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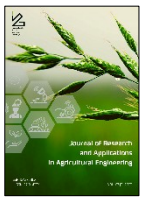

Advances in the design of quarter milking clusters

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The pulsation pattern of the liners and the operating parameters of the pulsator affect the health of the cows' udders and the quality of the milk produced. Quarter milking clusters are rarely used in cowsheds. Their use allows for individual control of the teatcups during milking, which helps, among other things, to reduce the negative effects of empty quarters in cows' udders. This study provides an overview of quarter milking clusters, both prototypes and those in mass production. Older designs (up to the 1990s) were based on mechanical and electrical components, whilst the main function of the quarter milking system was the individual removal of milking cups. In the 21st century, mass-produced quarter milking cluster appeared on the market, and in selected academic centres, prototypes of modern quarter milking clusters were developed. The quarter milking cluster with thermal milk flow indicators, developed at the Department of Biosystems Engineering at the Poznań University of Life Sciences, was the only design described and was the subject of scientific research. The main aim of this research was to optimise the operating parameters of the quarter pulsator and to evaluate the functionality of the thermal milk flow indicators fitted to the teatcups. Further research in cowsheds using quarter milking clusters requires the development of an effective method for mounting sensors on the teatcups or the development of a measurement module to be fitted inside the claw.

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1. Introduction

In cowsheds, the most common milking systems are milking machines with fixed pulsator operating parameters. Milking cows using alternating pulsation (less often simultaneous pulsation) does not correspond to the physiology of milk production by individual quarters of the cow's udder, as they differ in the amount of milk produced, the rate of milk flow and other parameters [1]. The uniform action of teatcups on teats that have already been emptied of milk leads to the formation of a very harmful and undesirable phenomenon known as overmilking. Prolonged overmilking causes injuries to the ends of the teats and infections [2, 3, 4]. Despite technological advances, modern milking cluster still only takes the physiological differences between quarters of the cow's udder into account to a limited extent. Eliminating or reducing the occurrence of overmilking during milking is only possible in quarter milking systems – milking robots, robotic milking parlours and quarter milking clusters [1].

The concept of quarter milking is not clearly defined in the literature. It is most often understood as the ability to individually remove teatcups from a quarter of a cow's udder that has been emptied of milk. This is implemented in all robotic milking systems available on the market and eliminates the occurrence of physiological overmilking. Another action defined as quarter milking is the ability to

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individually

control the operation of teatcups depending on the current milking phase or the intensity of milk flow (milking speed) from a quarter of the cow's udder. The operating parameters of individual teatcups are changed using a quarter pulsator consisting of four independent solenoid valves. The adjustable parameters are pulsation rate, pulsation ratio and vacuum pressure. This method of milking cows is currently used in one quarter milking cluster manufactured worldwide and in selected designs of milking robots [5].

The concept of quarter milking is not only associated by milking system manufacturers with the pulsating action of teatcups and the individual removal of teatcups. It can also include measurements of milking capacity parameters (milk yield, milking time, milk flow rate, etc.) and health diagnostics (milk conductivity, milk colour, presence of blood in milk, somatic cell count in milk, etc.) carried out in relation to individual quarters of the cow's udder. These activities are used not only in most robotic milking system designs, but also in a few milking controllers (based on the design of a classic milking cluster) [5].

Interest in quarter control in milking systems in Polish academic centres can be divided into two periods. In the 1980s and 1990s, agricultural universities in Poznań and Wroclaw were very active in this field [6, 7, 8, 9]. The second period covers activities carried out in the 21st century in Krakow and Poznań [10, 11].

The issues surrounding the design and use of quarter milking clusters in cowsheds have received very little attention in the literature. To date, there has been no comprehensive review in the literature of the functional characteristics of quarter milking clusters, whether developed in academic centres or mass-produced. In particular, no analysis has been carried out of the impact of technical and technological progress on the design of quarter milking clusters developed in the 21st century.

2. Objective of the work

The aim of this study was to review the design solutions of prototype and mass-produced quarter milking clusters. A review of the literature (in Polish and English) was conducted, drawing primarily on online databases. Subsequently, the construction and functional properties of new quarter milking clusters developed at the Department of Biosystems Engineering, Poznań University of Life Sciences, were described in detail. The results of scientific research obtained by the author during laboratory and field studies were presented. In the final section of the thesis, a preliminary functional assessment of quarter milking machines developed in the 21st century is carried out.

3. Overview of the design features of quarter milking clusters

Currently, the milking system market offers only one mass-produced solution: the Milpro P4C quarter milking cluster from the Italian company Milkline. In contrast, Polish and international scientific literature describes several design solutions for quarter milking clusters developed at academic institutions (in the form of prototypes).

Milpro P4-C quarter milking cluster (Milkline, Italy)
Currently, there is only one mass-produced solution for a quarter milking cluster available on the market. This is the Milpro P4-C milking controller from the Italian company Milkline. It was first unveiled at the EuroTier exhibition in Hanover in 2008 [12]. The most important component of the unit is a special measuring module installed in the claw, equipped with four milk conductivity sensors. The sensors are used as indicators of milk flow from individual quarters of the udder, which enables control of the quarter pulsator. During milking, after the pulsator is activated, the teatcups pulsate simultaneously (it is possible to adjust the pulsator parameters based on the milk meter readings) until the milk flow from the udder lobes stops. Then, quarter pulsation begins. The teatcup of the teat emptied of milk is closed, but opened at regular intervals (every few seconds). After milking the last quarter, the milking cluster is automatically removed [12, 13]. The operation of the Milpro P4-C quarter milking cluster during milking reduces the negative effects of physiological overmilking, though it does not eliminate them entirely and has a positive effect on teat condition. This has been confirmed by scientific research conducted at the University of Kentucky in the United States [14].

Milking cluster with individually removed teatcups (currently Leipzig University, Germany)
The quarter milking cluster, developed in the early 1970s, allowed for the individual removal of teatcups from each quarter of the cows' udders [15, 16]. The use of a specially designed claw and an original control module for removing the teatcups (forming an integral part of the milking cluster) enabled the system to be used in milking parlours. The development of this unit was made possible by close cooperation between research centres and industry, which allowed, among other things, the unit to be equipped with milk flow indicators and electric

pulsators available from specific milking system manufacturers [15]. Unfortunately, there is no information in the literature regarding the practical application of this design in cowsheds.

Milking cluster with individually removed teatcups (currently Poznań University of Life Sciences, Poland)

Developed in the early 1980s, the quarter milking cluster allowed the individual removal of teatcups from each quarter of the cows' udders [6]. The design of the milking cluster consisted of four autonomous functional units equipped with standard teatcups, milk tubes, milk flow sensors, solenoid valves and other components. The teatcups were connected to a common manifold and attached to a movable arm. In the final phase of milking, when the milk flow rate fell below the threshold value, the relay assembly of the functional units cut off the vacuum in the teatcups, causing them to be automatically removed (individually for each quarter). After milking the last quarter, the solenoid valve of the pneumatic actuator opened, pulling the arm with the milking apparatus away from the cow, thus ending the milking process [6]. The design of the milking machine developed at the Poznań centre was further refined [7]. There is no information in the literature regarding studies conducted in cowsheds.

Milking cluster with individually removed teatcups (currently Wrocław University of Environmental and Life Sciences, Poland)

The quarter milking cluster, developed in the late 1980s, allowed the teatcups to be removed individually from each quarter of the cow's udder [8]. The most important component of the milking system was the electrode-based milk flow sensors. In the first version, the correct progression of the mechanical milking process and the removal of the teatcup required continuous measurement of the instantaneous milk flow rate. The parameters of the milk flow meters also influenced the delay time of the devices responsible for controlling the operation of the teatcups during the final phase of milking. Laboratory and operational tests of the prototype of the first version of the milking cluster confirmed the reliability of the individual functional modules, including the measurement modules [8].

Milking cluster with quarter-by-quarter shut-off of the teatcups (currently Wrocław University of Environmental and Life Sciences, Poland)

In another version of the quarter milking cluster developed at the Wrocław centre in the early 1990s, it was possible to switch off individual teatcups. When the milk flow rate fell below a threshold value, the teatcup ceased operation (milking of the cow's udder quarter was interrupted during the massage phase, with reduced vacuum pressure). Eliminating the pulsating operation of the teatcup after milking the quarter (during the overmilking) had a significant impact on teat health. This version of the quarter milking cluster was tested in cowshed on a test group of cows [9].

Autonomous milking apparatus (currently University of Agriculture in Krakow, Poland)

In the first decade of the 21st century, an innovative concept for an autonomous milking apparatus was developed at the Krakow centre [10]. The design of this milking device consists of four independent collectors with a special construction, ensuring individual milking of each quarter of the cow's udder. The original design of the milk meters allows for the measurement of the volumetric flow rate of milk from individual quarters of the cow's udder [17, 18]. The milking apparatus has full quarter control capabilities: the ability to change the pulsator parameters in individual teatcups, their individual removal from the udder quarters emptied of milk and independent regulation of the vacuum in collectors [19]. A major advantage of the autonomous milking apparatus is its originality and innovation, including the extensive use of modern microprocessor techniques. A major advantage of the autonomous milking apparatus is its extensive use of modern microprocessor technology and precision measuring instruments. The functional capabilities of the autonomous milking apparatus are very high, but to date the new milking system has not been tested in cowsheds.

Quarter milking cluster with thermal milk flow indicators (currently Poznań University of Life Sciences, Poland)

Also in the first decade of the 21st century, the Poznań centre developed a quarter milking cluster fitted with thermal milk flow indicators. The quarter milking cluster with thermal milk flow indicators was ultimately developed in three design versions [11, 20, 21]. Design version 1 was intended for use in milking parlours, while the subsequent versions were adapted for use in cowsheds equipped with pipeline milking systems (design versions 2 and 3). The most important components of each design version were:

- thermal milk flow indicators (installed in transparent inspection glasses of teatcups) based on NTC 110 thermistors;
- quarter pulsator, constructed on the basis of four independent solenoid valves mounted in two

housings, equipped with a microprocessor controller;
- power supply module for thermal milk flow indicators based on voltage power supplies and high-current resistors (design versions 1 and 2);
- power supply module for thermal milk flow indicators based on highly stable current sources (design version 3);
- automatic measurement signal recorder with an 8-bit analogue-to-digital converter (design versions 1 and 2);
- automatic measurement signal recorder with an 16-bit analogue-to-digital converter (design versions 3);
- transparent milking (measuring) bucket with a capacity of 30 dm3 used in scientific research;
- a special dedicated air distributor mounted on the claw cover, enabling quarter-pulse operation;
- selected accessories and components for the Classic 300 milking cluster from GEA Farm Technologies.

An important feature of all versions of the quarter milking cluster was a specialised computer program that allowed the parameters of the quarter pulsator (individually for each quarter of the cow's udder) to be programmed using a PC and a USB interface (Fig. 1). The adjustable parameters are the pulsation rate in the range from 40 to 300 cycles per minute (with a resolution of 5 cycles per minute), the pulsation ratio in the range of 2 to 98 % (with a resolution of 2 %) and the delay time for switching the pulsator operating parameters in the initial phase of milking cows in the range of 5 to 60 seconds (with a resolution of 5 seconds).

Fig. 1. Programming the quarter pulsator before milking cows (source: author's own photograph)

In 2006–2007 tests were conducted in cowsheds using the first and second versions of the quarter milking cluster [11]. The first version was tested in a milking parlour, where one milking unit was adapted for testing. An additional vacuum valve and a quarter pulsator were permanently installed on the pipeline, a special platform for measuring equipment was built and a single-phase electrical installation was connected to the station. In total, several dozen high-yield cows were milked there using the experimental milking cluster. In the main studies, conducted on a fixed group of cows, the impact of quarter pulsation on the health of cow udder quarters (somatic cell count and microorganisms in milk) and on selected parameters of their milking capacity (milk yield, milking time and average milk flow rate from the udder) was analysed. The quarter pulsator was programmed in such a way that during the actual milking phase, the pulsation rate increased (at a constant pulsation ratio). In the initial and final phases of milking, the parameters of the teatcups remained constant. Similar tests were carried out in a cowshed with a pipeline milking machine using the second version of the quarter milking cluster. The measuring and electronic equipment blocks were mounted on a special platform that allowed free movement between the milked cows. The housings with electronic pulsator solenoid valves were mounted on the cover of the measuring bucket. The research methodology carried out on a fixed group of cows was similar to the research carried out in the milking parlour [11].

The results obtained from tests using a quarter milking cluster showed that the new milking method had a stimulating effect only on selected cows. Milk quality tests showed that changes in milking methods did not adversely affect the health of the cows' udders. Based on the recorded milk flow patterns for individual udder quarters, the performance of the microprocessor-controlled quarter pulsator and thermal milk flow indicators was evaluated. In the case of sensors installed in teatcups, ageing of thermistors was observed as a result of high current flow. An important design conclusion was the need to change the power supply for milk flow indicators and to develop a new method of installing them in teatcups [11].

Between 2009 and 2012 extensive research was conducted as part of a ministerial project using the third design version of the quarter milking cluster [21]. The planned activities were preceded by a partial modernisation of the cowshed with a pipeline milking machine (where the second version of the quarter milking cluster was tested). A connector integrated

with an electrical connection was installed at each milking unit. Subsequent activities included a thorough reconstruction of the quarter milking cluster by installing pulsators, electronic systems and an automatic recorder on a support platform made of acid-resistant steel and adding an integrated connection. This made it possible to freely move the quarter milking cluster between cows being milked in succession. The power supply for the thermal milk flow indicators installed in the teatcups was changed (by using highly stable power sources). An automatic signal recorder with higher measurement resolution was also used (Fig. 2).

Fig. 2. Quarter milking cluster equipment (design version 3) (source: author's own photograph)

The primary research objective of the new project was to optimise the operating parameters of a quarter milking cluster during the final stage of milking. To this end, both laboratory and field studies were conducted. The laboratory studies were carried out at the Institute of Agricultural Engineering at the University of Life Sciences in Wroclaw using specialist measuring equipment. Comparative tests were carried out on milking clusters operating alternately and simultaneously (simultaneous pulsation of the teatcups is the mode of operation of a quarter milking cluster until the final phase of milking begins). The results of the laboratory tests showed that the values of negative pressure at the teat end are influenced by the teatcup pulsation system, the mass flow rate of the fluid, and teat length. Greater fluctuations in negative pressure were recorded in the milking cluster operating simultaneously compared to alternating pulsation [22]. However, subsequent field studies did not show that the use of a simultaneous milking system at milking stations in the selected cowshed led to a deterioration in the health of the cows' udder quarters [21].

Under laboratory conditions, an assessment was also carried out of the effect of changes in the operating parameters of a quarter-wave pulsator – namely, the pulsation rate and the pulsation ratio – on the vacuum levels at the teat end under conditions simulating a leak between the teat and the mouth piece. The results of the study showed that controlling the pulsation ratio allows for the reduction of vacuum fluctuations at the teat end in the case of a simulated leak between the teat and the mouth piece. The lowest negative pressure values at the teat end under simulated conditions of the final phase of milking were obtained when teatcup pulsation was disabled [23].

In field studies using a quarter milking cluster with thermal milk flow indicators, the effect of quarter pulsation on udder health in a study group of cows was assessed [24, 25, 26]. Particular attention was paid to the issue of optimising the operating parameters of the quarter milking cluster during the overmilking of the cows' udder quarters. The studies considered two variants of teatcup operation during the final phase of milking. During single-stage regulation, when milk flow from the cow's udder quarter ceased, the pulsation rate was 40 cycles per minute (the lowest frequency generated by the quarter pulsator) and the pulsation ratio was 30 %. In the two-stage regulation variant, the pulsation rate was 40 cycles per minute, whilst the pulsation ratio was 30 % and 98 % (upon complete cessation of milk flow from the quarter). During the initial and main phases of milking, the pulsation rate was 52 cycles per minute and the pulsation ratio was 62 %. Based on the results of analyses of milk samples taken before and after quarter milking, it was found that the use of quarter pulsation may improve the health of cows' udder quarters. In field trials, lower mean somatic cell counts (SCC) were obtained in quarter milk from cows milked using a quarter milking cluster with two-stage adjustment of teatcup operating parameters during overmilking [21].

Another research focus was the functional evaluation of thermal milk flow indicators installed in the teatcups. The results of the field studies showed that a high supply current, the use of acidic and alkaline cleaning and disinfecting agents for washing the milking system, and contamination of the sensor surfaces with a layer of denatured protein caused changes in the values of selected metrological parameters of the thermal sensors. In turn, the presence of denatured protein in most cases contributed to increased proliferation of selected types of microorganisms on the sensor surfaces. The

cleaning process using an automatic cleaning installation in many cases led to their complete elimination [21].

Quarter milking cluster with temperature sensors (Poznań University of Life Sciences, Poland)

In 2020, at the Poznań centre, in collaboration with the Polish milking system manufacturer Polanes Sp. z o.o. from Bydgoszcz, a new quarter milking cluster was developed [27], based on an earlier design of a four-quarter diagnostic milking cluster [28]. The most important components of the new design are:

- thermistor temperature sensors (installed in transparent inspection glasses of teatcups) acting as milk flow indicators [29];
- a quarter pulsator, based on four independent solenoid valves mounted in two housings, equipped with a microprocessor controller (Fig. 3);
- a thermistor power supply module based on precision electronic current sources;
- automatic measurement signal recorder with a 16-bit analogue-to-digital converter;
- selected accessories and components of the milking cluster identical to those in the quarter milking cluster with thermal milk flow indicators.

Fig. 3. Pulsator of the new quarter milking cluster (source: author's own photograph)

The new quarter milking cluster is equipped with a specialised computer program that allows the operating parameters of the quarter pulsator (individually for each quarter of the cow's udder) to be programmed using a PC and an RS-485 interface. The adjustable parameters are the pulsation rate in the range from 1 to 300 cycles per minute (with a resolution of 1 cycle per minute) and the pulsation ratio from 0 to 100 % (with a resolution of 1 %). The delay time for switching the pulsator operating parameters in the initial phase of milking is fixed at 60 seconds.

The design of the new quarter milking cluster included a special measuring module equipped with a temperature sensor intended for installation in the claw (Fig. 4). Its construction proved to be a major technological challenge. An attempt to build a module containing four thermistors proved unsuccessful, and currently, in scientific research, temperature sensors are installed in transparent inspection glasses of teatcups.

Fig. 4. Measuring module equipped with a single thermistor (source: author's own photograph)

In 2026, the Department of Biosystems Engineering at the University of Life Sciences in Poznań plans to conduct research on a new quarter milking cluster using a special laboratory measuring station [28]. The main focus of the research will be to assess the impact of simulated disturbances occurring during milking on the control of teatcups. New research on thermal sensors installed in teatcups is also planned.

4. Functional assessment of quarter milking clusters developed in the 21st century

In the case of the first prototypes of quarter milking clusters, developed at Polish and foreign academic centres between 1972 and 1990, particular attention was paid to the ability to automatically remove the teatcups from the cows' udder quarters once they had been emptied of milk. This function, currently used in all robotic milking systems, required the development of unconventional and complex design solutions based on mechanical and electrical components with minimal use of modern electronic systems. Only selected quarter milking clusters were tested in cowsheds, but their

results have not been described in detail in the scientific literature.

In the early 1990s, Polish literature proposed the development of a completely new type of milking cluster with variable milking cup parameters, operating depending on the volume of milk flowing from the cow's udder quarters. The first step in this work would be to construct a cheap, accurate flow meter with a digital output signal that could work with a microprocessor controlling an electronic pulsator [30]. In turn, in the late 1990s, a vision of a modern cybernetic milking machine was presented in the literature [31]. One of the proposals put forward there was the need for individual control of the milking machine's operating parameters in relation to individual teats. A revolutionary proposal was to make the milking machine's operating parameters dependent on the cow's neurohormonal state [31].

The increase in cows' milk yield and the drive to improve milk quality are forcing manufacturers of milking systems to develop ever more sophisticated systems (taking into account the biological and physiological characteristics of the animals being milked) [32, 33]. It was not until the 21st century that the first mass-produced quarter milking unit designed for use in milking parlours appeared.
Based on the available literature and the author's direct contacts with Milkline, the following functional features of the Milpro P4-C system can be listed:

- state-of-the-art design of milking components and equipment (teatcups, integrated vacuum tubes, air distributor, specially designed claw, electronic milk meter, ACR system - automatic cluster remover);
- an original quarter pulsator housing four independent solenoid valves in a single unit;
- a unique measuring module equipped with four milk conductivity sensors mounted in the claw (the sensors are used to assess the health of the cow's udder quarters during milking, as well as to indicate milk flow);
- an electronic controller with a clear display controlling the milking process, including quarter pulsation;
- the ability for the unit to interface with a computerised herd management system.

The Milkline quarter milking cluster has been constructed using state-of-the-art materials, electronics and IT technologies. The innovative nature of the design solutions employed is currently beyond the technological capabilities of Polish manufacturers of milking systems.

In the first decade of the 21st century, academic centres in Krakow and Poznań began developing concepts and plans for the construction of new quarter milking systems. This work resulted in the development of an autonomous milking apparatus and quarter milking cluster equipped with thermal and temperature indicators for milk flow. Modern electronic and IT technologies were extensively utilised in the construction of the new milking systems. A major advantage of the autonomous milking apparatus is its
comprehensive approach to controlling and monitoring the milking process (this solution is closest to the concept of a cybernetic milking machine). Unfortunately, the project authors did not present a concept for the system's application in cowshed. The use of the new device in milking parlours would require significant changes to the design of the cowsheds.

The following innovative design solutions were employed in the construction of the quarter milking cluster with thermal milk flow indicators:

- thermal milk flow indicators based on NTC thermistors, powered by a highly stable current source (mounted in transparent glass inspection on the teatcups);
- a microprocessor module controlling the operation of solenoid valves, with the ability to set (using specialised computer software) the operating parameters of the quarter pulsator individually for each teatcup;
- an automatic recorder of measurement signals;
- a module for visualising measurement signals, consisting of an LCD display.

The ability to programmatically configure the quarter pulsators operation allows the selection of operating parameters for the teatcups depending on the specific characteristics of the cowshed. This feature was utilised during research into optimising the operation of the quarter milking cluster. It should be emphasised that, despite the research conducted, the issue remains poorly understood in the literature.

The next version of the quarter milking cluster with temperature sensors was developed in collaboration with a Polish manufacturer of milking systems. The temperature sensors act as indicators of milk flow. Ultimately, they may also be used (as part of an integrated measurement module) to diagnose selected physiological conditions and the health of the cow's udder quarters [28].

The implementation of new research in cowsheds using quarter milking clusters at the Department of Biosystems Engineering, Poznań University of Life Sciences, requires the development of a reliable method for mounting measuring sensors in the milking cluster (in the teatcups or as a module

mounted in the claw). On the market for milking systems, there are only two design solutions featuring a measurement module mounted in the claw, but equipped with milk conductivity sensors (from Milkline and S. A. Christensen & Co). Unfortunately, attempts to resolve this issue by establishing cooperation with Polish industry have so far encountered barriers in the form of technological limitations.

6. Final considerations

The operation of quarter milking clusters is adapted to the physiology of milk flow from the individual quarters of a cow's udder. Minimising the negative effects of overmilking helps to improve the health indicators of dairy herds in cowshed. Unfortunately, the design of a quarter milking cluster is a highly complex technical issue. Early prototype designs utilised mechanical and electrical solutions, which significantly limited their functional capabilities. Technological progress has led to the emergence of new quarter milking clusters in the 21st century. A quarter milking cluster with thermal milk flow indicators (developed at the Department of Biosystems Engineering, Poznań University of Life Sciences) was the subject of comprehensive scientific research. Since 2020, another version of the quarter milking cluster with temperature sensors has been available. New research in dairy barns requires a solution to the problem of reliably mounting sensors in teatcups. This problem can only be solved through cooperation with the manufacturer of milking systems. Since 2008, when the world's first mass-produced quarter milking cluster (the Milpro P4-C by the Italian firm Milkline) was launched, no similar designs have appeared on the milking systems market. It seems that for large farms, milking robots remain the primary quarter milking system (and, to a much lesser extent, robotic milking parlours). In Poland, Milpro P4-C units are, unfortunately, used on only a few farms. Milkline's efforts have demonstrated that, with access to modern production technologies, it is possible to build a modern quarter milking cluster.

References

[1] Jędruś A.: Wstępna klasyfikacja ćwiartkowych systemów udojowych. In: Doskonalenie technologii produkcji rolnej, w tym energii odnawialnej, z uwzględnieniem wymagań zrównoważonego rozwoju, 2021, vol.27, 102-108, ISBN 978-83-65426-62-8.

[2] Hillerton J.E., Pankey J.W. & Pankey P.: Effect of over-milking on teat condition. Journal of Dairy Research, 2002, 69, 81-84. https://doi.org/10.1017/S0022029901005386

[3] Olechnowicz J.: Zewnętrzne i wewnętrzne uszkodzenia strzyków krów. Medycyna Weterynaryjna, 2007, 63(7), 786-791.

[4] Upton J., Silva Bolona P. & Reinemann D. J.: Effects of changing teatcup removal and vacuum settings on milking efficiency of an automatic milking system. Journal of Dairy Science, 2019, 102(11), 10500–10505. https://doi.org/10.3168/jds.2018-16035

[5] Jędruś A.: Ocena funkcjonalna ćwiartkowych aparatów udojowych. In: Problemy zrównoważonego rolnictwa, odnawialnych źródeł energii, ochrony obszarów wiejskich i zasobów wodnych, 2022, vol.28, 122-128, ISBN 978-83-65426-67-3.

[6] Lipiński M.: Urządzenie do automatycznego zdejmowania kubków udojowych ze strzyków. Przegląd Hodowlany, 1981, 23, 17-18.

[7] Lipiński M.: Badania modelu urządzenia automatyzującego zdejmowanie kubków udojowych ze strzyków krowy. Roczniki AR Poznań, 1985, 163, 27-33.

[8] Szlachta J.: Parametry techniczno-funkcjonalne urządzenia do automatycznego, indywidualnego zdejmowania kubków udojowych z podojem mechanicznym. Roczniki AR Poznań, 1988, 200, 267-274.

[9] Szlachta J.: Urządzenia do automatycznego przerywania doju i zdejmowania kubków udojowych. Maszyny i Ciągniki Rolnicze, 1990, 4-5, 15-17.

[10] Juszka H., Lis S. & Tomasik M.: Koncepcja dwukomorowego kolektora autonomicznego aparatu udojowego. Inżynieria Rolnicza, 2011, 8(133), 161-165.

[11] Jędruś A.: Przebieg doju krów z maszynową stymulacją ćwiartek wymienia. Rozprawa doktorska. Maszynopis Uniwersytetu Przyrodniczego w Poznaniu, 2007.

[12] Lipiński M.: Trendy rozwojowe konstrukcji maszyn przeznaczonych dla obór mlecznych. Prace i Materiały Zootechniczne, 2009, 67, 137-150.

[13] Luberański A., Wiercioch M., Szlachta J., Krzyś A. & Skalska D.: Cluster With Flo-Star Max Claw With Crossing Milk Connection Pipes. Agricultural Engineering, 2016, 20(3), 105-114. https://doi.org/10.1515/agriceng-2016-0048

[14] Sterrett A.E., Wood C.L., McQuerry K.J. & Bewley J.M.: Changes in teat-end hyperkeratosis after installation of an individual quarter pulsation milking system. Journal of Dairy Science, 2013, 96, 4041-4046. https://doi.org/10.3168/jds.2012-6069
[15] Ordolff D.: Eine neue Generation von Melkmaschinen. (A new generation of milking equipment). Top Agrar, 1972, 7, 11-12.
[16] Ordolff D.: Introduction of electronics into milking technology. Computers and Electronics in Agriculture, 2001, 30, 125-149. https://doi.org/10.1016/S0168-1699(00)00161-7
[17] Juszka H., Tomasik M. & Lis S.: Wizualizacja sterowania zautomatyzowanym aparatem udojowym. Materiały Konferencyjne Państwowego Instytutu Zootechniki. Perspektywy produkcji mleka i wołowiny w Polsce i na Świecie. Kraków, 2012, 181-182.
[18] Lis S., Tomasik M. & Juszka H.: The design of a prototype system which controls the flow of milk in the collector's column of an autonomous milking apparatus. BIO Web Conf., 2018, 10, 02016 https://doi.org/10.1051/bioconf/20181002016
[19] Tomasik M.: Stabilization of suction pressure in the conceptual milking unit. Inżynieria Rolnicza, 2015, 2(154), 127-135. http://dx.medra.org/10.14654/ir.2015.154.128
[20] Jędruś A.: Właściwości funkcjonalne nowego ćwiartkowego aparatu udojowego. In: Aktualne problemy inżynierii biosystemów, 2016, 197-205, ISBN: 978-83-7160-827-8.
[21] Jędruś A.: Wpływ pulsacji ćwiartkowej sterowanej automatycznie na przebiegi końcowych faz dojów krów. Sprawozdanie merytoryczne MNiSW nr N N313 444937, 2012.
[22] Jędruś A. & Luberański A.: Badania porównawcze z zastosowaniem aparatu udojowego działającego przemiennie i równocześnie. In: Innowacyjne technologie w produkcji zwierzęcej z uwzględnieniem standardów Unii Europejskiej, ochrony środowiska i energii odnawialnej, 2018, 78-84, ISBN 978-83-65426-34-5.
[23] Jędruś A. & Luberański A.: Wybrane problemy budowy ćwiartkowych systemów udojowych. In: Innowacyjne technologie w produkcji zwierzęcej z uwzględnieniem standardów Unii Europejskiej i ochrony środowiska, 2017, 58-64, ISBN: 978-83-65426-28-4.
[24] Jędruś A.: Wpływ pulsacji ćwiartkowej na zdrowotność wymion krów. In: Aktualne problemy inżynierii biosystemów, 2017, 195-203, ISBN: 978-83-7160-859-9.
[25] Jędruś A. & Boniecki P.: Neuronowa analiza wpływu pulsacji ćwiartkowej na zdrowotność wymion krów. In: Aktualne problemy inżynierii biosystemów, 2019, 116-125, ISBN 978-83-7160-966-4
[26] Jędruś A., Boniecki P., Dach J., Pilarski K. & Przybył J.: Neural predictive model in the estimation process of somatic cell counts in milk. In: BICA'12: Proceedings of the 5th WSEAS congress on Applied Computing conference, and Proceedings of the 1st international conference on Biologically Inspired Computation, 2012, 58-61, ISBN: 978-1-61804-089-3.
[27] Jędruś A.: Wybrane aspekty projektowania nowego ćwiartkowego udojowego. In: Innowacyjne rozwiązania w produkcji rolnej ze szczególnym uwzględnieniem chowu zwierząt, 2020, 26, 109-117, ISBN 978-83-65426-41-3.
[28] Jędruś A.: Milk temperature measurements in milking systems – own research. Journal of Research and Applications in Agricultural Engineering, 2025, 70(2), 21–28. https://doi.org/10.53502/jraae-215072
[29] Jędruś A.: Zastosowanie czujnika temperatury jako indykatora wypływu mleka. In: Aktualne problemy inżynierii biosystemów, 2014, 163-171, ISBN: 978-83-7160-731-8.
[30] Lipiński M.: Dynamika końcowej fazy doju mechanicznego krów w aspekcie jego częściowej automatyzacji. Rocz. AR Poznań. Rozprawy Naukowe, 1991, 55-75.
[31] Kupczyk A.: Wstępne założenia dojarki cybernetycznej (An attempt to foredesign of cybernetic milking machine). Problemy Inżynierii Rolniczej, 1999, 2(24), 61-68.
[32] Gaworski M. & Boćkowski M.: Comparison of Four Generations of Milking on Polish Dairy Farms. Agriculture, 2025, 15(5), 548. https://doi.org/10.3390/agriculture15050548
[33] Østeras O. & Lund A.: Epidemiological analyses of the associations between bovine udder health and milking machine and milking management. Preventive Veterinary Medicine, 1988, 6, 91-108. https://doi.org/10.1016/0167-5877(88)90047-5