, as well as proper functioning of the equipment. It is impossible to fulfill the above conditions without automated techniques, particularly milking machines. Automatic
milking is designed to reduce the share of manual operations, specifically, at the final stage of milking that involves stripping and removing a milking unit to stop milk flow without harming the animal. The actuator in such equipment is referred to as a manipulator.

3. Materials and methods

Many domestic and foreign researchers have responded to the issues of adaptive machines used for milking cows, including automated units equipped with manipulators [3, 4]. A lot of research indicates the relevance of automation for strippings and removal of a milking unit, which significantly increases the productivity of dairymen. It is also evident that the final operations of machine milking should include such an important factor as stripping ratio, separately for each pair of mammary glands, which will enable stripping and removal of devices in a strictly defined period of time, thereby eliminating the “human factor” that might lead to under-milking or “idle milking”.

Most automatic milking manipulators have been proved to remove the devices when milk flows slow down up to 200 ml/min. The stripping (pulling down teat cups) is usually not provided, though. Actually, this causes the abnormal end of lactation, as well as failure to obtain up to 5-25% of a single milk yield, due to individual characteristics of milk extraction in various cows [5, 6]. In more than a quarter of cases, the rate of milk flow below 200 ml/min during milking is caused not by the completion of milk flow, but a streak canal closure by teat cups since they can crawl over the base of a teat. According to the research, it is advisable to further improve milking devices towards the differentiated automation, i.e. to create animal-adapted manipulators. Such devices are not so widespread. Moreover, there is a lack of feed data for the design of such equipment.

The main physiological feature to characterize the milk production is the rate of milk flow. Obviously, it is this indicator that should be the basis for the design of adaptive automated milking manipulators.

The authors believe that milking equipment adapted to animals should ensure vacuum stability, monitor and timely regulate parameters depending on the rate of milk flow, and separately for each pair of mammary glands. The presented requirements will be met by a milking manipulator that operates as follows: timely stripping from each teat separately at a decreased flow rate of below 200 ml/min; further maintaining the vacuum level at a minimum in the predetermined pairs of mammary glands until flow ceases in the teats left; automatic removal of the milking unit when flow rates decline to less than 50 ml/min in the whole udder.

The object of the study was structural and operational parameters of original teat cups of a milking manipulator. Teat cups were fitted with a pulsator. A rubber liner had a valve. The issue is discussed as to how vacuum variations in a teatcup chamber depend on the level of pipeline vacuum and the diameter of a metering orifice of the pulsator, and how the pressure drop to occur as the liner opens depends on the diameter of a non-return orifice and the number of spring coils. The research results were processed by methods of variation statistics, as well as regression and correlation analysis.

To determine the vacuum pressure in the pulsation chamber, subject to the diameter of the metering orifice of the pulsator, the diameter ranged from 1 to 2 mm in 0.2 mm increments. A computer was connected with a Velleman PSC 500 digital oscilloscope and a Micro Switch 143 PC 15D pressure regulator. The research included the following stages. A metering inlet valve was assembled on the experimental setup. Once the computer was on, the Micro Switch 143 PC15D pressure regulator was powered and a measuring system was heated for at least 5 minutes. After that, software installed on PC was run from the keyboard. Vacuum pressure was generated in the vacuum pulse tubes. The specified vacuum pressure was set by a regulator. The difference between the vacuum and atmospheric pressures caused the air to pass through the valve from the pulsation chamber to the teatcup chamber. The PC recorded a change in the vacuum pressure with the pressure regulator and by digitizing the signal with the oscilloscope. The vacuum regulator changed the vacuum pressure in a vacuum tube from 10 kPa to 50 kPa within a band of 10±0.1 kPa. After the experiment, the liner valve was replaced with a new one and the studies were renewed. The experiment was performed three times.
In addition, the authors were concerned with the dependence of pressure fluctuations as the liner opens on the diameter of the metering orifice and the number of spring coils. The valve mechanism with the metering orifice and a predetermined number of spring coils was fixed on the shell. The chamber was connected to the vacuum pipeline through a vacuum tap that changed the level of the vacuum pressure in the chamber from 5 to 50±0.1 kPa in increments of 5± 0.1 kPa and controlled by a vacuum gauge. The levels of the vacuum pressure were recorded on the computer by means of the pressure regulator and the digital oscilloscope. With a certain pressure drop, the valve began to open slightly, breaking the connection assembled to supply power from the power supply to the pressure regulator. The break was recorded by the computer. The last vacuum differential value stored in the computer memory was considered to be the front vacuum pressure at the valve opening moment. The inlet diameter ranged from 1 to 2 ± 0.01 mm. The number of coils ranged from 3 to 7. The experiment was carried out three times. After the experiment, the valve was replaced with a new one and the studies were renewed.

4. Results and discussion
For the implementation of the above operation, an algorithm is presented in Fig.1.

The authors proposed the design of an adaptive milking manipulator that includes a full-wave electrically-controlled pulsator, an original milking unit, a control unit with a receiver fitted into vacuum and milk pipelines, and a liner barrel connected via a flexible pulse tube to the clawpiece [7].

The proposed design of the milking manipulator is shown in Fig. 2. The control unit with the electrically-controlled pneumatic valve and a trap vessel with a float ball designed to float if milk flow from the claw is 50 ml/min.

![Figure 1. Control Algorithm for Adaptive Milking Manipulator](image-url)
The trap vessel is fitted with a seal switch and magnetic float connected to the control unit via the electric circuit. The electrically-controlled pneumatic valve is assembled to enable the connection between the liner barrel and the vacuum pipeline when the former opens and with the atmosphere when it is held closed. The milking machine is fitted with an original claw and teat cups with valves. The liner has a mouthpiece and a valve. Pneumatic valves are fitted on teat cup shells and look like a body divided into two chambers by an elastic membrane. The inner chamber fitted with a spring-loaded non-return valve interacts with the pulsation chamber of the teat cups, and the outer one, which has a regulator, with the pulsator. The claw has milk receivers with coaxial magnetic floats designed to interact with the seal switch closing an electric circuit on the electro-pneumatic valve. During milking, when flow rate is below 200 ml/min, the operating parameters do not differ from most devices (vacuum beneath teat is 46-50 kPa, depending on the type of milking unit fitted with a manipulator).

With a decrease in milk yield below 200 ml/min, collector floats start interacting with the seal switch closing the electric circuit on the electro-pneumatic valve, reducing the vacuum beneath teats to a minimum value within 25-33 kPa. The pulsator stretches the flexible tube to a certain limit, thereby enabling strippings. Further, when the milk flow from the claw declines to 50 ml/min, the control unit with the electrically-controlled pneumatic valve connects the liner barrel to the vacuum pipeline, thereby pulling the pulse tube downwards and, as a result, removing the teat cups from the teats.

![Figure 2. Mobile milking manipulator](image)

The authors were faced with the following challenges: establishing the dependence of vacuum fluctuations in the teatcup chamber on the pipeline vacuum level and the diameter of the valve metering inlet; establishing the dependence of the differential opening pressure in the liner valve on the diameter of the non-return inlet and the number of coils; establishing optimal operating and design parameters of the adaptive milking manipulator [8, 9].

The teat cup of the proposed adaptive milking manipulator includes the pneumatic valve that admits a predetermined amount of atmospheric air with a certain frequency. It is designed to reduce the vacuum level to a minimum during milking and ensure optimal conditions for milk evacuation from the cup to the claw. At first glance, it is obvious that the faster the milk passes from the teat cup to the claw, the greater the throughput of the device, and, consequently, its productivity. However, exceeding the milk-air rate in the teatcup-claw section above 1.5 m/s leads to a decrease in the quality of milk due to the formation of foam. It should be born in mind that the above pneumatic valve should...
maintain a minimum vacuum sufficient for the teat cup to fit over the teats to prevent the device from falling off the teats.

The studies made it possible to determine the dependence of the teatcup vacuum on the pipeline vacuum and the inlet diameter. A graphical interpretation is shown in Figure 3.

![Figure 3. The dependence of teatcup vacuum on pipeline vacuum and inlet diameter](image)

A purpose-made laboratory setup was used to determine the relationship between the opening vacuum fluctuations in the liners and the diameter of the non-return hole and the number of coils. A graph of this relationship is shown in Figure 4.

![Figure 4. The relationship between opening vacuum fluctuations in the liners and the diameter of non-return hole and the number of coils](image)

The dependence shown in Figure 4 indicates that five spring coils and a non-return diameter of 1.6 mm leads to a vacuum drop of 17.1 kPa in the teatcup chambers.

The non-return diameter can theoretically be found by the formula (1):
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\[
d_k = \sqrt[3]{\frac{4V_{TC}(1-K_{GP})}{2Y \left(\frac{1}{Y-1} \frac{1}{M_q} \sqrt{1-K_{GP}}\right)^\frac{1}{Y-1}}},
\]

where \(d_k\) is the diameter of the metering orifice, m; \(V_{TC}\) is the teatcup chamber volume, m\(^3\); \(K_{GP}\) is the pressure loss coefficient \((K_{GP} = P_T/P_p)\); \(P_T\) is the current pressure in the teatcup chamber, Pa; \(P_p\) is the current pressure in the pulsation chamber, Pa; \(\gamma\) is the ratio of specific heats; \(T_P\) is the temperature in the pulsation chamber, °K; \(M_q\) is the molecular weight of the gas, kg; \(t\) is the time of operations, s.

The number of coils is theoretically determined by the formula (2):

\[
n_s = \frac{M_q \varepsilon^4 (l_p + l_g)}{4 \frac{d_S^2}{2} (P_p - P_T) S_{in}},
\]

where \(n_s\) is the number of coils; \(M_q\) is the shear modulus, n/m\(^2\); \(l_p\) is the displacement of spring coils under the action of predeformation, m; \(l_g\) is the displacement of spring coils during working deformation, m; \(d_S\) is the average diameter of a spring coil, m; \(S_{in}\) is the inlet area, m\(^2\).

Laboratory studies resulted in the formula for the empirical dependence of the opening pressure drop in the linear valve on the diameter of non-return inlet and the number of coils (3):

\[
\Delta P = 18033.809 + 1283.333 \cdot n_s - 4411428.571 \cdot d_k,
\]

where \(\Delta P\) is the pressure drop at the moment the valve opens, Pa.

An experimental batch of mobile milking manipulators was used for production tests on the ADM-8A installation on one of the farms in the Belgorod Region (RF). ADU-1-03 machines were used to control the milking process. Two groups composed of 10 cows each were involved in the experiment. The general exercise and diets in both groups were the same [10, 11].

The experiment involved the study towards the progress of milk production by each pair of mammary glands, milking duration, the amount of a single milk yield and milk yield during the experiment period (90 days). The effect of milking devices on the teats and the incidence of mastitis was also analyzed. Stripping operation was manual via ADU-1-03 machine as soon as milk flows decrease (determined visually based on the amount of milk in the claw). The ADU-1-03 was also removed manually.

The data from the production experiment showed that the developed adaptive milking manipulator ensured milking rate of 98%, a total maximum milk yield of 2900 ml/min, and an average milk flow rate of 1600 ml/min. For ADU-1-03 machines used in the control group, these indicators were 96%, 2300 ml/min and 1400 ml/min, respectively. Such results are due to the additional air release into the teat cups to contribute to the intensive milk flow into the claw as well as the adaptation of parameters to the physiological characteristics of the cows.

There were no cases of mastitis in the experimental group. Four cases were detected in the control group, which can be due to the gentle (adaptive) modes of operation by the proposed automated milking manipulator. When milking the experimental group, there was no anxiety or stressful behavior among the cows.

5. Conclusion

The authors propose the design of an adaptive milking manipulator, which includes a half-wave electrically-controlled pulsator, an original milking unit, a control unit with a receiver fitted into vacuum and milk pipelines, and a liner barrel connected via a flexible pulse tube to the clawpiece. The
proposed adaptive manipulator ensures timely stripping separately for each teat and reduces the flow rate below 200 ml/min. It also maintains a minimum vacuum in the pairs of mammary glands after milking until the completion of milk flow. It provides an automatic removal of milking machine as the rate of milk flow falls below 50 ml/min in the udder as a whole.

Laboratory studies established the dependence of vacuum fluctuations in the teatcup chamber on the pipeline vacuum level and the diameter of the valve metering inlet; the dependence of the differential opening pressure in the liner valve on the diameter of the non-return inlet and the number of coils; optimal operating and design parameters of the adaptive milking manipulator.

The production check on the proposed manipulator gave positive results as compared to the ADU-1-03 devices, namely: stripping ratio is 98% (versus 96%), total maximum milk yield is 2900 ml/min (versus 2300 ml/min), average milk flow rate is 1600 ml/min (versus 1400 ml/min), decrease in the incidence of mastitis.

In this regard, it is recommended to include in the design of milking machines an option to switch to a gentle milking mode with a low intensity of milk flow for each pair of mammary glands separately.

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