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Robotic milking in dairy farming

W. ROSSING, P.H. HOGEWERF, A.H. IPEMA*, C.C. KETELAAR-DE LAUWERE AND C.J.A.M. DE KONING

Institute of Agricultural and Environmental Engineering (IMAG-DLO)
P.O. Box 43, 6700 AA Wageningen, The Netherlands
* Corresponding author (fax: +31-317-425670; e-mail: a.h.ipema@imag.dlo.nl)

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Abstract

In the last decade technical tools were developed for the full automation of the milking process. Solutions for different components of an automatic milking system (AMS), such as the milking stall, robot arm, teat sensing system, milking equipment and udder cleaning devices were found.

In the Netherlands two companies are on the market with an automatic milking system. Some other countries are following in the near future.

In an AMS situation cows are expected to visit voluntarily a milking stall several times daily. The attractiveness of the milking stall, lay-out of the barn and the introduction of a cow routing with special gates in the barn seem to be important in this respect. The effect of these systems on cow behaviour and welfare are studied.

Automatic milking systems make it possible to increase the milking frequency. Increasing the milking frequency from twice to three times per day results in a higher yield of about 1000 kg milk per lactation.

First steps have been made in the development of a control and management system to optimize the feeding and milking frequency for each cow individually. Under optimal conditions for cow traffic to and inside the AMS an occupation rate of 80% could be reached. In that case the capacity of a robotic milking stall will be about 6 milkings per hour under a regime of three daily milkings per cow.

It is expected that automatic milking will contribute to a lower physical and mental load on the farmer. But it should be considered that the farmer is working with complicated equipment.

Keywords: milking robot, milking frequency, milk yield, barn lay-out, animal welfare, labour

Introduction

Milking cows by machine, to replace the practice of milking by hand, has been known for more than a century. It was a major innovation for the dairy industry and resulted in a big labour saving on the dairy farm. The work load on the dairy farmer, however, is still considerable, among others due to the increase of herd size. In general, milking can be classified in the category of light to moderately heavy labour (Belt & Zegers, 1984). In a Dutch investigation it was found that 40% of the milkers had complaints with back and 30% with neck and shoulders (Hildebrand, 1989). The introduction of robotic milking will reduce these health complaints of farmers. Moreover, they will provide the farmer with more flexibility in his job and working hours.

Most cows are still milked twice a day, even though their milk yields have almost doubled in the last 30 years. The long intervals between milkings might be not optimal for the welfare of the high yielding cow. It points to a need for increasing the milking frequency to three times per day. Milk yield will benefit from increasing the milking frequency. Use of an automatic milking system (AMS) will open the possibility to milk more frequently without increasing the daily labour input. Therefore, the use of robots for milking creates a new challenge for dairy farming.

In the development of automated milking systems emphasis has been laid until now on self service milking, in which cows are expected to visit voluntarily a milking stall several times daily.

This paper reviews the role of engineering research in the developments in robotic milking systems and the integration of robotic milking in the dairy farm. Also a short overview about the commercial systems on the market at the end of 1996 is given.

Components of an automatic milking system

Equipment for automatic attachment of milking units has been developed in a number of countries. But the robot is only a part of the full system needed.
An automatic milking system is made of a number of different components. These are:
- the milking stall
- the milking robot
- milking equipment
- barn structures and equipment to support cow routing

The milking stall

The milking stall itself, and all aspects of the milking process, should be comfortable and positively reinforcing to the animals (Hurnik, 1992).

In conventional dairy farms cows are milked in a milking parlour. It would be possible to install a milking robot in an existing milking parlour. One robot per stall however is too expensive. A robot moving from one box in the parlour to another could be possible, but in existing milking parlours the freedom of movement of the animals is too large. For this reason special milking boxes were designed for robotic milking (Figure 1). When the milking system is active, the entrance gate opens. After a cow enters the milking stall and is identified by her neck transponder, a movable concentrates trough could be used to adjust the lenght of the milking stall to the

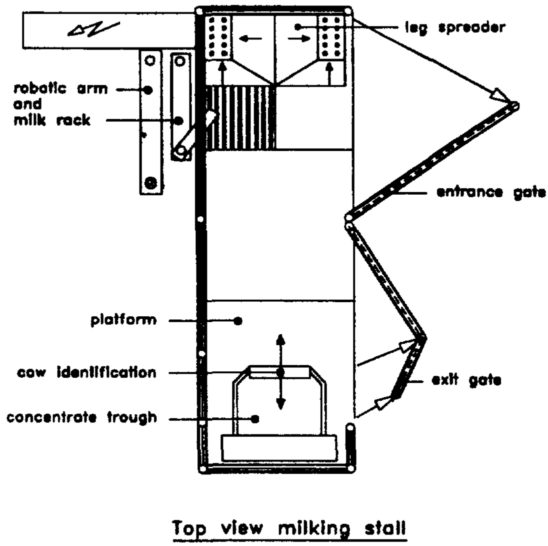

Figure 1. Top view of a robotic milking stall (Devir *et al.*, 1996)

length of the cow (Hogewerf *et al.*, 1992) while at the same time the entrance gate closes.

For better access to the udder for the robot arm, the front of the stand may be raised (Mottram, 1992, Mottram *et al.*, 1994). It is also possible to construct the floor in such a way that the cow is forced to spread her hind legs; this makes the udder more accessible and the teats easier to find.

After milking is finished, the concentrate trough is moved to its forward position, the exit gate opens and the cow can leave the milking stall. When a cow is reluctant to leave, a mechanical pusher may be used to push the cow out. When a cow has left the milking stall, the exit gate closes, and the entrance gate opens to make the milking stall available for the next cow.

The milking robot

A milking robot consists of a sensor system to locate the position of the teats and a manipulator to attach the milking unit to the teats.

Teat sensing systems

The shape of the udder and the distances between teats differ between breeds, herds, cows and within cows over time.

The wide variation in teat position and the possibility for the animal to move, requires a flexible teat sensing system. The position of the teats is dependent on the stage in the lactation and the milking interval. To investigate the influence of these variables the position of the teats of 400 dairy cows on a number of farms during a total of 100,000 milkings were measured (Figure 2). The increase in teat distances as the udder fills after milking is rather linear (Miller *et al.*, 1995).

The positions of the teats are also influenced by whether the cow was lying down or standing during the preceding hours. Therefore, data of each animal concerning the position of the teats with respect to a reference point (e.g. the right front teat) alone will not be sufficient for attaching successfully the teat cups.

Measuring the position of the animal in combination with a fine sensor for measuring the right place of the teats is a useful approach. In such a situation a fine sensor is guided to the area where the teat is expected, after the information about the position of the animal is available.

In various types of milking robots, the following techniques for teat location are applied:

- two ultrasonic sensors, one for locating the right front teat and a sensor with a rotating field to measure the distances and the angle between the other three teats and the right front teat (Hogewerf *et al.*, 1992);
- a laser sensor to find the positions of the teats with reference to a point on the robot arm (Dalebout, 1993);
- a laser plane and CCD (charge coupled device) camera in combination with a fine sensor with light barriers (Marchal *et al.*, 1992);
- a combination of a database of teat positions, an ultrasonic sensor and light barriers (Dück, 1992);

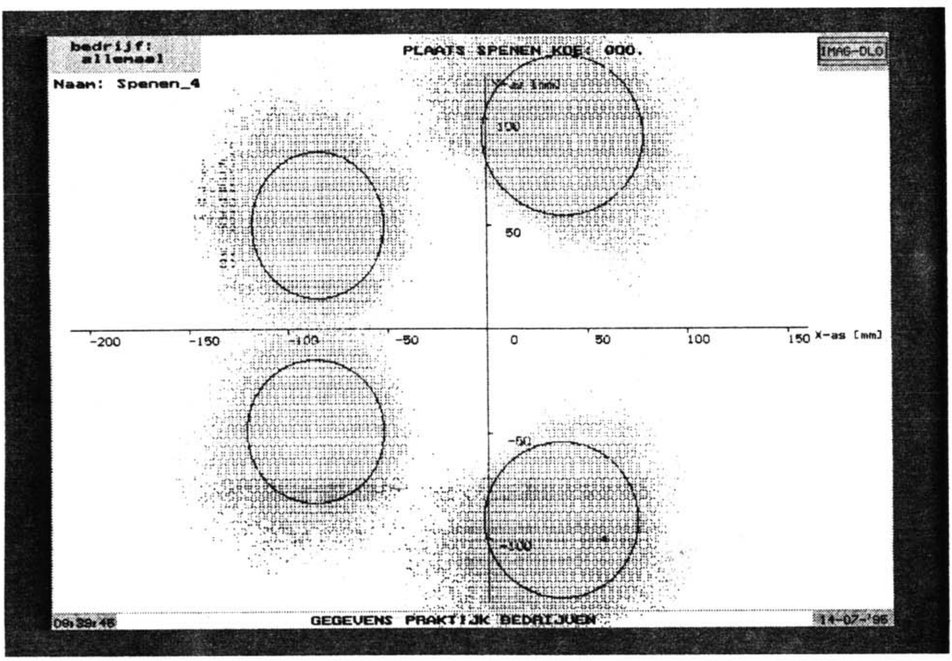

Figure 2. Variation in teat positions of cows. Data of 400 cows measured during a total of 100,000 milkings.

- tactile sensors combined with a database with teat position information and a fine sensor with light barriers (Street *et al.*, 1992)

Teat cup attachment systems
In an automatic milking system a robot arm has to move the teat cups to the teat end to attach the cup on the teat.

The attachment of teat cups in an automatic milking system is a dynamic process. Cows are often moving and the system for detecting the teat position must follow the position of the cow at each moment. The manipulator for attaching the teat cups must therefore be fast and accurate enough to follow precisely the movement of the animals during the attachment. The fulfilment of these demands require a high technical effort. To minimize problems with the inertia of the robot arm, the relationship between the mass of the arm and the required speed of the movements has to be considered carefully in the design.

The following types of robot arm have been developed:
- a single arm with gripper; such a system can imitate conventional milking in which a person picks up the cluster and attaches the four teat cups in succession (Street *et al.*, 1992, Dück, 1992). This way of attachment, in which one robot arm removes the teat cups one by one from a rack on the side of the stall, is time consuming and requires long milk tubes;
- one arm with four permanently attached teat cups; milking of all quarters can start at once or in a short time span (Bottema, 1992; Van der Linde & Lubberink, 1992). The teat cups can directly be connected to the robot arm or to a separate arm which is picked up by the robot arm. The last type of robot arm can serve more milking stalls.

Teat cup attachment systems might approach the cow from the side, from the rear or from underneath (Schön *et al.*, 1992). However, when the teat cups are attached from behind, it is essential that the cow's hind legs are spread apart and that soiling of equipment is prevented.

The system should also detect whether the teat cups are attached correctly on the teat. Teat detection inside the cup by means of a capacitive sensor or milk flow detection per quarter.

Milking equipment

The basic elements of a milking machine are a vacuum system, the pulsation components. an arrangement for transporting and collecting milk, and the milking cluster (with four teat cups) which brings the vacuum and pulsation to the cow. These elements are also used in an automatic milking system. Nevertheless there are some differences. An automatic milking system lacks a milking claw. The teat cups are connected by milk tubes to a recorder jar or milkmeter.

Teat cleaning
Milk should be produced under clean and hygienic conditions. It is essential that robotic milking systems meet the current and future milk quality standards; milk quali-

ty is expected to be an important issue in the coming years (De Boer *et al.*, 1994).

In conventional milking systems the milker can differentiate between cows with dirty and clean udders. Therefore, he can carry out a special cleaning treatment to cows with dirty udders. In robotic milking systems, it is unclear if the teats of all cows have to be cleaned. Automatic detection of dirty udders or teats could help to clean only those cows with contaminated udders. Some experiments with automatic detection of dirt have been carried out (Bull *et al.*, 1995). However, until now there are no commercial dirt detection systems available.

Udder cleaning can be executed by rotating brushes or discs, with or without a water supply (Van der Linde & Lubberink, 1992). An automatic cleaning device described by Bottema (1992) sprays water in the teat cup liner after attachment to the teat. Another manufacturer uses a robotic device with towels (Dalebout, 1993).

Experiments with automatic cleaning of udders and teats have shown that such systems are better than no cleaning, but are unlikely to remove all visible dirt (Schuiling, 1992). Teats which are contaminated with dry manure can only be cleaned after soaking for some time. Systems have to be developed to complete this process before a cow enters the milking stall. The processes which have to be executed in-line are soaking, cleaning and drying of the teats and udder.

Milking machine cleaning

A good cleaning and disinfecting routine for milking equipment is one that with the minimum of time, effort and cost results in visibly clean equipment and milk consistently meeting the buyer's requirement for hygienic quality.

The process of cleaning milking equipment usually consists of pre-rinse, alkali or acid cleaning, desinfection and after-rinse. In conventional milking, cleaning is done after each milking. When milkings are spread throughout the day as in an automatic milking system, a proper cleaning frequency should be applied. In robotic milking, a relatively small amount of fresh milk flows continuously through the circuit to the milk tank. Experiments have shown that the bacteriostatic action of fresh milk suppresses the bacterial count. Nevertheless, there is an exponential increase in the number of bacteria (Schuiling, 1995) between two system cleanings. Therefore, there should be at least three cleanings per day.

Milk cooling and storage

After milking the milk is stored and cooled in a bulk tank. The purpose of cooling milk is to keep it in satisfactory bacteriological condition during a storage period of 2–3 days. This means that the milk cooling system design should be considered a cooling and a storage component. The storage capacity should be sufficient for the required storage period. The cooling capacity is the refrigeration effect required for adequate cooling of milk to a temperature below 4 °C, within 2–3 hours.

In robotic milking situation, there is a relatively small amount of milk continuously flowing to the bulk tank. Therfore, in-line cooling systems offer good possibilities. In an in-line cooling system, milk is cooled separately and the cooled milk is stored in a storage tank. Boerekamp & Slaghuis (1993) could not detect any significant differences in bacteriological quality between both systems.

Barn layout

In a conventional system the milker brings the cows to a waiting area from where the animals can enter the milking parlour. The cows leave the parlour to find their way back to the barn. In an AMS situation cows are expected to voluntarily visit a milking stall several times daily.

Possible solutions for controlling the visiting frequency to an AMS are based on the barn layout (location of the milking stall) and the attractiveness of the milking stall. In figure 3 different solutions for the cow traffic in a barn are given:

- routing layout A: the cows are free to move from the lying to the feeding area and back. From the lying area they have free access to the AMS. In this situation the visiting frequency will mainly depend on the attractiveness of this stall. Motivation to be milked is unlikely to be a sufficient stimulus to attract cows intc the AMS (Prescott *et al.*, 1996). Offering concentrates in the stall is one way to attract cows. In 1985 research was carried out to milk cows in a concentrate feeding station that could be visited voluntarily (Rossing *et al.* 1985). Cows visited this simulated automatic milking station 5.4 times daily on average. The cows were milked 4.0 times a day on average.
- routing layout B: unnecessary visits can be prevented by placing a selection unit (SU) in front of the AMS. If the robotic system is to be used efficiently, each individual cow must be milked at intervals that are spread over the day as evenly as possible. Visiting the milking station frequently, when milking is not needed, reduces the unit's capacity as a robotic milking system.In this SU it is established whether a cow is be admitted to the milking station or returned to the herd.

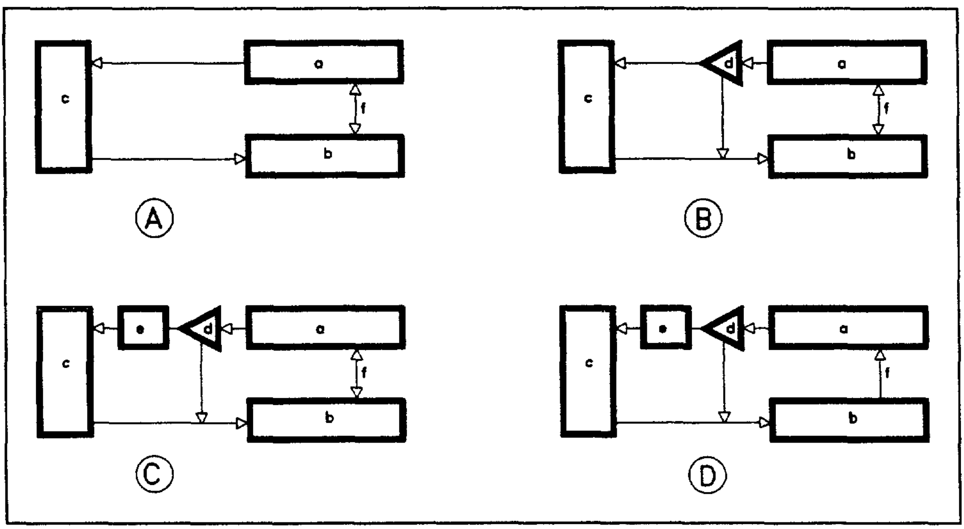

Figure 3. Routing lay-outs for cow traffic in a barn with a robotic milking system (for explanation of A, B, C and D, see text).

a. lying area	c. AMS	e. waiting area
b. feeding area	d. SU	f. passage

Results from Devir *et al.*(1996) showed that when the concentrate ration is fed in SU and AMS the cows visited the system about 6 times daily on average. It was concluded that this offers good possibilities for a more frequent milking regime.

- routing layout C: a waiting area between the SU and the AMS is added. If the decision in the SU is to milk, the cows can enter the waiting area and go on to a milking stall, if one is free. In this situation the capacity of the SU is expected to increase.
- routing layout D: one way cow routing is introduced to address the problem of cows visiting the automatic milking station less often than the desired milking frequency. In this routing the cows must pass the milking robot system in order to move from the lying area to the feeding area. If cows have free access to the forage, they will consume it in 7 to 10 meals per day independent of production level (Pirkelmann, 1992). By controlling this movement with one-way gates cows can be selected for milking en route from lying to feeding. One way cow traffic guarantees sufficient visits to an automatic milking system (Ketelaar-de Lauwere, 1992; Winter & Hillerton, 1995). A more individual approach of one-way cow traffic with selection umits was used by Devir (1995). In this approach a decision support system controls and operates the daily milking and concentrates feeding routine. The robotic milking system consists of a milking stall with two selection units in a barn with one-way cow traffic. Concentrates are fed in the AMS and the SU's. The results indicated that all cows could be milked four times a day without the need to bring any cow to the robotic milking system.

Systems operating in practice

In a number of countries equipment for the automatic attachment of milking units has been developed (Schön *et al.*, 1992; Rossing *et al.*, 1994a,b). All these automatic milking systems have the same aim; the complete automation of the milking process, efficient milk production that takes human and animal welfare into account. However, the principles and techniques employed differ from each other.

Two Dutch systems are already commercially available. Some systems in other countries are still under development. An overview of the technical principles used and the numbers produced for the different systems is given in Table 1.

At the end of 1996 around 60 installations are in use on commercial dairy farms and research institutes. A majority of the robotic milking systems are located in the Netherlands. It is expected that in the year 2005 the number of farms with robotic milking systems in the Netherlands will be between 5 and 20% (De Boer *et al.*, 1994). Uncertain factors such as the costs of a robotic milking system and the development of the milk price will influence the further introduction in practice.

Table 1. Robotic milking systems

Manufacturer	Number of installations	Principle	Remarks
A. Systems on the market (end of 1996)			
Lely Industries (The Netherlands)	34 farms with 48 robot arms all on commercial farms	one box systems, one robotarm/box laser sensor for teat detection with a milk rack with 4 teat cups	most systems used for milking in self service
Prolion Development (The Netherlands)	38 farms with 98 boxes; 4 on experimental farms 34 on commercial farms	1, 2, 3 or 4 box system with one robot moving along these boxes Ultrasonic sensors for teat detection	systems used for milking in self service as well as for milking in batches arm with milk rack and 4 teat cups
B. Systems under development			
AFRC, Silsoe Research Institute (UK)	2 on experimental farms	one box system; one arm attaches the 4 teat cups one by one	system now under development by Alfa Laval
CEMAGREF (France)	1 on experimental farm	one box system; 4 arms, each attaches one teat cup	
Düvelsdorf/Westfalia (Germany)	2 on commercial farm	one or two box system; one arm attaches the 4 teat cups one by one	system taken over by Westfalia
Gascoigne Melotte (The Netherlands)	2 on experimental farms	one box system; one arm with a milk rack and 4 teat cups	teat cups are attached from behind between the hind legs

Consequences of automatic milking

Milk yield and milk quality

An important aspect of the introduction of the milking robot is that it makes it easier to increase the milking frequency which has a positive effect on the daily milk yield. Erdman & Varner (1995) concluded from a literature survey that increasing the milking frequency from twice to three times per day results in an increase of 1000 kg milk and 28 kg of milk fat per lactation.

Ipema & Benders (1992) found a decreased teat end quality when increasing the milking frequency to 4 times per day, indicating that udder health is at greater risk.

Another risk of an increased milking frequency is the increased free fatty acid (FFA) content of milk (Ipema & Schuiling, 1992). The larger predisposition following an increase in the FFA contents requires that the construction and installation of the milking equipment should be designed to minimize further damage to the milk fat droplets.

Milking process and capacity

Robotic milking presents a challenge for research on the milking process. For example, milking intervals and moments of milking throughout the day will be variable from milking to milking. Also the time between entrance in the milking stall and attachment of the cluster may vary more than in conventional milking. Devir (1995) analysed the relation between 5 levels of this time and milking duration. A longer attachment time of the cluster gave a shorter duration of milking. The milk yield decreased when the time for attachment increased to over 3 minutes, but after this it decreased. These results implied that for up to 3 minutes the process of attachment stimulates the milk flow. A longer time for attachment might lead to incomplete milking and a reduction in milk yield, as supported by Rasmussen (1994).

The conditions for milking have to be as constant as possible from milking to milking. This was also shown in an experiment conducted by Rossing *et al.* (1985), in which the cows were used to get concentrates during milking. In milkings without concentrates feeding, the ejected amount of milk was lower than expected. Feeding concentrates not only improves the attractiveness of the milking stall, it may also improve the milk ejection, by affacting the release of oxytocin (Svennersten *et al.*, 1990).

The higher milk yields caused by an increase in milking frequency will increase the total milking time considerably. This causes extra stress on the teats. Ipema & Benders (1992) found an increase in the total daily duration of machine milking by 40% between 2 and 3 times milking and by 56% between 2 and 4 times milking a day. The machine milking times per milking were 7.1, 6.6 and 5.5 minutes at milking frequencies of 2, 3 and 4 times per day, respectively. For this reason it is questionable whether the conventional way of milking is the most suitable for a dairy cow. It is possible to adapt the different parameters of the milking machine for each individual animal. To study the influence of the vacuum level and the pulsator frequency on

Table 2. Milk ejection parameters per udder quarter; mean values for 16 cows (Ipema & Hogewerf, 1996)

Parameter	Rear quarters		Front quarters	
	right	left	right	left
Machine milking duration (min)	7.33	7.38	7.44	7.27
Milk yield (kg)	4.62	4.72	3.29	3.44
Average flowrate (kg/min)	0.65	0.65	0.46	0.49
Peak flowrate (kg/min)	0.95	0.94	0.83	0.80
Duration of overmilking (min)	0.53	0.34	1.47	1.04

the milk flow rate, special equipment to measure all the variables during milking from each individual teat was developed (Ipema & Hogewerf, 1996). An experiment using this equipment (Table 2) showed that there was a difference in yield and flow rates between teats. Controlling the different parameters for each animal and for each individual teat can optimize the milking process and so decrease the total machine milking duration.

To determine the capacity and size of a robotic milking system (number of milking stalls), it is important to know the capacity per milking stall.

In cases where selection units are used the number of selection units has to be tuned to the number of milking stalls and herd size. Factors such as milk yield, milking frequency, accessibility of a milking stall during the 24 hours and the occupation rate of the barn are important in this context.

When cows visit the milking robot system voluntarily the milking stall will be occupied for less time than the time available. The idle times depend on the cows' visiting pattern and on cows loitering at or obstructing the entrance or exit of the milking robot system. Ipema *et al.* (1987) reported that with a frequent milking regime the number of milkings is lowest between midnight and 06:00. However, about 20% of all daily milkings still took place in this period. Devir (1995) found that the milking station was occupied fairly evenly throughout the day. Table 3 shows that at a

Table 3. Mean milk production, milk flow rate, net machine milking times, milking stall occupation times per milking and milking stall capacity in relation to milking frequency per day (after Ipema, 1996)

	Milking frequency Times per day		
	2	3	4
Milk production per day (kg)	28.2	32.2	32.3
Average milk flow rate (kg/min)	2.0	1.6	1.5
Net machine milking time per day (min)	14.1	19.8	22.0
Milk production per milking (kg)	14.1	10.7	8.1
Net machine milking time per milking (min)	7.1	6.6	5.5
Milking stall occupation time per milking (min)	8.5	8.1	7.0
Milking stall capacity (milkings/hour)	7.1	7.5	8.6

100% occupation rate of a milking station theoretically 7.1, 7.5 and 8.6 milkings per hour at 2, 3 and 4 daily milkings are possible. From his experiment, Devir (1995) concluded that under optimal conditions for cow traffic to and inside the milking robot system, and good technical performance of the attachment system, a robotic milking unit could reach a capacity of at least 5.9 milkings per hour at three daily milkings per cow. This implies an occupation rate of a milking station of nearly 80%.

Animal welfare

Animal behaviour in relation to automatic milking is crucial for the welfare of the cows.

A positive aspect is the fact that high-yielding cows have increased lying times when milked more times daily (Ipema *et al.*, 1988). A lower tension in the udder which offers more comfort to the cow to lie down, might explain the increased lying times.

In an automatic milking system cows are no longer milked in batches but more or less one by one throughout the day. Significant disruptions to diurnal patterns of activity were not recorded (Winter *et al.*, 1992). Adaptation to increased frequency of milking was achieved through maintenance of lying time and compensatory feeding occurring at milking time.

At present, automatic milking designs are based on sequential access of cows over a 24-h period, with a feed reward to attract them. Nevertheless, in barns where the cows are free to choose their own moments to visit the automatic milking system, for a certain number of cows the preferred milking frequency will be difficult to reach. Therefore one-way cow routing systems are introduced in the barns (Figure 1). This active selection guarantees visits of all cows to the automatic milking system, but inhibits the cows' movements through the cowshed and the animals spend less time at the feeding gate (Ketelaar-de Lauwere, 1992; Winter *et al.*, 1992). Therefore, it is advised that active selection should not be applied for long periods. It seems possible to guarantee enough visits to an automatic milking system with passive selection after a certain training period of active selection (Ketelaar-de Lauwere, 1992).

Ketelaar-de Lauwere *et al.* (1996) concluded that effects of social dominance will appear when fully automatic milking systems are introduced. These effects may not concern the daily frequency of visits, nor the total time spent lying or feeding, but may be seen in the timing of the visits to the AMS and to the feeding gate and the time spent in the waiting area in front of the AMS. Cows with low dominance values seemed to adapt their visits to the AMS and the feeding gate to the cows with higher dominance by visiting both parts of the cowshed more at quiet times. Winter *et al.* (1992) also reported an overall reduction in feeding synchrony.

Another important aspect in the field of animal welfare and in the consumers' attitude to robotic milking is the possibility of grazing. Further research is required to investigate whether cows can be allowed some outdoor exercise or grazing in combination with such virtually continous milking regimes.

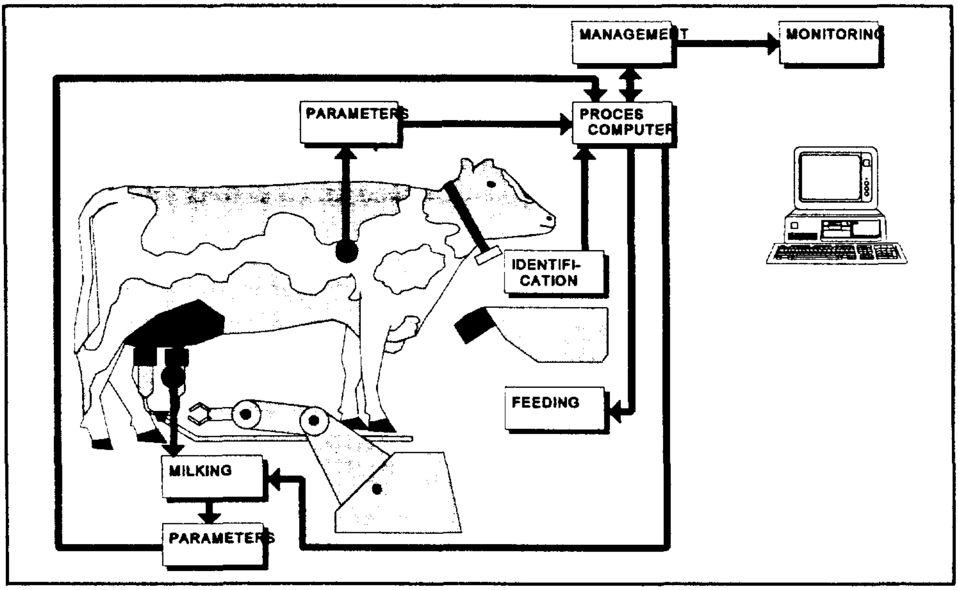

Figure 4. Outline of a system for cow monitoring, automatic milking and process control.

Management and labour organization

The installation of an automatic milking system on a dairy farm also requires a completely different attitude, operational routines in management and work organization. Because the farmer is not present each time a milking or feeding decision is needed, a new generation of dairy control and management systems has to be designed. The farmer can use a part of the labour saving for individual animal management. On-line data collection and processing have to be done to control the feeding and milking process. A Dairy Control and Management System (DCMS) has been developed for fully controlling daily milking, feeding and cow traffic (Devir, 1995). In this system, milking and feeding decisions are taken on-line and automatically implemented. This enables the daily routine of the AMS dairy farm to be fully automated. The total management system comprises the Dairy Control and Management System, the milking robot and milking controller, and a feeding and gate controller.

Measuring the individual cow parameters (Figure 4) opens the possibility for an individual approach to the animals. Measuring feed input, milk yield and body weight and controlling the milking frequency the production capacity of each cow in a herd can be fully exploited (Maltz & Metz, 1994).

Another task of the milker is to detect deviations in the cow status. This task has to be taken over by sensors. These technical tools can be integrated into the system to measure the different physiological parameters (Maatje *et al.*, 1994) and so help the dairy farmer in the decision-making process (Figure 4). Temperature sensors, which are integrated with the milking machine, can be used for detecting illness or oestrus. Milk parameters can give information about milk composition or udder inflammation. Udder inflammation (mastitis) is mostly accompanied by an increase in the concentrations of sodium and chloride and hence a change in the electric conductivity of milk. Sensors for measuring the milk conductivity of each quarter have been developed and integrated with the milking equipment. The activity level is known to increase during oestrus periods, so a pedometer attached to the cow's leg may enable oestrus detection. In the robotic dairy farm the automatic measurement of different parameters is essential for controlling the technical facilities and for optimal farm management.

Automatic milking will contribute to a lower mental and physical load on the farmer, but in some situations it can lead to more complications as the farmer is working with complicated equipment.

The effects of the integration of an automatic milking system on the labour organization will depend on the characteristics of the farm. Calculations with a developed task time program (Sonck, 1996) show that automatic milking with human-controlled cow traffic during the whole year and with a milking frequency of three times a day results in important physical labour savings for milking (37.5%). Automatic milking with computer-controlled cow traffic with cows kept indoors the whole year results in the largest labour reduction (66.1%).

Conclusions

An increase in milking frequency desired to reduce problems associated with higher yields per milking can be realized while reducing the labour requirements by using automatic milking systems.

In the design of automatic milking systems the biological variability of cows, the behaviour of animals and the technological specifications are essential information to develop systems with a satisfactory performance.

Automatic milking systems allow for the individual allocation of milking frequency, and combined with automated individual feeding and individual monitoring the concept of individual cow management becomes a possibility.

More attention has to be paid to farm management, labour organization, teat cleaning and milking technology on the robotic milking dairy farm.

References

Belt, A.H.M. & D.H.A. Zegers, 1984. Labour conditions during machine milking (In Dutch). IMAG-DLO, Wageningen, Publication 194. 34 pp.

Boerekamp, J.A.M. & B.A. Slaghuis, 1993. Instant cooling and conventional cooling of raw milk. Report 4. Research and Advisory Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad. 19 pp.

Bottema, J., 1992. Automatic milking: reality. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 63–71.

Bull, C., T. Mottram & H. Wheeler, 1995. Optical teat inspection for automatic milking systems. *Computers and Electronics in Agriculture*, 12: 121–130.

Dalebout, C.A., 1993. Technical aspects of the milking robot system (In Dutch). *Landbouwmechanisatie*, 9: 10–11.

De Boer, P.B., J.H.M. Metz & F.L. De Pater-Huijsen, 1994. Full automatic milking systems (In Dutch). Report 4. Department of Science and Knowledge Dissemination (DWK, LNV). Ministry of Agriculture, Nature Management and Fisheries, The Hague, 89 pp.

Devir, S., 1995. The dairy control and management system in the robotic milking farm. Ph.D. Thesis. IMAG-DLO, Wageningen, The Netherlands. Report 95–21, 172 pp.

Devir, S., H. Hogeveen, P.H. Hogewerf, A.H. Ipema, C.C. Ketelaar-de Lauwere, W. Rossing, A.C. Smits & J. Stefanowska, 1996. Design and implementation of a system for automatic milking and feeding. *Canadian Agricultural Engineering* 38(2): 107–113.

Devir, S., J.P.T.M. Noordhuizen & P.J.M. Huijsmans, 1996. Validation of a daily automatic routine for dairy robotic milking and concentrates supply. *Journal of Agricultural Engineering Research*, 64: 49–60.

Dück, M., 1992. Evolution of Düfelsdorf milking robot. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 49–54.

Erdman, R.A. & M. Varner, 1995. Fixed yield responses to increased milking frequency. *Journal of Dairy Science*, 78: 1199–1203.

Hildebrand, V.H., 1989. Prevention affection locomotion in Agriculture. Health and locomotion problems by workers in 14 different agricultural sectors (In Dutch). Report 89104, NIGP-TNO, Leiden.

Hogewerf, P.H., P.J.M. Huijsmans, A.H. Ipema, T. Janssen & W. Rossing, 1992. Observation of automatic teat cup attachment in an automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 80–90.

Hurnik, J.F., 1992. Ethology and technology: the role of ethology in automation of animal production processes. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 401–408.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effects of more frequent milking on production and health of dairy cattle. In: Proceedings of the Third Symposium Automation in Dairying. Institute of Agricultural and Environmental Engineering (IMAG-DLO), Wageningen, pp. 283–293.

Ipema, A.H., H.K. Wierenga, J. Metz, A.C. Smits & W. Rossing, 1988. The effects of automated milking and feeding on the production and behaviour of dairy cows. Proceedings of the Symposium of the Commission on Animal Management and Health and Cattle Production. European Association for Animal Production (EAAP), Wageningen, pp. 11–24.

Ipema, A.H. & E. Benders, 1992. Production, duration of machine-milking and teat quality of dairy cows milked 2, 3 or 4 times daily with variable intervals. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 244–252.

Ipema, A.H. & E. Schuiling, 1992. Free fatty acids; influence of milking frequency. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 491–496.

Ipema, A.H. & P.H. Hogewerf, 1996. Milking per quarter – milk ejection (In Dutch). *Landbouwmechanisatie*, 2: 38–39.

Ipema, A.H., 1996. Future aspects of milking: robotic milking. Proceedings of the Symposium on Milk Synthesis, Secretion and Removal in Ruminants. Berne, pp. 96–102.

Ketelaar-de Lauwere, C.C., 1992. The use of a selection unit for automatic milking; consequences for cow behaviour and welfare. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 270–277.

Ketelaar-de Lauwere, C.C., S. Devir & J.H.M. Metz, 1996. The influence of social hierarchy on the time budget of cows and their visits to an automatic milking system. *Applied Animal Behaviour Science* 49: 199–211.

Maatje, K., W. Rossing, P.H. Hogewerf & R.T. Ferwerda-van Zonneveld, 1994. In: Lind, O. & K. Svennersten (Eds.), Proceedings of the International Symposium Prospects for Future Dairying: A Challenge for Science and Industry. Uppsala, pp. 283–301.

Maltz, E. & J.H.M. Metz, 1994. An individual approach to manage the dairy cow: A challenge for research and practice. In: Lind, O. & K. Svennersten (Eds.), Proceedings of the International Symposium Prospects for Future Dairying: A Challenge for Science and Industry. Uppsala, pp. 267–282.

Marchal, Ph., G. Rault, Ch. Collewet & L. Wallian, 1992. Mains Project – Automatic Milking. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 33–39.

Miller, R.H., L.A. Fulton, B. Erez, W.F. Williams & R.E. Pearson, 1995 Variation in distances among teats of Holstein cows: Implications for Automatic Milking. *Journal of Dairy Science, 78: 1456–1462.*

Mottram, T.T., H. Caroff & C. Gilbert, 1994. Modifying the posture of cows for automatic milking. *Applied Animal Behaviour Science.* 41: 191–198.

Pirkelmann, H., 1992. Feeding strategies and automatic milking. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 289–295.

Prescott, N.B., T.T.F. Mottram & A.J.F. Webster, 1996. The effect of feed type and location on the voluntary attendance to, and the behaviour in, an automatic milking system. Proceedings of the 30th International Congress of the International Society for Applied Ethology, Guelph, p. 35.

Rasmussen, M.D., 1994. Possibilities for optimal milking efficiency. In: Lind, O. & K. Svennersten (Eds.), Proceedings of the International Symposium Prospects for Future Dairying: A Challenge for Science and Industry. Uppsala, pp. 86–95.

Rossing, W., A.H. Ipema & P.F. Veltman, 1985. The feasibility of milking in a feeding box. Research Report 85–2, Institute of Agricultural and Environmental Engineering (IMAG-DLO), Wageningen, 35 pp.

Rossing, W., S. Devir, P.H. Hogewerf, A.H. Ipema, C.C. Ketelaar De Lauwere & J. Metz-Stefanowska, 1994a. Robotic milking – State of the art. In: R. Buclin (Ed.), Proceedings of the Third International Symposium on Dairy Housing, Dairy Systems for the 21st Century. Amarican Society of Agricultural Engineers (ASAE), St.Joseph, MI, pp. 92–101.

Rossing, W., S. Devir, P.H. Hogewerf, A.H. Ipema, K. Maatje & J.H.M. Metz, 1994b. Automation in dairying. In: Lind, O. & K. Svennersten (Eds.), Proceedings of the International Symposium Prospects for Future Dairying: A Challenge for Science and Industry. Uppsala, pp. 267–282.

Schön, H., R. Artmann & H. Worstorff, 1992. The automation of milking as a key issue in future oriented dairy farming. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 40–49.

Schuiling, E., 1992. Teat cleaning and stimulation. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 164–169.

Schuiling, E., 1995. Requirements for cleaning at automatic milking (In Dutch). Research and Advisory Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad. *Praktijkonderzoek*, November, pp. 29–30.

Sonck, B.R., 1996. Labour organisation on robotic milking dairy farms. Dissertation Wageningen Agricultural University, Wageningen, 201 pp.

Street, M.J., R.C. Hall, D.S. Spencer, A.L. Wilkin, T.T. Mottram, & C.J. Allen, 1992. Design features of the Silsoe automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 40–48.

Svennersten, K., L. Nelson & K. Unväs-Moberg, 1990. Feeding-induced oxytocin release in dairy cows. *Acta Physiologica Scandinavica* 140: 295–296.

Van der Linde, R. & J. Lubberink, 1992. Robotic milking system (RMS): design and performance. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 55–62.

Winter, A., R.M. Teverson, R.M. & J.E. Hillerton, 1992. The effect of increased milking frequency and automated milking systems on the behaviour of the dairy cow. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.), Proceedings of the International Symposium on Prospects for Automatic Milking. Publication 65. European Association for Animal Production (EAAP), Wageningen, pp. 261–269.

Winter, A. & J.E. Hillerton, 1995. Behaviour associated with feeding and milking of early lactation cows housed in an experimental automatic milking system. *Applied Animal Behaviour Science* 46: 1–15