Development of automatic milking systems and their classification

D R Sharipov, O A Yakimov, M K Gainullina, A R Kashaeva, I N Kamaldinov

Kazan State Academy of Veterinary Medicine named after N.E. Bauman, 35, Sibirskiy tract, Kazan, 420029, Russia

E-mail: Abdul0401@rambler.ru

Abstract. The paper presents the history of the development of automatic milking systems and their classification. The objects of study were automatic milking systems that are used in world practice. The analysis of automatic milking systems showed that they have technological and design differences. Technological and design features of automatic milking systems such as "Astronaut A4", "VMS", "M'erlin", "MR-S2", "MR-D2", "RDS FutureLine", "Galaxy Starline" and "Mlone" were considered in working out of this classification. The studies have shown that the existing automatic milking systems differ in the number of milking boxes and their location, type of robot arm, drive control of robot arm, robot arm location, decision of cleaning the teats and stimulating milk flow, decision of entry and exit of cows from the milking boxes.

1. Introduction

There is a growing trend throughout the world in the using of automated technologies in agriculture, including livestock [1]. This direction in dairy cattle breeding is an emphatic success thanks to the application of an automatic milking system.

The history of the development of automatic milking machines dates back to last mid century. So, in the 50s of the XX century, they conducted operations related to the study and implementation of full milking process automation. However, only in the 1970s, when the labor cost began to grow many countries, started putting ideas of a fully automatic milking process into practice. In 1970-90, a number of institutions in Western Europe worked on a system for determining the correct position of the teats, developed a device for automatically attachment milking clusters [2], and most of these developments were carried out at the Silsoe Research Institute (England). Such manufacturers as "Lely Industries N V" (the Netherlands), "Gascoigne Melotte" (Belgium), "Insentec" (the Netherlands) began scientific developments of automatic milking systems almost simultaneously. The first experimental milking robot of "Gascoigne Melotte" company was introduced in 1986 at the experimental research farm "De Waiboerhoeve" in Lelystad (the Netherlands) and at the same time, the research was carried out on the possibility of adapting cows to milking in these units [3]. In 1990, company "Prolion" (the Netherlands) demonstrated its system in the experimental farm "IMAG-DLO" which is located in Duiven (the Netherlands) [4]. However, after numerous changes and improvements, their final use and manufacturing application was carried out in 1992, when farmers made a purchase of the first four milking robots of "Lely Industries N V" company [5].

By 1998, about 100 automatic milking systems "Astronaut" were installed on Netherlands farms,
At the end of 2002, there were 1754 automatic milking systems in the world, in 2007 there were 8190, in 2010 more than 16,000. At the same time, in Germany and France in 2010 30% of all milking equipment was automatic milking systems, in Denmark – 50%, in the Netherlands – 57% [7].

In 2017, the number of operated automatic milking systems was amounted to more than 35,000 worldwide [8]. This number will increase whereas automatic milking technology is becoming more available and precise for farmers, and it reduces the use of human labor.

Our analytic investigation of automatic milking systems application in practice showed that they have technological and design features.

The objective of this research is to structure the available information about automatic milking systems and to develop a classification of existing automatic milking systems by technological and design features.

2. Materials and methods

The objects of study were automatic milking systems that are used in world practice. When developing the classification, the following automatic milking systems were considered:

- "Astronaut A4" (Lely Industries N V, Maassluis, the Netherlands);
- "VMS" (DeLaval International AB, Tumba, Sweden);
- "M2rlin" (Fullwood Limited, Ellesmere, England, UK);
- "MR-S2", "MR-D2" (BouMatic Robotics, Emmeloord, the Netherlands);
- "Mlone" (GEA WestfaliaSurge GmbH, Oelde, Germany);
- "RDS FutureLine" (S A Christensen & Co, Kolding, Denmark);
- "Galaxy Starline" (Insentec, Marknesse, the Netherlands).

Automatic milking systems were grouped by design features and main distinguishing characteristics that affect the milking process of cows.

3. Results and Discussion

Figure 1 shows the proposed classification of automatic milking systems.

![Classification of automatic milking systems](image-url)
The basic rule when operation of the automatic milking system is to observe the direction of traffic of the animals. There are two ways of animals’ traffic direction: forced (guided) and free (voluntary).

In the case of using the first way of animals’ traffic direction, the barn is divided into lying, milking and feeding areas. There are "first milking" and "first feeding" systems here.

When implementing the "first milking" system, animals gain access to feed only after passing through the milking area. The "first feeding" system provides cows with access to feed at any time and, depending on how much time has passed since the last milking, this system heads the animals for the particular area. The disadvantage of this solution is that cows often wait in line for milking. In contradistinction from the first way in the system with voluntary traffic, the access to the feeding area is free in order to stimulate the arrival of cows to the milking box. The ways of animals’ traffic direction designed for automatic milking make it possible to bring the average number of milking up to 2.45-3.20 times a day (table 1).

### Table 1. Literature data on milking frequency in automatic milking systems

| Author                  | Cow traffic systems | Milking frequency | Reference |
|-------------------------|--------------------|-------------------|-----------|
| Carlström C et al.      | forced             | 2.45              | [9]       |
| Pezzuolo A et al.       | free               | 2.62              | [1]       |
| Castro A et al.         | free               | 2.69              | [10]      |
| Hermans G G N et al.    | forced             | 2.80              | [11]      |
| Madsen J et al.         | free               | 2.96              | [12]      |
| Sharipov D et al.       | free               | 3.10              | [13]      |
| Paddick K et al.        | forced             | 3.20              | [14]      |

The current designs of automatic milking systems vary in the number of milking boxes (figure 2).

**Figure 2.** Design of automatic milking systems: a – single-box; b – multi-box with two parallel milking boxes; c – multi-box with several milking boxes located in one row.

Single-box ("Astronaut A4" (Lely Industries N V), "VMS" (DeLaval International AB), "M'Erlin" (Fullwood Limited), "MR-S2" (BouMatic Robotic) etc.) are placed directly in the cowsheds between places for cows lying (figure 2 a). Each such system can milk not more than 70 cows per day.

Multi-box automatic milking systems which contain from 2 to 5 places are located in a separate room and can milk from 120 to 350 cows per day. At the same time, multi-box milking robots can consist of two parallel milking boxes ("RDS FutureLine" (S A Christensen & Co), "Galaxy Starline" (Insentec), "MR-D2" (BouMatic Robotics) etc.) (figure 2 b) and several milking boxes mounted in the
The main working element of an automatic milking system is a multifunctional robot arm, designed in the image of a human hand. The robot arm is able to make three-dimensional movements, and it prepares the udder for milking (cleaning on the teats of the udder), attaching milking clusters on the teats, and in some versions disinfection of the teats after milking.

Herewith, automatic milking systems can be classified according to the type of the used robot arm. Some manufacturers produce automatic milking systems with a special robot arm, designed especially for animals’ milking ("Astronaut A4" (Lely Industries N V), "M2erlin" (Fullwood Limited), "Mlon" (GEA WestfaliaSurge GmbH)). Other manufacturers in their automatic milking systems use an industrial robot arm, which is also found in other industries ("VMS" (DeLaval International AB), "MR-S2" and "MR-D2" (BouMatic Robotics), "RDS FutureLine" (S A Christensen & Co), "Galaxy Starline" (Insentec)).

According to drive control of robot arm, there are systems with hydraulic drive ("VMS" (DeLaval International AB) etc.), pneumatic drive ("Astronaut A4" (Lely Industries N V) etc.), electric drive ("RDS FutureLine" (S A Christensen & Co) etc.).

According to the location of the robot arm, we can distinguish systems with a side location from the udder ("Astronaut A4" (Lely Industries N V), "VMS" (DeLaval International AB) etc.) and systems with a location behind the cow's udder ("MR-S2" and "MR-D2" (BouMatic Robotics)).

The existing automatic milking systems are also differed in cleaning the teats and stimulating of milk flow, they can be divided into three types [15]. Several manufacturers use the udder preparation module with a special cluster, designed specifically for these procedures. Herewith, each teat of the udder is individually washed, stimulated, per-milked and dried by warm air ("VMS" (DeLaval International AB), "MR-S2" and "MR-D2" (BouMatic Robotics), "RDS FutureLine" (S A Christensen & Co), "Galaxy Starline" (Insentec)). Others produce a cleaning and stimulation system so called rotating brushes. This system cleans the area around the teats that the milking clusters come into contact with. Pre-milking and disposal of the first jets of milk takes place when milking clusters are worn ("Astronaut A4" (Lely Industries N V), "M2erlin" (Fullwood Limited) etc.). There is a system where all every step of the milking process, including cleaning and teat stimulation, occur within the milking clusters ("Mlon" (GEA WestfaliaSurge GmbH)).

There are several design decisions of entering and exiting animals from milking box. On this basis, they can be divided into side location, straight location and combined location (figure 3).
the process of training cows for milking and increases the system capacity. "Fullwood Limited" company developed a combined entry and exit in the latest generation of the automatic milking system "M'Erin", animals enter and exit the milking box through the side as well as straight (figure 3c). Thanks to the double exit, the design combines the output and sort gates into a single unit, which allows controlling the traffic of cows without using of additional sort gates.

4. Conclusion
Thus, the presented classification of the developed and commercially available automatic milking systems allows grouping them by design and technological features.

Conflict of interest
We confirm that no commercial organization has encountered a conflict of interest with respect to the materials discussed in this scientific article.

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