




ATB
Agrartechnik Bornim



International Workshop
The future of the quarter
individual milking

14. - 15. September 2010
Potsdam



Bornimer Agrartechnische Berichte

Heft 76

Potsdam-Bornim 2010



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Foreword

The main objective in dairy farming at present is to obtain the highest quality raw milk at lowest costs. Precision livestock farming are becoming wide spreading applications especially at dairy farms due to consumer consciousness, the use of technology and reduced labor force in European countries in agriculture.

Milk quality monitoring at teat end helps achieving the above mentioned objectives in many aspects. Lately, quarter individual milking found an extensive application area in automatic milking and conventional milking systems in dairy farms.

Many studies in the past were conducted by the scientists in order to determine the relationships among raw milk quality, animal health and milking system being used. Scientific studies and findings with today's technology and communications tools can be shared easily. Hence, world-wide collaboration by establishing new ties among the institutions and projects can be finalized in a faster way.

The objective of the workshop titled "The future of the quarter individual milking" is to discuss the results of such collaboration with the pioneering scientists and to light the future path in milking technology area. This objective is planned to be achieved by gathering international state of knowledge in quarter individual milking and discussing the fundamental papers.

The project titled "Testing and Developing of New Milking Equipment in Dairy Herds to Improve Udder health and Raw Milk Quality" as proposed by Leibniz-Institute for Agricultural Engineering Potsdam-Bornim e.V. (ATB) (Postdam-Germany) and Ege University was funded by International Bureau of the Federal Ministry of Education and Research (BMBF) between 2008 and 2010 and the results from this project and Quarter Individual Milking will be the main topic of this workshop.

The project leaders, Dr. Sandra Rose-Meierhöfer (Germany) and Asst. Prof. Dr. Hülya Öz (Turkey) extend their sincere thanks and appreciation to Siliconform GmbH (Türkheim-Germany) for their support and Jakob Maier, Prof. Dr. Hamdi Bilgen and Prof. Dr. Adnan Değirmencioglu, Ulrich Strobel, Dr. Christian Ammon and ATB technicians.

We believe that the concepts that will be developed and brought into Quarter Individual Milking Applications will make the workshop reach its objectives possible and provide the future path to be followed in Milking Technology. We also believe that the workshop will result in new international ties in terms of research and contribute to milking industry.

We thank all the participants and hope that this workshop proceeding will be useful for all who work in the field of Milking Technology.



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THE FUTURE OF THE QUARTER INDIVIDUAL MILKING

Program

14th September 2010

- 12.00 Registration/lunch
13.00 Opening R. Brunsch, Potsdam-Germany

Techniqual Aspects

- 13.30 Pros and Cons of technical aspects in quarter-individual milking systems
Keynotespeaker: *D. Reinemann, Wisconsin USA*

Chairman: *H. Bilgen, Izmir-Turkey*

14.30 – 16.15 Presentations

- 14.30 Quarter individual milking in conventional milking parlour
H. Öz and S. Rose-Meierhöfer, Izmir-Turkey and Potsdam-Germany
- 14.45 Coffee break
- 15.15 The potential of quarter individual milking to reduce the work load
M. Jakob, Potsdam-Germany
- 15.30 Mathematical modeling and optimization of vacuum related variables in conventional and quarter individual milking systems using response surface methodology
A. Değirmencioğlu et al., Izmir-Turkey
- 16.00 Controlling and regulation of vacuum at teat end in quarter individual milking systems
U. Ströbel, Potsdam-Germany
- 16.15 Discussion
- 18.00 End of the day
- 19.00 Boat trip and Dinner

15th September 2010

Quality of Milk

08.30 Evaluation of milk quality by quarter individual milking
Keynotespeaker: *Morten Dam Rasmussen, Foulum-Denmark*

Chairman: *R. Brunsch, Potsdam-Germany*

09.30 – 10.45 Presentations

09.30 Effects on milkability traits by using conventional and quarter individual milking systems

A. Müller, Potsdam-Germany

09.45 On-farm analysis in quarter individual milking

L. Forsbäck and K. Svennersten-Sjaunja, Sweden

10.00 Coffee break

10.15 Milk quality in AMS

K. de Koning, Netherlands

10.30 Fast mastitis detection during milking process for milk quality monitoring

O. Schlüter and A. Fröhling, Potsdam-Germany

10.45 Using image analysis to measure teat dimension

I. Zwertvaegher, Netherlands

11.00 Discussion and end of sessions

12.00 Lunch time

12.30 Excursion

ATB Potsdam

14.00 LVAT Groß Kreutz (research farm)

16.00 LKV Brandenburg (milk control organisation)

18.00 End of excursion (arriving at Potsdam)

Review of some of the potential benefits of quarter-milking

Review über den potenziellen Nutzen des viertelindividuellen Melkens

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Abstract: *As with any milking technology, the disadvantage of increased mechanical complication must be outweighed by the advantages the technology provides to the milking process in order to gain widespread acceptance. Individual teatcup removal is likely to produce a large reduction in congestion and oedema in teat tissues and an improvement in cow comfort during milking. Individual teatcup removal is likely to produce moderate reduction in teat-end hyperkeratosis. Separating quarters will eliminate pathogen cross-contamination between quarters but is unlikely to have a large effect on the new mastitis infection rate. Quarter control of pulsation and/or vacuum is possible in quarter milking systems, but the increased cost and complexity of this technology is unlikely to merit commercial development. Separating milk streams by quarter will improve the sensitivity of automated mastitis detection but will also increase the cost and complexity of these systems. Separation of milk streams also allows for diversion of quarter milk which can be a useful tool for controlling bulk tank somatic cell counts while minimizing milk loss from infected cows.*

Keywords: *machine milking, quarter milking, teat condition*

Zusammenfassung: Wie bei jeder Melktechnologie, muss der Nachteil der erhöhten mechanischen Aufwendungen durch die Vorteile der eingesetzten Technik beim Melken überwiegen, um allgemeine Verbreitung zu finden. Die viertelindividuelle Zitzenbecherabnahme trägt zu einer Reduzierung von Ansammlungen und Ödeme im Zitzengewebe bei und steigert den Kuhkomfort während des Melkens. Zusätzlich trägt die einzelne Zitzenbecherabnahme dazu bei Hyperkeratosen zu reduzieren. Die Trennung der einzelnen Viertel verhindert die kross-Kontamination mit Pathogenen jedoch scheint dies keinen großen Effekt auf die Neuinfektionsrate zu haben. Die viertelindividuelle Steuerung der Pulsation und/oder des Vakuums ist möglich, aber die dadurch höheren Kosten und die Komplexität dieser Technologie machen eine kommerzielle Nutzung unwahrscheinlich. Die viertelindividuelle Milchableitung erhöht die automatische Erkennungsrate von Mastitis, erhöht aber auch die Kosten und die Komplexität dieser Systeme. Zusätzlich kann die viertelindividuelle Milchableitung dazu genutzt werden die Zell-

zahl in der Tankmilch zu kontrollieren und die Milchverluste durch infizierte Tiere zu reduzieren.

Schlüsselwörter: maschinelle Milchgewinnung, viertelindividuelles Melken, Zitzenkon-
dition

Introduction

There have been a number of quarter-milking devices developed over the past hundred years. The udder can be divided into quarters in the milking claw (with a common long milk tube). The milk flow path can also be completely separated using 4 'short' milk tubes extending from an individual teatcup to a receiver vessel or milk-line. The former has seen application in number of commercial units. The later is commonly used in automatic milking systems. Either configuration can be capable of removing individual teatcups when an individual quarter is milked out

As with any milking technology, the disadvantage of increased mechanical complication must be outweighed by the advantages the technology provides to the milking process in order to gain widespread acceptance. Quarter milking presents the possibility of improving the milking process in the following ways:

- Reduced teat tissue stresses in slow milking quarters
 - Reduction of teat-end Hyperkeratosis
 - Reduction of teat tissue congestion and edema
- Eliminate pathogen cross-contamination between quarters
- Quarter control of pulsation and/or vacuum
- Improved mastitis detection
- Diversion of quarter milk

This paper will review each of these benefits.

Reduced teat tissue stresses

The cumulative milk yield plot in **Figure 1** illustrates three distinct regions of milk flow for one cow at a milking:

- a brief period of increasing slope during which flow-rate increases to a maximum;
- a period of more or less constant slope indicating constant flow-rate, often referred to as maximum or peak flow-rate. Frequently, this is assessed from cumulative milk yield graphs as the maximum yield in any 1 minute of milking;
- a period of declining slope as the flow-rate falls. This low flow-rate period may be about 25% of the total milking time and involve about 10% of the total yield.

Eventually, the graph becomes horizontal as milk flow stops. Usually, some additional, trapped milk can be obtained when milk flow stops by applying downward pressure by hand or by adding a weight to the cluster. This is known as machine stripping, shown as a fourth period (d).

Milk flow-rate from the whole udder is influenced by the different milking characteristics of the individual quarters (Mein *et al.* 1973a). The curves of yield versus time for the separate quarters, also plotted in **Figure 1**, show clearly that the decline in flow-rate from the whole udder occurs mainly because the different quarters milk out at different times. These curves indicate that most of the milk from a quarter is obtained at almost constant flow-rate. However, flow-rate curves for the separate quarters often show a small but steady increase in slope (of perhaps 5%). This reflects a gradual increase in the effective diameter of the teat canal, probably due to stress relaxation of the tissues surrounding the teat canal and/or to loss of mature keratin cells lining the teat canal. The period of peak flow-rate usually ends abruptly and is followed by a period of reduced flow at constant or declining rate (the low flow-rate period).

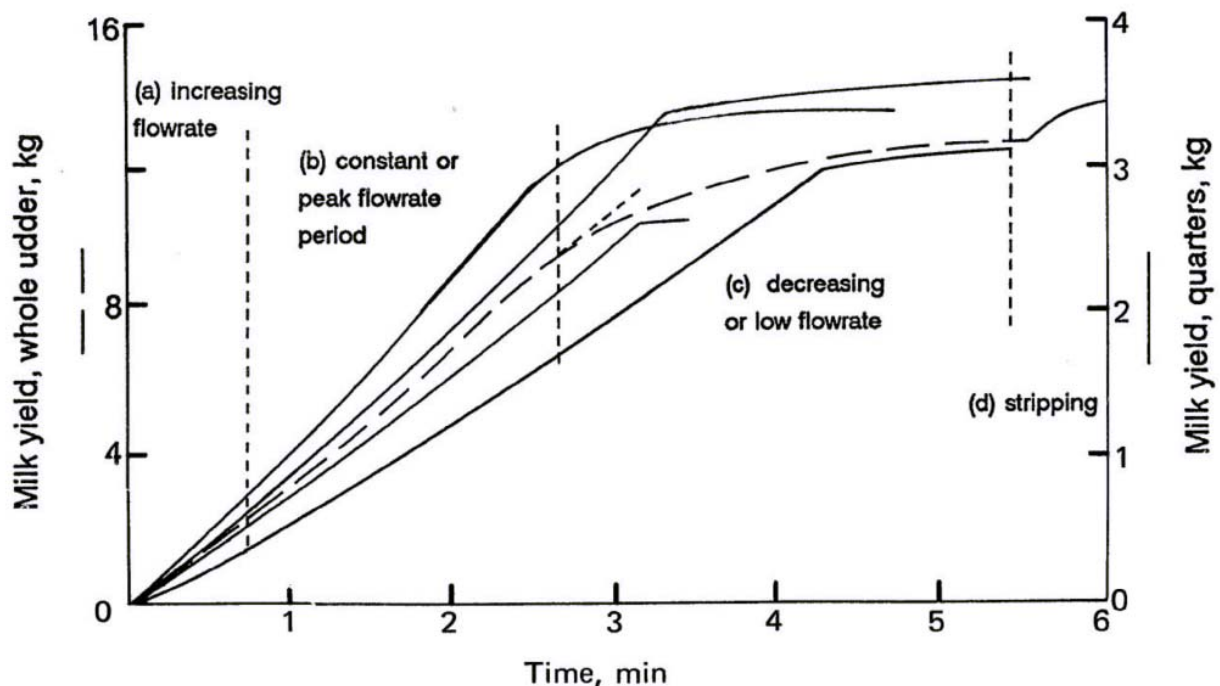


Figure 1: Typical curves of cumulative milk yield plotted against time for a whole udder at a single milking (broken line), and for the separate quarters plotted on a four times more open scale (solid lines). Note the long period of declining flow-rate of the whole udder curve and the sudden change from peak to low flow-rate of the separate quarter curves (MEIN *et al.* 1973a).

The milk flow-rate curve for the whole udder, shown in **Figure 2**, shows 4 distinct step reductions in milk flow indicating the end of the peak flow period of each individual quarter. The transition from peak to low flow-rate is not always so clearly defined for each quarter as in this figure. TANCIN *et al.* (2006) showed that rear quarters have higher milk yield,

peak flow-rate and average flow-rates and milk for longer than front quarters. With clusters detached at a whole-udder flow threshold of 0.3 kg/min, the duration of over-milking was almost twice as great for front quarters compared to rear quarters.

The reduced flow time of the slower quarters prolongs machine time. Low flow-rate time, low flow-rate yield and strip yield of quarters are inter-related measures of inefficiency in the milking properties of the machine. They are associated with the phenomenon known as teatcup crawl.

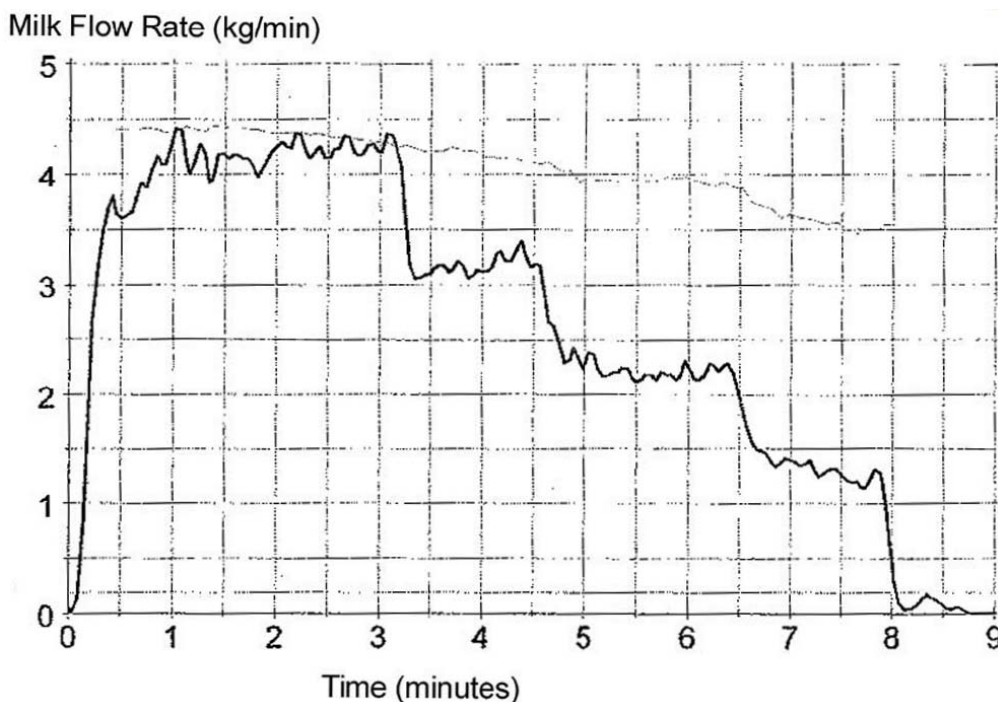


Figure 2: Milk flow-rate curve for the whole udder showing 4 distinct step reductions in milk flow indicating the end of the peak flow period of each individual quarter

Most milking machines produce a vacuum drop between the milkline (system) vacuum and the teat end which is proportional to the milk flow rate. The low flow period at the end of milking produces the highest vacuum levels in the claw and at the teat end. Teat tissues are under the greatest stress from high liner compression and high liner vacuum during this period. Removal of teatcups from quarters that have entered the low-flow period will therefore greatly reduce the stresses on teat tissues. In a study by HILLERTON *et al.* (2002), limited over-milking was not detrimental to the teat condition or to the udder health under normal milking conditions whereas over-milking for 2 to 5 minutes caused discolouring and ringing of teats, indicative of congestion and possible oedema.

The forces generated by the milking vacuum, which cause the teat to stretch both radially and longitudinally, induce congestion and oedema in the teat wall. Throughout about the first three quarters of a milking, the induced congestion is relatively low because the teat sinus pressure remains above atmospheric pressure. After the end of the

peak flow-rate period of milking, however, congestion (and perhaps oedema) is increased markedly because the teat sinus pressure falls sharply, whenever the liner is open, to a level well below atmospheric pressure. Typically, the pressure of milk in the teat sinus falls to about 60-80% of the milking vacuum level in the open liner. It remains at these reduced levels, when the liner is open, throughout the low flow-rate and over-milking periods of milking unless a clear milk pathway between the udder cistern and the teat sinus is re-established, e.g., by machine stripping.

Congestion is a pre-condition for the development of oedema. The milking vacuum generates strain in the teat wall which induces dilation of:

- 1 Blood vessels (i.e. the teat becomes congested);
- 2 Expandable compartments in the peri-vascular tissue, such as lymph vessels and extra-cellular spaces. This dilation results in increased net movement of fluid from the vascular space to the extra-cellular spaces (i.e. the tissue becomes oedematous). The extent and persistence of oedema depends on the milking conditions and duration (HAMANN & MEIN 1990).

Thickening of the wall of the teat was not apparent during the peak flow-rate part of milking, as shown in radiographs 1 and 3 in **Figure 3**, taken near the beginning and the end of that period. From then on, the volume of the teat remained more or less constant but the volume of teat tissue increased as the volume of the teat sinus decreased. The degree of congestion was calculated as the percentage increase in tissue volume between the marks on the teat (originally 10 and 60 mm from the tip). Compared with no. 2, the volume of tissue had increased by 20% in no. 4, 40% in no. 6, and 50% in no. 8. It is likely that these changes occurred because blood pressure in the teat wall was much higher than the milk pressure in the teat sinus once the flow of milk into the teat becomes restricted. Thus, thickness of the teat wall increases markedly during milking, even when normal pulsation is applied.

Calculations from other radiographic studies indicated that the area of the teat wall increased by only 3% from the start of milking to the middle period (the peak flow-rate period), by a further 10% during the low flow-rate period, and by an extra 10% during overmilking (MELLINGER 1988).

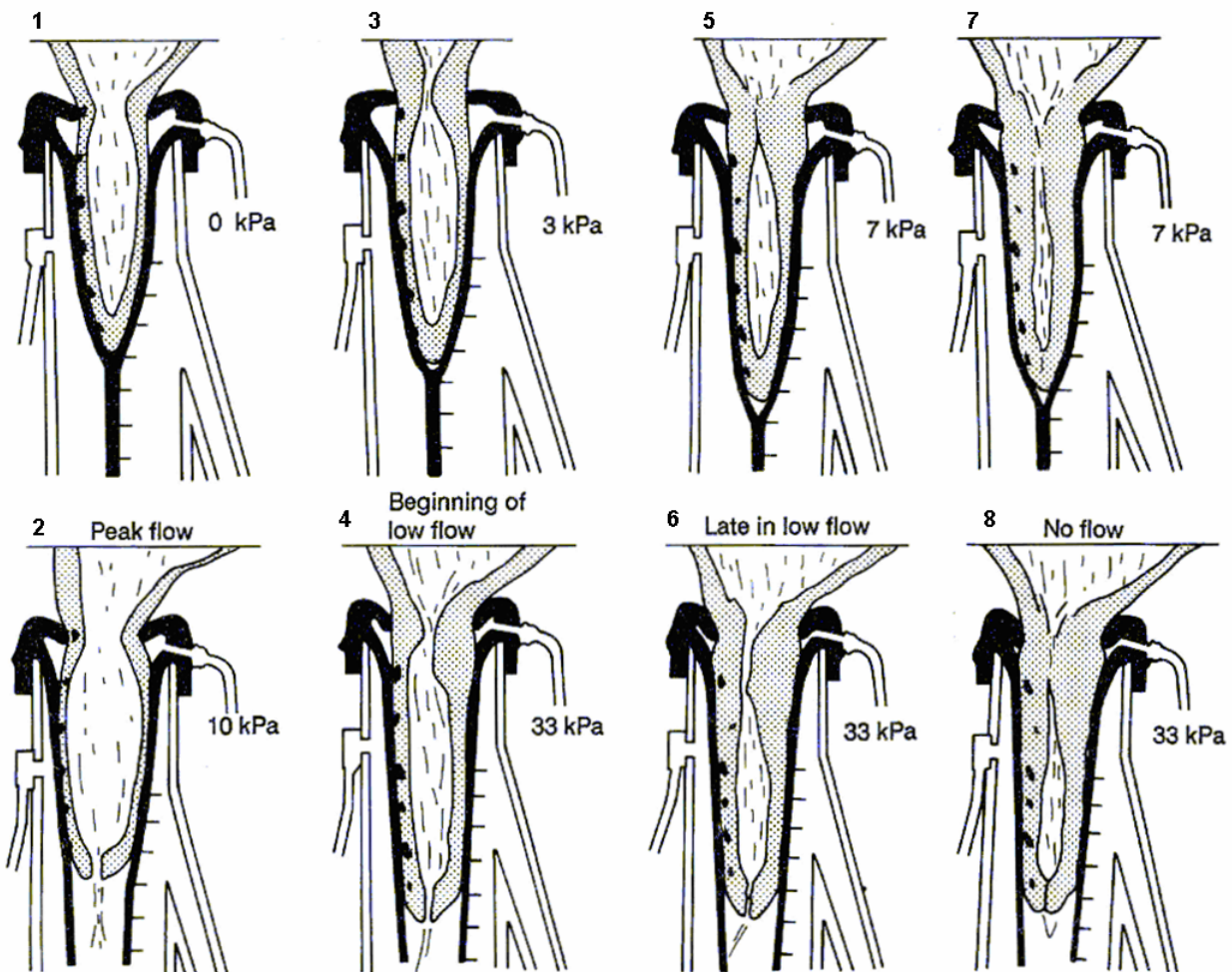


Figure 3: Tracings of pairs of radiographs at four stages of milking. Marks on the left side of the teat were originally 10 mm apart just before the teat entered the teatcup at the start of milking. Marks on the right side of the liner are 10 mm apart. Values of vacuum level measured in the mouthpiece chamber are shown (MEIN *et al.* 1973b).

One of the advantages of individual teatcup removal is clearly the avoidance of congestion and oedema in those quarters that milk faster and/or contain less milk. Congestion in teat tissues at the end of milking is the main factor contributing to cow discomfort and the stepping and kick behaviors commonly observed at the end of milking.

Individual quarter removal can also theoretically reduce the severity of teat end hyperkeratosis. The main factors influencing the development of hyperkeratosis is the level of liner compression (which increases with liner vacuum for any individual liner) and the shape of the teat (MEIN *et al.* 2003). It is likely that teat ends experience higher liner compression at the end of milking because the vacuum difference across the liner in the d phase of pulsation is at its highest. It is also likely that this effect is highly dependent on teat shape. Some studies on the effects early removal of milking units have shown moderate improvement in teat-end hyperkeratosis. On farms using automatic milking systems with quarter removal, rear quarters have the highest milk yield and most cases of mastitis while front quarters still have most teat end hyperkeratosis. The effects of quarter removal on teat-

end hyperkeratosis are likely to be smaller than the effect of liner compression and milking vacuum level.

Quarter control of pulsation and/or vacuum

Pulsation and vacuum settings could theoretically be controlled by quarter in a milking machine that had complete separation between quarters. This technique could be used to minimize the milking time of all quarters with early removal of fast milking quarters or to slow down (and milk more gently) the faster milking quarters so that all quarters finish milking at the same time.

The peak flow period of milking can be reduced to some degree in any milking machine by increasing milking vacuum and/or adjusting the pulsation settings to increase the milk-to-rest ratio. This increase in the peak milk flow rate will not result in a commensurate decrease in the total machine-on time (BADE *et al.* 2009).

IPEMA & HOGWERF (2008) defined four distinct phases of the milking of an individual quarter: 1. Increasing flow, 2. steady flow, 3. declining flow, and 4. overmilking. In this study, the duration of phases 1, 2 and 3 decreased when the vacuum was increased from 42 to 45 kPa, with the main reduction in phase 2. A further increase in vacuum to 48 kPa did not reduce the duration of any of the phases.

More aggressive milking settings will increase the stress on the teat tissue. Early detachment of the individual teat cup can limit the effects of overmilking on teat condition. It is possible to decrease the peak flow period of individual quarters by adjusting quarter pulsation and/or vacuum levels but the decrease on the total milking time for the cow is likely to be small.

Eliminate pathogen cross-contamination between quarters

Air speeds > 2 m/s (6.5 ft/sec) up the short milk tube may assist bacterial penetration into or through the teat canal. Normal liner movement is much too slow to generate these air speeds. Vacuum fluctuations in the milk line or receiver are also too slow to cause bacterial penetration of the teat canal unless they increase the frequency of slipping liners or cluster falls. Correlations linking unstable milkline or receiver vacuum with increased mastitis are likely to be associative rather than cause-effect relationships (MEIN *et al.* 2004)

The only event that can produce air speeds > 2 m/s in the short milk tube is a large liner slip or falloff that introduces substantial air admission through one of the teatcups.

Such events can cause large (15-30 kPa; 4.5-9 inHg) transient drops in claw vacuum (often lasting less than 1-2 sec) with very fast rates of vacuum change (150-300 kPa per sec; 45-90 inHg/s). The resulting high transient pressure gradients between the claw

and adjacent liners can accelerate milk droplets to speeds > 2 m/s towards the teat-ends in adjacent teatcups within the same cluster.

Quarter milking will eliminate the possibility of cross contamination within udders. However, the widespread use of more stable clusters, larger-bore short milk tubes and larger, free-draining claw bowls has probably already reduced the potential gain from eliminating the claw in many milking systems. There are also more dominant factors are likely to mask this modest potential improvement.

Improved mastitis detection

Published evidence shows clearly that monitoring of mastitis indicators in milk from individual quarters increases accuracy and reliability of interpretation (BERGLUND *et al.* 2007, MEIN 2010). However, quarter sensing increases the complexity and cost of monitoring.

Diversion of quarter milk

Farms with conventional milking machines sometimes use manually implemented quarter milking devices to divert milk from high SCC quarters from the bulk tank. This can result in a dramatic reduction in bulk tank SCC with a minimal effect on milk volume. The majority of high SCC cows have one problematic quarter, and this quarter typically represents less than 25% of the milk produced. Individual quarter milking allows for the implementation of this strategy but again involves increased complexity and cost in the milking machine. An accurate and comprehensive manual or automatic method of detecting clinical and/or high SCC quarters is also required for the success of this strategy.

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Quarter individual milking in conventional milking parlour

Viertelindividuelles Melken im konventionellen Melkstand

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Abstract: *The interaction between milking machine and udder health always is a phenomenon considered to be for the past 100 years. In this approach, a new quarter individual milking system called Multilactor[®] (MULTI) developed in order to eliminate the detrimental effects on udder health of conventional milking systems (CON). This system can be used at milking parlour and teat-cups are attached by milking person. The objective of this study was to determine the effects of milk flow on average liner vacuum during b-phase and d-phase in conventional and single tube system by using wet-test methods in practical conditions as defined in ISO 6690 (2007) and International Dairy Federation IDF, 1999.*

In order to achieve the above written objectives, measurements were conducted in two different milking parlours where conventional (CON) and single tube systems (MULTI) were installed separately (Remptendorf, Germany). Wet tests were made at water flow rates ranging between 0-6 l/min. The vacuum recording device used for the tests was named "Bovi Press", A & R Trading GmbH. The sampling rate of measuring equipment was 18 kHz, measuring accuracy was ± 0.1 kPa, response rate was 1700 kPa/s. The vacuum was recorded at the ISO artificial teat end (ISO 6690,2007), pulse chamber, claw and main vacuum line, simultaneously. The working vacuum level was 40 kPa and 38 kPa in conventional and Multilactor milking parlor, respectively. From the study conducted it was found that in 4.8 l/min flow rate, the average liner vacuums during phase-b were calculated to be 35.7 kPa in CON and 32.3 kPa in MULTI systems that fits the desired average vacuum level in the liner mentioned in ISO 5707 (2007) as 32-42 kPa for cows. On the other hand, at the same flow rate, the average liner vacuums during phase-d were found to be different in the both systems. It was 34.4 kPa for CON and 12.8 kPa for MULTI. The reason for a big difference between two vacuum levels is considered to be normal since Multilactor has Biomilker system that allows periodic air inlet in pulse chamber.

As a conclusion it can be stated that this new system has two distinguishable advantages. The first advantage is that the system will provide an improvement in teat health

by the application of effective massage. The second advantage is the protection of teat against Mastitis since the system provides individual milking for each teat.

Keywords: Vacuum, b-Phase, quarter individual milking, wet test

Zusammenfassung: Ein Einfluss der Melkmaschine auf die Eutergesundheit ist schon seit über 100 Jahren bekannt. Ein neues viertelindividuelles Melksystem der Multilactor® (MULTI), wurde in den letzten Jahren entwickelt, um die nachteiligen Einflüsse und Belastungen auf das Eutergewebe und das Zitzengewebe bei Einsatz von konventioneller Melktechnik (CON) zu reduzieren. Das System kann im konventionellen Melkstand eingesetzt werden und das Melkzeug wird durch den Melker angesetzt. Das Ziel der vorliegenden Studie war es, den Effekt des Milchflusses auf das mittlere Vakuum während der b- und d-Phase bei konventionellen und Einzelschlauchmelksystemen mit Hilfe von Messungen unter Melkbedingungen (ISO 6690,2007; International Dairy Federation IDF, 1999) beim Melken zu charakterisieren.

Die Untersuchungen wurden im selben Betrieb (Remptendorf, Germany) in zwei separaten Tandem-Melkständen durchgeführt, in denen ein konventionelles System (CON) und ein viertelindividuelles Melksystem, der Multilactor (MULTI) eingebaut waren. Nassmessungen mit Wasserdurchflüssen von 0-6 l/min wurden durchgeführt. Die genutzten Vakuumsensoren waren von der Firma "Bovi Press", A & R Trading GmbH. Die Abtastrate der Messsensoren betrug 18 kHz, die Messgenauigkeit ist mit $\pm 0,1$ kPa angegeben und die Responserate betrug 1700 kPa/s. Das Vakuum wurde simultan an der ISO Zitzenspitze gemessen (ISO 6690,2007), im Pulsraum, im Sammelstück und in der Vakuumschleule. Das Anlagenvakuum betrug 40 kPa im konventionellen Melkstand und 38 kPa im Multilactor. Es konnte festgestellt werden, dass bei einem mittleren Milchfluss von ungefähr 4,8 l/min/Euter, das mittlere Vakuum an der Zitze während der b-Phase 35,7 kPa im CON und 32,3 kPa im MULTI betrug. Dies deckt sich mit den Angaben in der ISO 5707 (2007) mit einem Vakuumniveau im Zitzengummi von 32-42 kPa/Kuh. Das mittlere zitzenendige Vakuum in der d-Phase bei selbem Milchfluss unterschied hingegen sich signifikant voneinander. Es betrug 34,4 kPa für CON und 12,8 kPa für MULTI. Der Grund für die hohe Vakuumdifferenz zwischen den beiden Systemen liegt vermutlich darin begründet, dass der Multilactor® das BioMilker® System mit periodischem Lufteinlass besitzt.

Zusammenfassend lässt sich sagen, dass das neue System zwei klar erkennbare Vorteile besitzt. Ein Vorteil ist, dass durch die effektive Massagephase zur Zitzengesundheit beitragen werden kann. Der zweite Vorteil liegt darin, dass der Mastitis vorgebeugt werden kann, da die Milch viertelindividuell abgeleitet wird.

Schlüsselwörter: Vakuum, b-Phase, viertelindividuelles Melken, Nassmessungen

Introduction

The target of the developments in the field of milking technique is to obtain the whole milk from the teat of the animal in a shortest time without causing any detrimental effect on udder health. The most direct measure of the milking system effect on the cow is the vacuum in the claw of the milking unit (REINEMANN *et al.* 2007). According to NMC guidelines, accurate recordings of vacuum levels at various locations during milking provides the best means of demonstrating the adequacy of the vacuum production and regulation function of any milking system.

The quarter individual milking is still introduced by automatic milking systems (AMS). There are many studies about the effects of AMS milking on udder health conducted by different scientists. RASMUSSEN *et al.* (2003) and WIRTZ *et al.* (2002) detected an increase in bulk-milk somatic cell count (SCC) after using of AMS. This shows the necessity of having an additional method to detect clinically infected cows and measuring the milk composition especially SCC per each udder quarter is important (BERGLUND *et al.* 2007). To satisfy these needs, a new milking system called “Multilactor[®]” was developed. Multilactor[®] eliminates the detrimental effects on udder health and this system uses the single tube system like AMS. But these systems include periodic air inlet in pulse chamber (like Biomilker) and can be adapted for the use at milking parlour. It has a sequential pulsation and cluster is adapted by milking person (Öz *et al.* 2008). As an advantage of this system –using quarter individual milking in conventional milking parlours- it is expected to reduce SCC as an indicator of udder health (ROSE *et al.* 2006).

The objective of this study was to determine the effects of milk flow on average liner vacuum during b- and d-phase in both, conventional and single tube clusters by using wet-test method in practical conditions as defined in ISO 6690 (2007) at the teat end.

Materials and methods

Two different types of milking systems, a conventional and a quarter individual milking units were tested during the experiments on two similar tandem milking parlours located in a German test farm cooperating with Leibniz-Institut for Agricultural Engineering Potsdam-Bornim. Both milking parlours are equipped with milk meters, with low level vacuum line and devices that are common in many modern milking parlours.

The conventional milking cluster manufactured by GEA (Bönen, Germany) with a claw volume of 300 ccm (CON) was used as a reference cluster. Alternative pulsation at a rate of 60 cycles/min and the ratio of 60:40 was applied. The system working vacuum level was 40 kPa.

As a second system, MultiLactor^{*®} (Siliconform GmbH Türkheim, Germany) (MULTI) is a quarter individual milking system that can be used in conventional milking parlour. The

* Mention of trademark or company name does not imply the endorsement of this product by the authors.

length of the long milk tubes and the inside diameter are 2100 and 10 mm, respectively. The pulse tubes have the same length with long milk tubes but they have an inside diameter of 8 mm. The pulsation rate and the ratios were adjusted to the same levels as in the conventional milking parlour. The system working vacuum level was set to 38 kPa. The teat cups with silicon liners have Bio-Milker system that allows periodic air inlet to the pulse chamber. This system has a different concept in terms of pulsation type called sequential pulsation. This means that pulsation starts in each liner individually and shifts 0.25% of the total pulsation duration. This system provides a better distribution when milk comes together in the long milk tube and also the fluctuations are lower, compared to simultaneous pulsation (STRÖBEL *et al.* 2009).

Vacuum measurements were conducted by using wet test (ISO 6690, 2007). During the experiments ISO artificial teat was used (ISO 6690, 2007). Water at room temperature was used to simulate the effects of milk flow ranged between 0-6 l/min as its physical properties are very close to milk. The vacuum recording device named "Bovi Press" (A & R Trading GmbH Echem, Germany) was used at the sampling rate higher than 300 Hz and measuring accuracy of ± 0.1 kPa. The vacuum was recorded for 21 pulse cycles for each measurement at the ISO-teat end, pulse chamber, claw and main vacuum line, simultaneously. The sensors were connected with 16-gauge injection needle (BD Nokor Admix Kanüle 16G 1) to short pulse tube and claw. From the data recorded, the mean vacuum in b-phase, the mean vacuum in d-phase, and the percent share of the phases of the pulsation cycle were calculated at each one of twelve selected pulsation cycles.

Statistical analysis

The collected data of the Multilactor[®] were compared with vacuum measurements in the conventional system. The data were analyzed with the statistic software SAS 9.1.3, service pack 4 WindowsTM. For the calculation was used: The SAS-procedures PROC MEANS for mean value calculation and PROC DGPLOT for depiction of graphs were used. The ascertainment of the cyclic pulse phases, was done by Microsoft Visual Basic 6.5, Version 1024, with an own macro, according to the formulas mentioned in ISO 5707 (2007).

Results and discussion

Figure 1 is depicted to show the results of the wet-test for two different milking systems for flow rates ranging between 0 and 6 l/min. As seen from the figure, for both systems the teat end vacuum decreases with increasing flow. But mean vacuum reductions for Multilactor[®] are greater than the ones in conventional system. Mean vacuum values shown in this figure are the averages of b- and d-phase vacuum values. For this reason, these systems have to be compared in terms of the differences in b and d-phases. **Fig-**

Figure 2 is drawn to show the differences in mean vacuum at the teat end in b and d-phases at different flow rates. As seen from the the reductions in b- and d-phase have a similar slope for the conventional system while big differences in Multilactor® in b- and d-phase are visible. Considering the system working vacuum levels for the two milking systems (40 kPa for CON and 38 kPa for MULTI) it could be stated that the differences in b-phase vacuum levels are normal. The mean vacuum in d-phase dramatically goes down in MULTI as the flow rate increases.

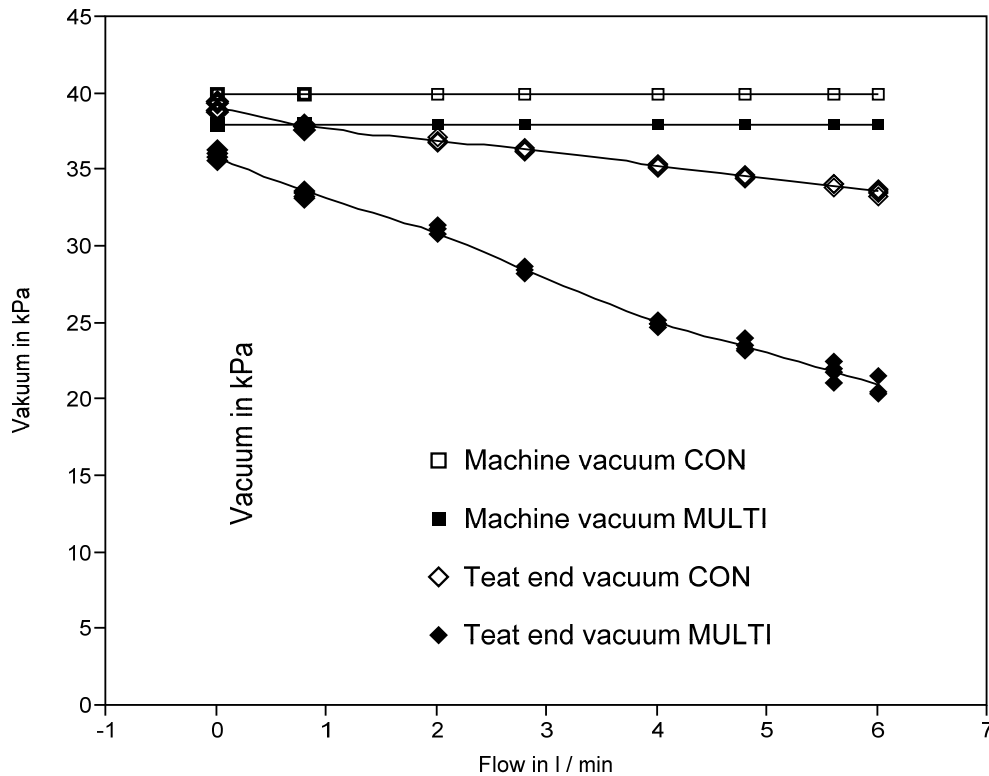


Figure 1: Mean vacuum at the teat end in CON and MULTI at different flow rates

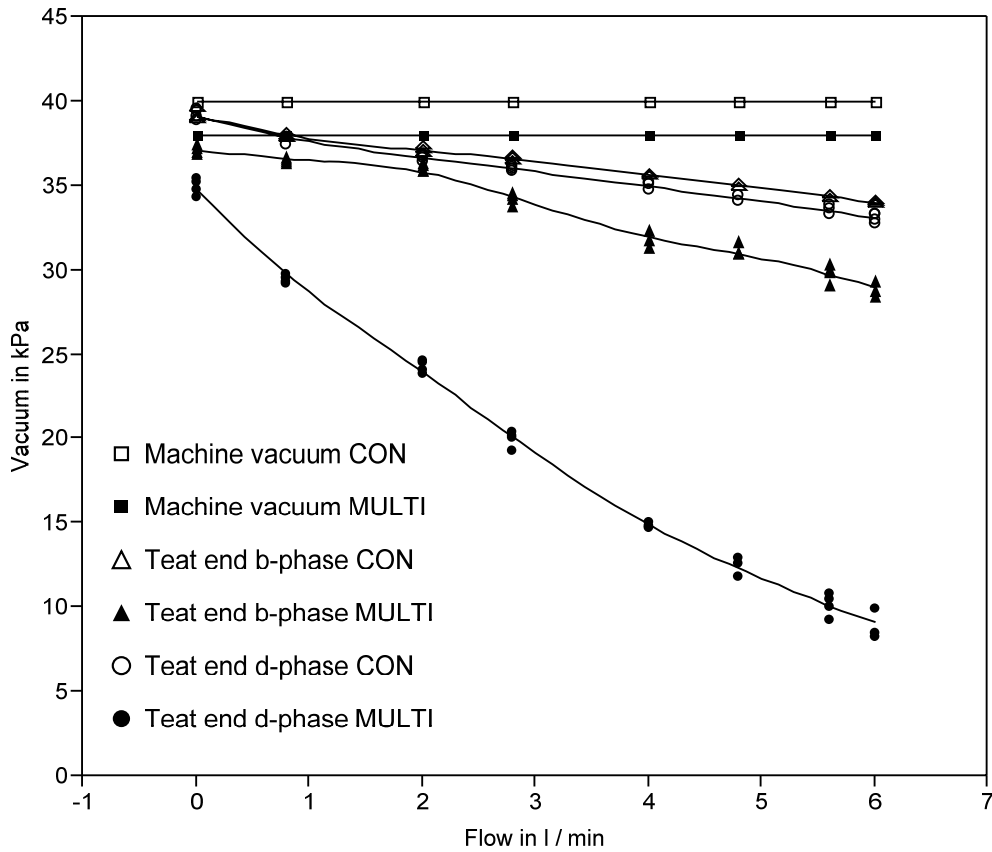


Figure 2: Mean vacuum in b- and d-phase of CON and MULTI at different flow rates

The above mentioned trends can be verified by the values such that at a flow rate of 4.8 l/min, the mean liner vacuum during phase-b were calculated to be 35.0 kPa in CON and 31.1 kPa in MULTI.

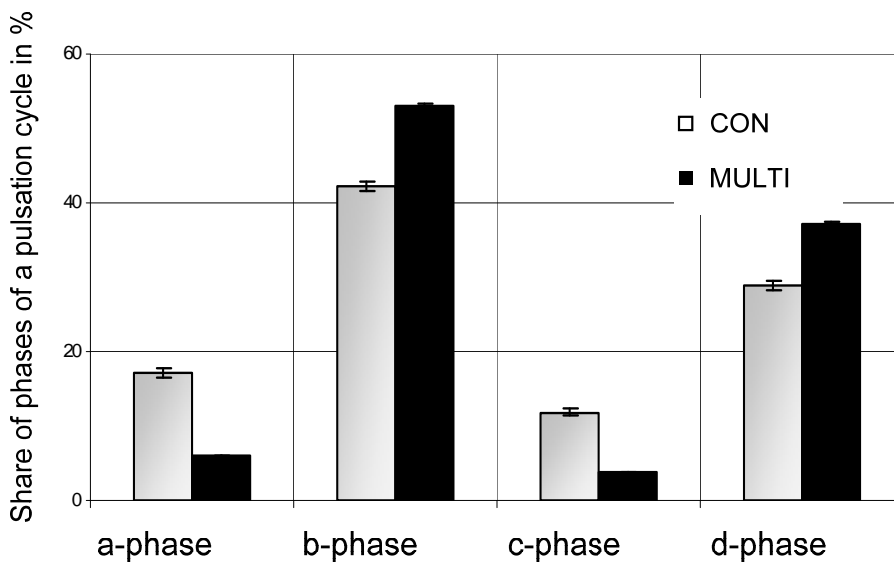


Figure 3: Share of phases of a pulsation cycle in percent at CON and MULTI

These vacuum levels are the desired average vacuum levels since they are in the range (32-42 kPa) as mentioned in ISO 5707 (2007) standard for cows. On the other hand, the mean liner vacuums during phase-d were different in the both systems at 4.8 l/min. It was 34.2 kPa for CON and 12.3 kPa for MULTI. The reason for a big difference between the two systems is considered to be normal since Multilactor[®] has Biomilker system that allows periodic air inlet in the pulse chamber. WORSTORFF *et al.* (1983) asserted that periodical air inlet led to substantial improvement in teat hardness, teat end lesions, milk production and cell count. Additionally MULTI could be very helpful to reduce udder problems especially teat liaisons. Further, HAMANN *et al.* (2001) showed that a positive pressure system caused significantly smaller teat end diameters and lower thickness values compared to the conventional system. **Figure 3** shows the shares of the milking phases of one cycle duration in percent. The ratio is 60:40 at both systems. But the shares of a- and b-phase is different in CON and MULTI, although they are 60% in sum in both systems. The graph shows, that MULTI works with a shorter opening and closing time of the liner than CON. The a- and c-phases are shorter in MULTI than in CON. The sum of a- and c-phase at MULTI takes 9.6% and at CON these both phases take 29.0% of a cycle duration.

Conclusion

The followings were drawn from the study: For both, CON and MULTI, the teat end vacuum decreases with increasing flow. Multilactor[®] may provide an improvement in teat health and protect teat against mastitis since the system provides individual milking for each teat. The reductions in b-phase for both systems are considered to be normal since the system working pressures are different and 2 kPa lower in MULTI than CON. The reduction of the mean vacuum level in d-phase as the flow rate increases can provide an effective message on teat and this could be considered as an advantage of MULTI and BioMilker system. Further research is needed to find out facts about the impact of long and short a- and c-phases to the udder condition. At the moment there is no clear statement if long or short a- and c-phases are good for udder health.

Acknowledgments

The authors would like to thank "Siliconform GmbH" for their kind help to allocate the Multi-lactor[®] for the measurements. This study was funded by German Aerospace Center (DLR) as Management Agency for the Federal Ministry of Education and Research (BMBF).

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The potential of quarter individual milking to reduce the work load

Potential des viertelindividuellen Melkens die Arbeitsbelastung zu senken

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Abstract: *Dairy production in Europe is strongly affected by structural changes. Farm sizes and milk yields have continuously been increasing whereas the number of farms decreased. Those structural changes have influenced work organisation and design in milking parlours. If possible tasks were mechanised and divided. The number of cows milked per hour increased with mechanisation, the number of work operations for the individual decreased and also the spare time in between tasks. In consequence an increase of health problems is noticed especially regarding the incidence of MSD among the workers. This is contradictory to the actual reduction of physical load due to process mechanisation.*

Keywords: *work load assessment, musculo-skeletal-disorders, quarter individual milking*

Zusammenfassung: Die Milchproduktion in Europa ist starken strukturellen Veränderungen ausgesetzt. Die Betriebsgrößen und die Milchleistungen sind stetig gestiegen während die Anzahl der Betriebe gesunken ist. Dieser strukturelle Wandel hat auch auf die Arbeitsorganisation und die Gestaltung von Melkständen Einfluss genommen. Arbeitsabläufe werden möglichst mechanisiert und Arbeitsaufgaben werden immer stärker arbeitsteilig erledigt. Mit der Mechanisierung ist die Anzahl gemolkener Kühe pro AK und Stunde stark gestiegen, die Aufgabenvielfalt hingegen ist gesunken. Leerlaufzeiten gibt es kaum noch. In Folge ist eine Zunahme von Gesundheitsproblemen, insbesondere von Muskel-Skelett-Erkrankungen zu beobachten. Diese Tatsache steht entgegen der insgesamt gesunkenen körperlichen Belastung im modernen Gruppenmelkstand.

Schlüsselworte: Arbeitsbelastung, Muskel-Skelett-Erkrankungen, viertelindividuelles Melken

Introduction

A number of studies from all over Europe (TUURE & ALASUUTARI 2009, JAKOB *et al.* 2009, PINZKE 2003) and from the USA (CHAPMAN *et al.* 2009) have shown that despite a remarkable workload reduction due to process mechanisation the number of MSD among the workers on dairy farms has not been reduced. Along with the structural changes such as fewer farms with more animals, fierce competition for costs and an increasing worker's performance the variety of tasks for the individual has decreased. Unfavourable postures, static load and little task variation may be the reasons for the continuing high or even increasing incidence of work absenteeism on dairy farms.

While the dimensioning of the work place is the basic element to control the physical load for manual handling tasks this seems to work sub-optimal in modern milking parlours. The work place design changes from cow to cow due to different parameters that influence the working height and the necessary horizontal reach to fulfil the tasks. The udder height has an average variation of approximately 35 cm between the highest and lowest udder on one farm. In an experimental study the impact of the working height variation on the muscular load, body posture and the perceived exertion were measured. There is evidence that certain settings may cause physical overload (JAKOB *et al.* 2009), but so far there is no technical solution to ensure the optimal working height for the worker at any time.

Recent research focussing on work operations in the milking parlour has named three facts to be avoided: working with raised arms (above shoulder level), bent back and heavy milking clusters (2 kg +). Technical devices such as adjustable floors, service arms, indexing and light milking units are available to improve the situation for the milker.

According to recent publications various parameters influence the actual work place design. The results of comparing a light conventional milking unit with the Multilactor® regarding the working height and the cluster weight are presented here.

Study design and methods

The study was designed and performed as an experimental study in a laboratory setting to be able to control and adjust the working height. Three working heights were defined according to the individual shoulder height, 15 cm above, at and 15 cm below shoulder respectively, covering a range of 30 cm altogether. A light conventional milking unit (1,4 kg) was compared with the quarter individual milking system, the Multilactor® (300 g/ tube). For each layout (three working heights vs. two milking units) 15 repetitions were conducted concurrently measuring the body posture, the process duration, the muscular activity and the subjective strain while attaching the teat cups.

The sequence of the six settings was systematically changed for each subject according to an ex ante defined experimental matrix to avoid sequence effects.

The body posture was recorded with a video based 3-D-motion-analysis-system working with Simi Motion (Unterschleißheim, Germany) software. Eight retroreflective markers were attached on top of the clothes (see **figure 1**). The motion data was interpreted and evaluated based on DIN EN 1005-4 and ISO 11226 calculating the characteristic angles based on the raw data. The work routine was restricted on attaching the cluster. The duration per repetition was fixed to one minute assuming an hourly work rate of 60 cows.



Figure 1: Location of markers, working height above shoulder level, conventional cluster

Simultaneously to the motion analysis surface Electromyography (EMG) signals were recorded for 7 muscle groups on the left and right side of the body focussing on lower back and upper extremities (see **figure 3**). The EMG technique is widely used in ergonomic research for evaluating and recording the electrical activity produced by skeletal muscles. The signals were analyzed to describe the activation level.

For subjective strain assessment the 6-20 Borg scale was used (BORG 1970; rating between “no strain at all” and “maximum”). The scale was presented to the test persons three times per setting (after cycle 5, 10 and 15).

The work routine was restricted to attaching the cluster and repeated once per minute.

Results

Subjective strain assessment

The rate of perceived exertion on the 6-20 Borg scale (6 = no exertion, 13 = somewhat hard, 20 = maximal exertion) was 9 on average for the Multilactor® system and 11 for the conventional milking unit disregarding less of the working height.

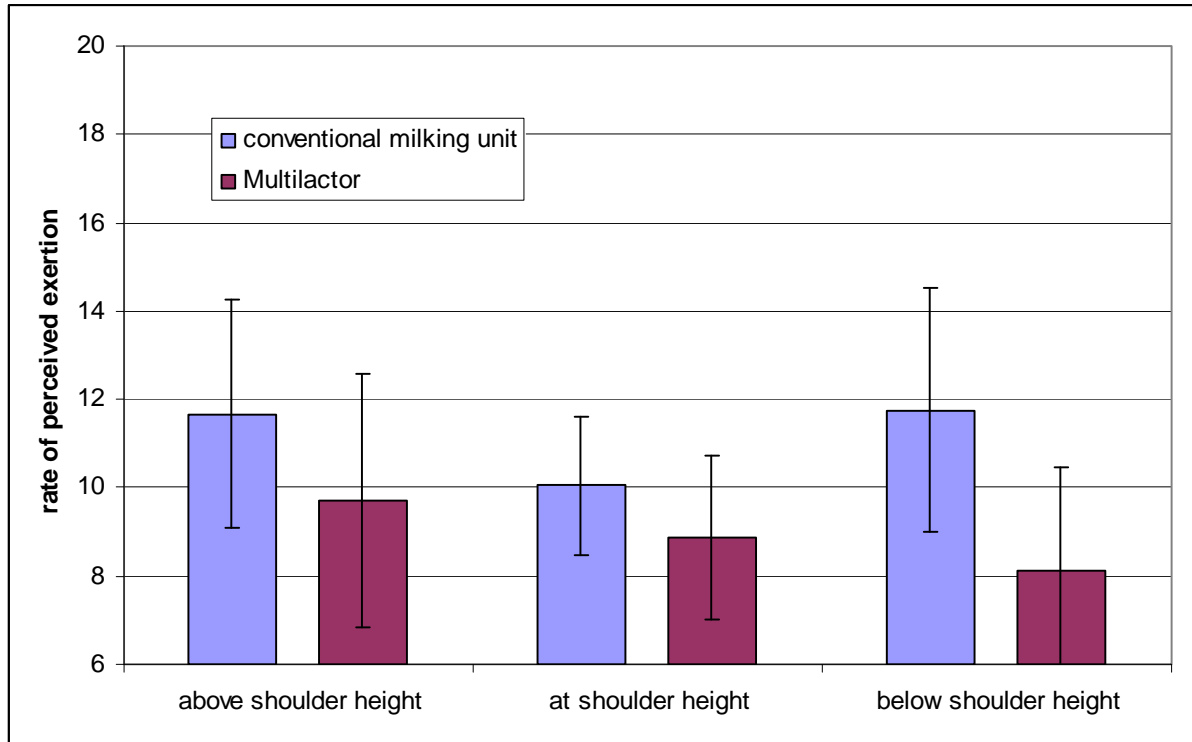


Figure 2: Average rate of perceived exertion and standard deviation for the different settings

Statistical analysis showed significantly lower values for the Multilactor® in comparison to the conventional cluster but no significant differences for the different working heights.

Body posture analysis

3-D-motion-analysis was applied to identify awkward postures for the process of attaching teat cups. Posture analysis was also used to compare the different settings.

The working height strongly influenced the body posture regarding the upper arm elevation and the trunk flexion. Trunk flexion and upper arm elevation were antagonistic. When working above shoulder level, the upper arm elevation was higher, when working below shoulder level, the trunk flexion was higher. Bending and twisting were also calculated, but only values above 10° of side bending or twisting were taken into account. A significant difference between working at shoulder level and working below or above

was noticed. There was no significant difference between the conventional and the Multilactor® system.

The average values for upper arm elevation ranged from 50 to 30° when using the Multilactor® and from 40 to 29° when attaching the conventional milking cluster.

No significant influence of the working height was noticed for the Multilactor® system regarding the trunk flexion. The values for trunk flexion ranged from 7 to 17° on average when attaching a conventional cluster. For an average duration of 3 seconds the values exceeded 20° from a neutral upright position. This is classified to increase the risk of injury. No values above 20° of trunk flexion were noticed for the Multilactor® system.

Process duration

The time that was needed for attaching the four teat cups was extracted from the EMG diagrams and averaged for the 15 repetitions. The process duration is of course not equivalent to time studies, because extra activities like adjusting the tubes were included in the overall times.

Attaching the conventional milking unit took approximately 15 seconds disregard less the working height. The time for the Multilactor® was reduced by about 4,5 s and therefore significantly shorter. Again there was no difference for the working heights.

Muscular activity

The activity of seven muscle groups on the left and the right side of the body were recorded putting an emphasis on the upper extremities and the lower back. The electromyographic signals were filtered, rectified, integrated and finally standardised to the individual maximum volunteer muscular contraction.

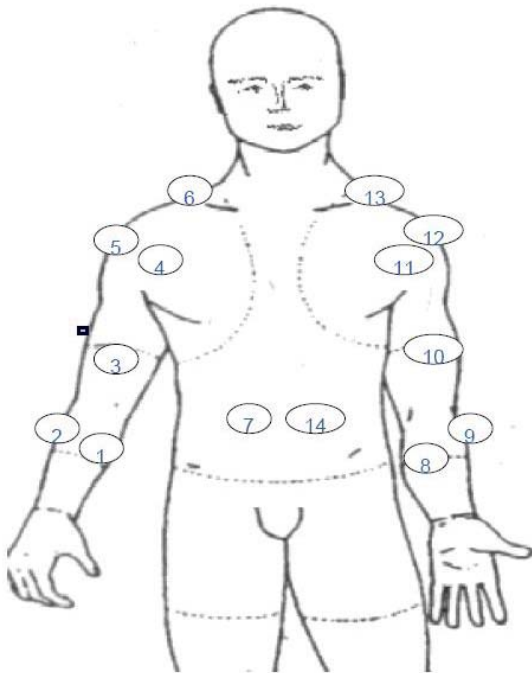


Figure 3: Location of EMG electrodes

Attaching the conventional milking cluster required a higher muscular activity for nearly all muscle groups apart from the trapezius on both sides (location 6 and 13) and the extensor of the right arm (location 2). An average of 14% of the maximum volunteer muscular contraction was found for the conventional cluster, weighing 1,4 kg. A variation between 6% (location 12) and 23% (location 4 and 11) was found for the different muscle groups. The mean muscular activity was approximately 30% lower when the Multilactor® system had to be attached. The average muscular activity here was 10%, ranging from 5% (location 6) to 17% (location 5 and 11).

There were dynamic as well as static components of muscular activity. The dynamic components were extracted from the integrated EMG signals using the standard deviation.

The percentage of dynamic activities ranged from 40 to 78% for the Multilactor® and was in consequence about 73% higher than attaching the conventional cluster.

The working height of course required a significantly higher muscular activity of the shoulder muscles when working above shoulder height.

Discussion and conclusions

Attaching a milking unit requires approximately 10 to 15% of the maximum volunteer muscular contraction. Using the conventional milking unit required an average of 14% whereas the Multilactor® reduced the muscular contraction by 30%. Those results were confirmed by the subjective strain assessment, where the Multilactor® had a signifi-

cantly lower rating than the conventional milking cluster. Furthermore the duration of attaching the teat cups was shorter for the Multilactor®. The body posture analysis is not quite as simple to interpret due to the antagonistic behaviour of arms and back. Nevertheless there was no upper body inclination exceeding 20° when the Multilactor® was used which is eliminating one of the risk factors.

Regarding the fact that the conventional milking unit used in the experiment is very light in comparison to most other clusters found on farms a change from the conventional system to the quarter individual has an even greater potential to reduce the work load than the results displayed in this study. On the other hand one has to keep in mind that the validity of the results is restricted to the experimental framework. On farm measurements may be different and should follow. The work routine was very strict and limited to attaching the milking unit. Additional tasks like udder control or pre milking were not regarded. The work capacity was equivalent to 60 cows per hour, possibly a different workload may occur when the work capacity is changed.

Considering the complete set of parameters that was recorded in the study the Multilactor® can be an effective measure to reduce the workload. The Multilactor® was nearly in all cases superior to the light conventional milking cluster or at least equal.

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Mathematical modeling and optimization of vacuum related variables in conventional and quarter individual milking systems using response surface methodology

Mathematische Modellierung und Optimierung der vakuumbezogenen Variablen in konventionellen und viertelindividuellen Melksystemen unter Verwendung der Response Surface Methodology

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Abstract: *The objective of this study was to develop empirical functions in order to predict vacuum fluctuations in b and d-phase and in claw using response surface methodology (RSM) and to verify the optimum points and the mathematical models in both, conventional and quarter individual milking system. The independent variables considered in the study consisted of the system working vacuum, pulsation rate and ratio and milk flow rate. Experiments based on the central composite design (CCD), one of the designs in RSM and using water and artificial teat were conducted in the laboratory.*

The data obtained in the laboratory were then used to develop functions in polynomial form that allowed predicting the vacuum fluctuations in claw for conventional system and junction point in quarter individual milking system, b and d-phase for both systems.

Only an optimum point for vacuum was obtained for both systems and it was 38.9 and 39.7 kPa for conventional and quarter individual milking systems, respectively.

The fluctuation models obtained from the study indicated the complexity of the fluctuation phenomena in milking systems. But, it is believed that the models developed may be used for the design of conventional and quarter individual milking system for a better performance.

Keywords: *claw vacuum, b and d-phase, wet test, response surface methodology, milking systems*

Zusammenfassung: Das Ziel der Studie war, empirische Funktionen zu entwickeln, um Vakuumfluktuationen in der b- und d-Phase im Sammelstück unter Verwendung der response surface methodology (RSM) vorauszusagen und die optimalen Punkte und die mathematischen Modelle in beiden Melksystemen (konventionell und viertelindividuell) zu überprüfen. Die unabhängigen Variablen, die in der Studie betrachtet wurden, bestanden aus dem Anlagenvakuum, der Pulsrate, dem Saug-/Druckverhältnis und dem Milchfluss. Die Experimente, die auf dem central composite design (CCD) basierten, einem der Entwürfe in RSM, wurden mit Wasser und künstlicher Zitze im Labor durchgeführt.

Die im Labor gemessenen Daten wurden dann verwendet, um polynomische Funktionen zu entwickeln, welche die Vakuumfluktuationen im Sammelstück für konventionelle und viertelindividuelle Melksysteme, in der b- und in der d-Phase voraussagen können.

Für beide Systeme wurde nur ein optimaler Punkt für das Vakuum erreicht. Dieser lag jeweils bei 38.9 kPa und 39.7 kPa für die konventionellen und viertelindividuellen Melksysteme. Die Fluktuationsmodelle, die aus der Studie erhalten wurden, zeigten die Komplexität der Fluktuationsphänomene in Melksystemen auf. Dennoch kann angenommen werden, dass die entwickelten Modelle zu einer Steigerung der Leistung in der konventionellen und viertelindividuellen Melktechnik beitragen können.

Schlüsselwörter: Vakuum im Sammelstück, b- und d-Phase, Nassmessungen, response surface methodology, Melksystem

Introduction

Milking systems have evolved over the years with the introduction of new technology and automation and the objective of the evolutions was to obtain the whole milk from the teat of the animal in a shortest time without causing any detrimental effect on udder health while increasing the productivity by reducing the labor.

As a new system that allows milking each teat individually, Multilactor (MULTI) has been developed in order to eliminate the detrimental effects that induced by conventional milking systems such as teat damage, teat irritation/pain. This system includes periodic air inlet at the teat end and can be adapted for the use at milking parlour. It has a sequential pulsation and cluster is adapted by milking person (Öz *et al.* 2008). As an advantage of this system using quarter individual milking in conventional milking parlours- it is expected to reduce SCC as an indicator of udder health (ROSE *et al.* 2006). This new system can also be used at milking parlours and introduced by Automatic Milking Systems (AMS).

The studies using automated milking systems mostly focused on udder health. RASMUSSEN *et al.* (2003) and WIRTZ *et al.* (2002) found an increase in the number of bulk-milk somatic cell count once AMS was used. This shows the necessity of having an addi-

tional method to detect clinically infected cows and measuring the milk composition especially SCC per each udder quarter is important (BERGLUND *et al.* 2007).

The use of real time tests like wet and dynamic tests in order to determine the vacuum behavior in milking clusters is useful, but factorial type tests require time and effort. But mathematical functions are helpful in order to predict the variables considered in a study for a better system design and use.

Vacuum fluctuation in milking systems has two major components: cyclic (periodic or regular) fluctuation and irregular fluctuation. These fluctuations in vacuum in the teat cup liner have important effects on mastitis and milk flow. Irregular fluctuations occur when the teat cup liners slip or fall from the teats or air enters when milking units are changed carelessly. Vacuum recovery is slow if there is inadequate vacuum pump capacity. Cyclic fluctuations are due to the cyclic movements of the liner in each pulsation cycle and as a result of this, the volume of the liner under the teat changes (FAO, 2009).

Vacuum fluctuations are of importance for the evaluation of milking equipment and for the evaluation of a milking system along with the mean vacuum in the system. In this respect, ISO offered a test method which is called as wet-test method. Wet-test method was also recommended by the International Dairy Federation (IDF) for testing milking equipments and it is very important method to determine the effects of milking flow rate on mean vacuum level and vacuum fluctuations in milking units (Öz *et al.* 2004). Wet-tests are performed while the milking machine is running without milking animals, but having both air and liquid (water, milk or artificial milk) flowing through the machine (IDF, 2000).

Studies on vacuum fluctuations were conducted by Öz *et al.* (2008; 2010) and mathematical approaches were made to the problem.

But, no mathematical based study that enables one to predict vacuum fluctuations in b and d-phase and in claw (the junction point of 4 long milk tubes in quarter individual milking system) as a function of the variables in conventional and quarter individual milking systems. Hence a study was conducted and the objective of the study was to develop mathematical models that allow predicting the vacuum fluctuation related variables as a function of four variables namely system working vacuum, pulsation rate and ratio and milk flow rate and to verify the optimum level of the variables and sensitivity of the mathematical models in both, conventional and quarter individual milking system.

Theoretical background of response surface methodology

The RSM designs are not primarily used for understanding the mechanism of the underlying system and assessing treatment main effects and interactions, but to determine, within some limits, the optimum operating conditions of a system (MYERS 1971). It is less laborious and time-consuming than other approaches and an effective technique

for optimizing complex processes since it reduces the number of experimental trials to evaluate multiple parameters and their interactions (LEE *et al.* 2006)

The response surface problem usually centers on an interest in some response Y , which is a function of k independent variables $\xi_1, \xi_2, \dots, \xi_k$, that is,

$$Y = f(\xi_1, \xi_2, \dots, \xi_k)$$

and response surface can take the different forms according to the function types of response and usually response function is defined in the quadratic polynomial form as follows.

$$Y = \beta_0 + \sum_{i=1}^k \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum_i \sum_j \beta_{ij} X_i X_j + \varepsilon, \quad i \leq j$$

where: Y is the response; β_0 is the intercept; $\beta_i, \beta_{ii}, \beta_{ij}$ are the regression coefficients; X_i, X_j are the coded variables; and ε is the error.

The coding of independent variables into X_i is expressed by the following equation:

$$X_i = \frac{\xi_i - \xi^*}{d_s}$$

where: ξ_i is the actual value in original units; ξ^* is the mean value (centre point); and d_s is the step value.

For a better understanding and detailed theoretical knowledge on RSM, the reader is referred to read the textbook written by BOX & DRAPER (1987) and one of the applications of RSM to an agricultural machinery related problem was conducted by YAZGI & DEGIRMENCIOGLU (2007). The RSM was applied to a milking problem by BADE *et al.* (2009). They conducted experiment based on RSM in order to quantify the milking machine effects of vacuum, b phase and liner compression on milk flow rate.

Materials and methods

The lab experiments using RSM were conducted in 2009 and artificial teats were used during the wet tests and vacuum measurements were made according to ISO 6690 (2007) and the data were recorded by the use of Milko Test MT52⁹. The measuring accuracy and scan frequency of this device are $< 0.5\%$ and 1 kHz, respectively and it is specially designed for testing vacuum pumps, milking equipments and pulsators. The vacuum fluctuations in b- and d-phase and in claw were found as a function of four independent variables considered in this study. The vacuum fluctuations (F) were determined as the difference between the highest (V_{\max}) and lowest vacuum (V_{\min}) at ran-

⁹ Mention of trademarks or company names are for scientific purposes only and does not imply the endorsement of these products by the authors or their institutions they represent.

domly selected sequential 12 cycles and calculated as in the following. The typical pulsation waveform and phases are depicted in **figure 1**.

$$F = \left(\frac{\sum_{i=1}^{12} V_{\max}}{12} \right) - \left(\frac{\sum_{i=1}^{12} V_{\min}}{12} \right)$$

These independent variables were system working vacuum, pulsation rate and ratio and flow rate. The coded and uncoded levels of the variables are given in **Table 1**.

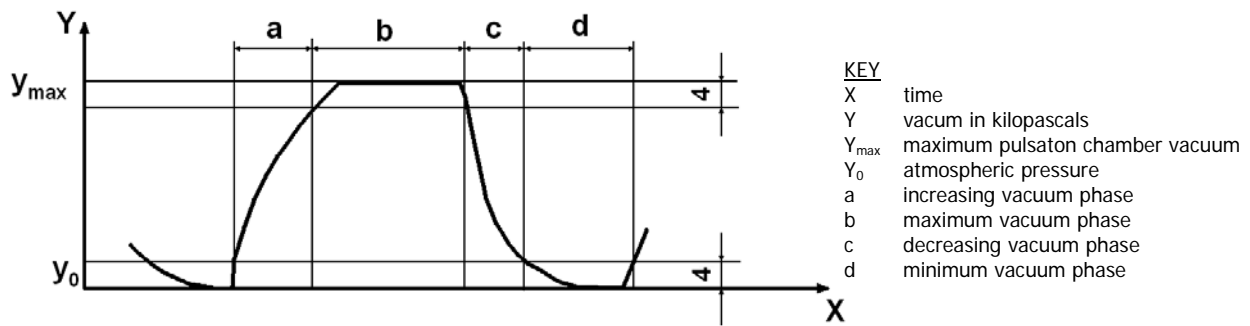


Figure 1: A typical pulsation waveform and phases

Table 1: Coded and uncoded level for independent variables used in the development of RSM functions

Independent variables	Coded level					
		-2	-1	0	+1	+2
System working vacuum (kPa)	X ₁	30	37	44	51	58
Pulsation ratio	X ₂	50:50	57:43	62:38	66:34	70:30
Flow rate(L min ⁻¹)	X ₃	2	3.5	5	6.5	8
Pulsation rate	X ₄	41	53	65	77	89

A total of thirty experiments were carried out in the laboratory based on CCD and five levels of each independent variable were considered. The results from the experiments were used to develop functions for each dependent variable. A general theoretical cubic function for four variables in full was defined and submitted to a statistical package program and stepwise regression procedure was applied in order to select the variables at a probability level of 95%.

Results and discussion

The experimental results obtained in the laboratory based on CCD are given in **Table 2** and **3** for conventional and quarter individual milking system, respectively.

Table 2: CCD design with coded independent variables and measured vacuum related variables for conventional milking system

Design point	Coded and uncoded independent variables				Vacuum fluctuations (kPa)		
	X_1	X_2	X_3	X_4	FC_b	FC_d	FC_w
1	+1 [51]	-1 [57:43]	+1 [6.5]	+1 [77]	1.76	3.86	7.85
2	+1 [51]	-1 [57:43]	-1 [3.5]	+1 [77]	1.78	3.92	6.57
3	-1 [37]	+1 [66:34]	-1 [3.5]	+1 [77]	3.51	2.41	5.94
4	+2 [58]	0 [62:38]	0 [5]	0 [6.5]	2.12	6.50	9.44
5	+1 [51]	-1 [57:43]	-1 [3.5]	-1 [53]	3.17	4.20	6.77
6	+1 [51]	+1 [66:34]	-1 [3.5]	-1 [53]	5.43	3.42	7.40
7	0 [44]	0 [62:38]	-2 [2]	0 [65]	3.61	3.30	5.30
8	-1 [37]	-1 [57:43]	-1 [3.5]	-1 [53]	3.69	3.64	6.06
9	+1 [51]	+1 [66:34]	+1 [6.5]	-1 [53]	4.95	3.59	10.24
10	0 [44]	+2 [70:30]	0 [5]	0 [65]	4.33	2.04	8.45
11	+1 [51]	+1 [66:34]	-1 [3.5]	+1 [77]	2.74	2.75	6.28
12	-2 [30]	0 [62:38]	0 [5]	0 [65]	6.93	2.81	8.24
13	-1 [37]	+1 [66:34]	+1 [6.5]	-1 [53]	6.82	6.82	10.60
14	-1 [37]	-1 [57:43]	+1 [6.5]	-1 [53]	3.38	7.11	7.70
15	+1 [51]	-1 [57:43]	-1 [3.5]	+1 [77]	1.68	3.28	6.68
16	+1 [51]	+1 [66:34]	+1 [6.5]	+1 [77]	3.39	2.14	8.57
17	-1 [37]	-1 [57:43]	-1 [3.5]	+1 [77]	2.19	3.55	5.39
18	-1 [37]	+1 [66:34]	+1 [6.5]	+1 [77]	4.15	3.31	7.55
19	0 [44]	0 [62:38]	0 [5]	-2 [40]	6.38	4.73	8.95
20	0 [44]	0 [62:38]	0 [5]	+2 [90]	1.79	3.20	6.70
21	-1 [37]	-1 [57:43]	+1 [6.5]	+1 [77]	1.98	4.74	7.57
22	0 [44]	-2 [50:50]	0 [5]	0 [65]	1.68	7.28	7.10
23	-1 [37]	+1 [66:34]	-1 [3.5]	-1 [53]	6.47	2.81	7.33
24	0 [44]	0 [62:38]	+2 [8]	0 [65]	4.16	7.13	9.43
25	0 [44]	0 [62:38]	0 [5]	0 [65]	3.63	2.96	8.28
26	0 [44]	0 [62:38]	0 [5]	0 [65]	3.70	2.77	7.20
27	0 [44]	0 [62:38]	0 [5]	0 [65]	4.10	3.21	7.79
28	0 [44]	0 [62:38]	0 [5]	0 [65]	3.07	3.09	7.56
29	0 [44]	0 [62:38]	0 [5]	0 [65]	3.49	3.10	7.47
30	0 [44]	0 [62:38]	0 [5]	0 [65]	3.60	2.78	7.48

Table 3: CCD design with coded independent variables and measured vacuum related variables for quarter individual milking system

Design point	Coded independent variable levels				Vacuum fluctuations (kPa)		
	X ₁	X ₂	X ₃	X ₄	FQ _b	FQ _d	FQ _w
1	+1 [51]	-1 [57:43]	+1 [6.5]	+1 [77]	4.88	18.15	10.42
2	+1 [51]	-1 [57:43]	-1 [3.5]	+1 [77]	7.16	17.98	6.59
3	-1 [37]	+1 [66:34]	-1 [3.5]	+1 [77]	9.01	14.08	6.03
4	+2 [58]	0 [62:38]	0 [5]	0 [6.5]	5.14	13.71	8.42
5	+1 [51]	-1 [57:43]	-1 [3.5]	-1 [53]	6.77	21.47	5.94
6	+1 [51]	+1 [66:34]	-1 [3.5]	-1 [53]	7.99	13.56	7.60
7	0 [44]	0 [62:38]	-2 [2]	0 [65]	7.84	18.40	4.68
8	-1 [37]	-1 [57:43]	-1 [3.5]	-1 [53]	10.57	16.49	6.65
9	+1 [51]	+1 [66:34]	+1 [6.5]	-1 [53]	6.28	13.04	9.80
10	0 [44]	+2 [70:30]	0 [5]	0 [65]	8.36	11.75	7.89
11	+1 [51]	+1 [66:34]	-1 [3.5]	+1 [77]	6.65	15.26	6.12
12	-2 [30]	0 [62:38]	0 [5]	0 [65]	8.58	10.77	6.97
13	-1 [37]	+1 [66:34]	+1 [6.5]	-1 [53]	5.93	10.81	8.63
14	-1 [37]	-1 [57:43]	+1 [6.5]	-1 [53]	5.87	12.68	8.59
15	+1 [51]	-1 [57:43]	-1 [3.5]	+1 [77]	6.21	16.69	6.18
16	+1 [51]	+1 [66:34]	+1 [6.5]	+1 [77]	6.57	11.46	8.95
17	-1 [37]	-1 [57:43]	-1 [3.5]	+1 [77]	7.26	18.28	5.86
18	-1 [37]	+1 [66:34]	+1 [6.5]	+1 [77]	7.36	7.77	7.66
19	0 [44]	0 [62:38]	0 [5]	-2 [40]	5.68	17.19	9.10
20	0 [44]	0 [62:38]	0 [5]	+2 [90]	5.88	13.10	7.03
21	-1 [37]	-1 [57:43]	+1 [6.5]	+1 [77]	8.32	10.86	7.82
22	0 [44]	-2 [50:50]	0 [5]	0 [65]	9.36	16.01	7.55
23	-1 [37]	+1 [66:34]	-1 [3.5]	-1 [53]	9.67	14.03	7.31
24	0 [44]	0 [62:38]	+2 [8]	0 [65]	5.86	12.90	9.80
25	0 [44]	0 [62:38]	0 [5]	0 [65]	8.29	15.77	7.93
26	0 [44]	0 [62:38]	0 [5]	0 [65]	8.85	15.70	7.88
27	0 [44]	0 [62:38]	0 [5]	0 [65]	8.48	16.17	7.89
28	0 [44]	0 [62:38]	0 [5]	0 [65]	7.84	14.97	7.63
29	0 [44]	0 [62:38]	0 [5]	0 [65]	8.46	15.70	8.04
30	0 [44]	0 [62:38]	0 [5]	0 [65]	8.67	17.00	7.87

As a general finding from the data obtained it could be stated that the vacuum fluctuations are much higher in quarter individual milking system as compared to the conventional one in all cases.

The following polynomial functions with transformed-dependent variables for more precise predictions were developed for the vacuum fluctuations in b and d-phase and in

claw for both, conventional and quarter individual milking systems. The models given below are written as in the order the variables enter into the model so that the contribution of each term to the model could be identified from this order and they are valid under the following conditions (in uncoded levels);

$$58 \text{ kPa} \geq V \geq 30 \text{ kPa}$$

$$70:30 \geq P_r \geq 50:50$$

$$8 \text{ L min}^{-1} \geq Q \geq 2 \text{ L min}^{-1}$$

$$90 \geq P_t \geq 40$$

Where; V is the system vacuum, P_r is the pulsation ratio, Q is the flow rate and P_t is the pulsation rate.

Mathematical models developed for vacuum fluctuations in conventional milking system

The function developed in this study for the vacuum fluctuations in b-phase is given below.

$$\sqrt{FC_b} = 1.945 - 0.277 X_4 + 0.245 X_2 - 0.0729 X_1^3 - 0.061 X_2^2$$

The coefficient of determination of the above written function is 94.56% and it allows predicting the vacuum fluctuation in b-phase as a function of above written variables.

The polynomial function obtained from the stepwise regression analysis for vacuum fluctuation in d-phase (F_d) is written as in the following:

$$\sqrt{FC_d} = 1.959 - 0.088 X_2^3 + 0.168 X_3 - 0.134 X_4$$

The prediction function for the vacuum fluctuation in claw is given below.

$$\sqrt{FC_w} = 2.756 + 0.192 X_3 - 0.107 X_4 + 0.068 X_2 + 0.05 X_1 + 0.044 X_1^2 - 0.057 X_2 X_4 - 0.05 X_1 X_2 - 0.028 X_3^2 + 0.037 X_1 X_2 X_4$$

where; the coded form of the variables were X_1 , the system working vacuum; X_2 , pulsation ratio; X_3 , flow rate and X_4 , pulsation rate.

The coefficients of determination for the vacuum fluctuations in d phase and for the claw are 55.13 and 94.46%, respectively. As compared to fluctuation in b-phase and in claw model, the coefficient of determination for the d-phase model is low.

As seen from the above written models it could be stated that the only main effects of the variables affect the fluctuations in b and d-phase while interactions also make significant contributions to the developed model for predicting the fluctuations in claw. The model developed for the b-phase does not include flow rate while other three variables significantly affect the fluctuations in b-phase. On the other hand, vacuum is not included in the d-phase model.

Mathematical models developed for vacuum fluctuations in quarter individual milking system

The polynomial functions developed to find out the fluctuations in quarter individual milking system are given below.

The fluctuation function in b-phase (FQ_b) in quarter individual milking system has the following form and it accounts for the 79.55% of the variation in fluctuations in b-phase.

$$\sqrt{FQ_b} = 2.93 - 0.155 X_3 - 0.138 X_1 - 0.123 X_4^2 + 0.112 X_3 X_4 - 0.075 X_1^2 - 0.072 X_3^2 + 0.073 X_1 X_2$$

The fluctuation function in d-phase (FQ_d) has the reduced cubic form and is given below. The model explains 84.33% of the variation in fluctuations in d-phase.

$$\sqrt{FQ_d} = 3.901 - 0.217 X_3 - 0.222 X_2 + 0.151 X_1 - 0.109 X_1^2 + 0.131 X_1 X_3 - 0.035 X_4^3$$

The fluctuations at junction point (FQ_w) can be predicted from the function below with a coefficient of determination of 98.76%.

$$\sqrt{FQ_w} = 2.801 + 0.233 X_3 + 0.071 X_1 - 0.091 X_4 + 0.0579 X_1 X_3 - 0.0384 X_3^2 - 0.0358 X_1 X_2 X_4 - 0.0388 X_2 X_4 - 0.0367 X_2 X_3 + 0.0233 X_1 X_4 - 0.0266 X_1 X_2 X_3 + 0.038 X_1^2 X_4$$

Determination of the optimum points of the variables

From the developed models presented above, the search and finding of an optimum point was achieved using mathematical software named Maple⁹. A special code was written in this program. Each mathematical model given above was defined in the program and a global or a local optimum was searched. As a result of using this software within the coded range of – and + 2, global optimum values were obtained just on the boundary of the region. The region was then restricted to – and +1 and a local minima was obtained for the claw model in this range for system vacuum for both conventional and quarter individual milking system.

The coded values for conventional and quarter individual milking system were -0.71 and -0.61, respectively. Converting these coded values to uncoded values by using equation 3 and a predetermined step value of 7 kPa for the system vacuum results in 38.9 and 39.7 kPa for conventional and quarter individual milking systems, respectively. Even though the operational principles of both systems are different it is very interesting to obtain a similar vacuum level. These vacuum levels are within the recommended range for cow milking and this was implied in ISO 5707 (2007) with a statement that “both research and field experience indicate that a mean liner vacuum within the range 32 kPa to 42 kPa during the peak flow period of milking for cows ensures that most cows will be milked quickly, gently and completely”.

Some of the response surfaces are depicted in **figures 2** thru **4** for conventional and quarter individual milking systems.

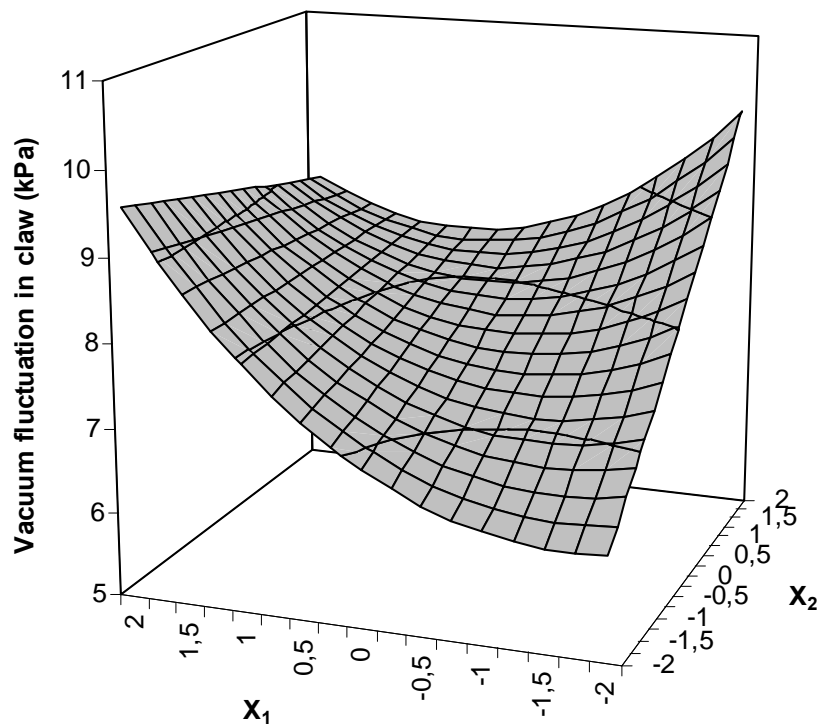


Figure 2: Vacuum fluctuations in claw as a function of vacuum (X_1) and pulsation ratio (X_2) in conventional milking system (flow rate and pulsation rate are at center point)

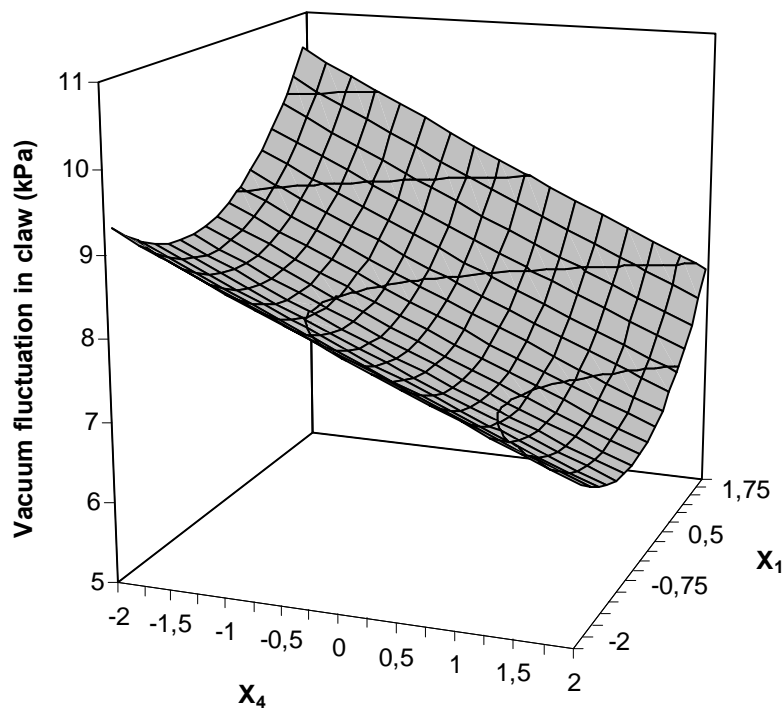


Figure 3: Vacuum fluctuations in claw as a function of vacuum (X_1) and pulsation rate (X_4) in conventional milking system (flow rate and pulsation ratio are at center point)

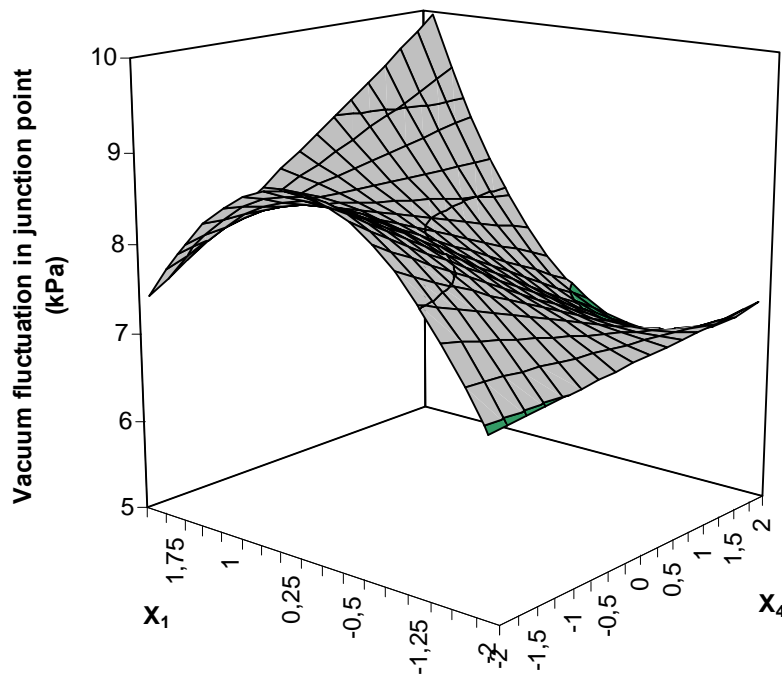


Figure 4: Vacuum fluctuations in claw as a function of vacuum (X_1) and pulsation rate (X_4) in quarter individual milking system (Pulsation ratio and flow rate are at center point)

Verification at optimum vacuum level for testing the sensitivity of the mathematical models

Some verification tests were carried out at optimum vacuum level of 39 kPa the test results are given in **table 4** and **5** for conventional and quarter individual milking system respectively. As seen from the tables, the measured and predicted fluctuations in claw and junction point are at acceptable level.

Table 4: Measured and predicted fluctuations in claw for conventional milking system

Coded and uncoded independent variables				Vacuum fluctuation		
X_1	X_2	X_3	X_4	Measured	Predicted	
-0,71 [39]	-1 [57:43]	-1 [3.5]	+0,833 [75]	5.75	5.75	
-0,71 [39]	-1 [57:43]	0 [5]	+0,833 [75]	7.46	6.86	
-0,71 [39]	-1 [57:43]	-1 [3.5]	-0,42 [60]	6.1	5.9	
-0,71 [39]	-0,41 [60:40]	0 [5]	-1 [53]	8.03	7.69	
-0,71 [39]	-0,41 [60:40]	0 [5]	-0,42 [60]	8.85	7.45	
-0,71 [39]	-1 [57:43]	-1 [3.5]	+1 [77]	5.41	5.73	
-0,71 [39]	-1 [57:43]	0 [5]	+1 [77]	8.18	6.84	

Table 5: Measured and predicted fluctuations at junction point for quarter individual milking system

Coded and uncoded independent variables				Vacuum fluctuation	
X_1	X_2	X_3	X_4	Measured	Predicted
-0,71 [39]	-1 [57:43]	-1 [3.5]	+0,833 [75]	5.83	5.95
-0,71 [39]	-1 [57:43]	0 [5]	+0,833 [75]	6.93	7.22
-0,71 [39]	-1 [57:43]	-1 [3.5]	-0,42 [60]	5.66	6.42
-0,71 [39]	-0,41 [60:40]	-1 [3.5]	-1 [53]	6.83	6.73
-0,71 [39]	-0,41 [60:40]	0 [5]	-0,42 [60]	7.18	7.75

Conclusions

The followings were drawn from the study conducted;

- The fluctuation models in b and d-phase and in claw have different structure. This means that vacuum, pulsation ratio and rate and flow rate affect the fluctuations either as the main effects or interactive way.
- The b and d-phase fluctuation models developed for conventional and quarter individual milking systems has a simple form while the fluctuation models in claw in conventional milking system or the junction point for quarter individual milking system are highly affected by the main effects and their interactions of the variables and more complex structure.
- In general the fluctuations are lower in b and d-phase and claw in conventional system as compared to quarter individual milking system.
- The optimum vacuum in order to minimize the vacuum fluctuations as obtained from the mathematical models are similar and could be considered to be 40 kPa even though the operational principles of the two systems are different.
- There is no optimum point that minimizes the fluctuations for pulsation rate, ratio and the milk flow rate.

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Controlling and regulating the vacuum at the teat end in quarter individual milking systems

Überwachung und Regelung des zitzenendigen Melkvakuums in viertelindividuellen Melksystemen

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Abstract: *The aim of this study was to develop a technical solution for introducing a pressure sensor into the milk-tube of a milking system. The requirement for a permanent inserted sensor was, to measure the vacuum in the milk-tube as exact as a certified external vacuum measuring system. To compare the inserted sensors with an external measuring system, many simultaneously tests have been filled out at different liquid flow rates in a milk-tube. After calculation of the vacuum differences at each simultaneously measured data pair, an evaluation and discussion about the developed technical solution was possible. The developed technical solution is a new constructed casing for a pressure sensor. So the most important result of this study is that the measuring deviation between the pressure sensor in the new developed casing and the pressure sensor of a certified external vacuum control device show, that an assembly of a pressure sensor into a milk-tube is possible, because the mean of measuring deviation is at maximum 3.5% related to the milking vacuum. For this reason the basic step for developing a vacuum control system with casing for the pressure sensor and online measuring of vacuum data is done. Whether this system is applicable for vacuum controlling after an improvement step depends on the correlation of vacuum condition at the teat end and at the end of the teatcup. First results are already available and show a low measuring deviation between these both measuring points. Online regulating of vacuum at the teatcup will help to improve udder health and milk quality.*

Keywords: *Vacuum, milking system, quarter individual milking, sensor, regulation.*

Zusammenfassung: Ziel der vorliegenden Arbeit ist es eine technische Lösung für den dauerhaften zitzennahen Einbau eines Drucksensors in den Milchschauch zu entwickeln. Dabei soll der dauerhaft eingesetzte Sensor das Vakuum im Milchschauch genauso genau messen, wie es mit einem zertifizierten externen Vakuummessgerät möglich ist. Um den eingesetzten Sensor mit einem externen Messgerät vergleichen zu können wurden mehrere Messungen bei unterschiedlichen Milchflüssen durchgeführt.

Beide Messgeräte wurden dabei zeitgleich benutzt. Nach Berechnung der prozentualen Abweichungen, für jedes simultan erfasste Datenpaar, konnte eine Beurteilung für die Testhülse mit Sensor vorgenommen werden. Die Testhülse ist ein eigens für den Sensoreinbau entwickeltes Bauteil. Bei einer Messreihe zur Messgenauigkeit des eingesetzten Sensors zeigt sich, dass der Sensoreinbau mit Testhülse möglich ist, da die Mittelwerte der Messabweichung im Vergleich mit einem Messgerät maximal bei 3,5% des Melkvakuums liegen. Damit ist die Grundlage zur Entwicklung einer Vakuumsteuerung mit Testhülse als Halterung für den Signalgeber geschaffen. Ob dieses System bei Weiterentwicklung zur Vakuumsteuerung geeignet ist, hängt maßgeblich davon ab, ob sich die Vakuumverhältnisse in unmittelbarer Zitzennähe stark von denen am Melkbecher unterscheiden. Bereits durchgeführte Messungen weisen auf geringfügige Unterschiede zwischen den beiden Messpunkten hin. Nur eine Steuerung für das zitzenendige Vakuum kann helfen, die Eutergesundheit und die Milchqualität beim Melken zu verbessern.

Schlüsselwörter: Vakuum, Melksystem, viertelindividuelles Melken, Sensor, Regelung.

Introduction

Many milking systems are equipped with sensor technique for data recording. Currently available milking systems, however offer no possibility for continuous measuring and saving of the vacuum data in the teatcup. The creation of solid vacuum conditions in the milking system however is one of the most important preconditions for guaranteeing satisfactory milking characteristics in the plant (HOEFELMAYR & MAIER 1979). Negative impacts for the udder health are being attributed to over-milking and to unlimited vacuum effects on the teat tissue (IDF 1994). THIEL & MEIN (1979) showed that an increase of machine vacuum leads to higher milk flow levels but also amount of re-milk was higher. So the adjustment of the teat-end vacuum is very important for the whole milking process. Some researchers have the opinion that to high vacuum at the teat end especially in d-phase lead to damage of the teat tissue. RASMUSSEN & MADSEN (2000) reported that milking at low vacuum 26 to 30 kPa in average at the teat end compared to high vacuum of 33 to 39 kPa increased machine-on time and frequency of liner slip. Indeed the stated vacuum levels are regarded to the mean vacuum level of a whole pulse cycle. Milking at high vacuum, in contrast has been shown to decrease machine-on time slightly (REINEMANN *et al.* 2001a), increase the number of teat ends open after milking and the amount of time for teat ends to close after milking and increase teat-end hyperkeratosis (MEIN *et al.* 2003).

Hyperkeratosis can lead to mastitis in the long-run. HAMANN (1987) concluded that mastitis can be caused through sub-optimal adjustment of the milking technique like failure in pulsation and through sub-optimal teat-end vacuum. This is true for all kind of milking systems. HAMANN *et al.* (2001) showed that a positive pressure system significantly caused smaller teat-end diameters and lower thickness values as compared to the con-

ventional system. This corresponds well with REINEMANN *et al.* (2001a). The higher the vacuum under the teat is, the more folds the teatcup liner together in c- and d-phase and the tissue get squeezed to much (HOEFELMAYR & MAIER 1979). According to HÖMBERG (2008) the teat-end vacuum in d-phase should be under 20 kPa, which is very low, but leads how he found out, to lower affecting the udder tissue.

Öz *et al.* (2010) showed for a conventional milking cluster with 160 ccm claw volume fluctuations in b-phase between 4.0 and 5.0 kPa for flow rates between 0.8 l/min and 6.0 l/min. The main reason for the cyclical fluctuations is the cow-individual milk flow intensity that means the flow rate per time interval, WORSTORFF (1976) found out. In 2002, BJERRING & RASSMUSSEN (2002) found that the vacuum fluctuations at the teat end are larger in automatic milking systems than in conventional milking systems. That implies that it is a necessity to design the vacuum control system in a way that it can be introduced to both quarter individual milking systems for milking parlour and to all kind of automatic milking systems. Additionally, ROSE-MEIERHÖFER *et al.* (2010) found in milking-time tests (farm experiments) a vacuum reduction of 15.0 kPa at 8.0 l/min flow rate for a conventional milking system with milking cluster (claw volume of 300 ccm) at a machine vacuum of 42 kPa. So the aim with the planned vacuum control system is, to produce vacuum fluctuations which are lower than 5.0 kPa for a flow rate of 6.0 l/min, regarding to the results of Öz *et al.* (2010) for modern conventional milking systems. For vacuum reductions the aim is to reach much lower reductions than MEIERHÖFER *et al.* (2010) found in the conventional milking system with milking cluster. A first analysis of own measurement results show that here is a high potential for improvement. Probably it is even possible to produce low vacuum reductions at high flow rates and high reductions at low flow rates, which would be much better for teat tissue and which would be a minor revolution in milking technique. The quarter individual vacuum data of the teat-end milking vacuum, collected with the test set-up of this study can be used for controlling the vacuum at this point during the entire milking process. However the development of a vacuum control system is a very important scientific issue. With this new technique it will be possible to guarantee and to document, that the vacuum conditions at the teat are all the time within the limits according to ISO 6690 (2007). If nevertheless a system error happens the regulation system will immediately correct the error or stop the milking system and give an alert.

The streak canal of the teat is very sensitive and it is the opening for bacteria which can move into the udder and cause inflammations. With a reduction of mechanic pressure at the teat, to the lowest level as possible, the teat can be hold healthy and resistant against bacteria, referring to HAMANN (1987) and to the other authors quoted before. So the amount of hyperkeratosis which makes it easier for bacteria to infect the teat can be decreased with the help of a teat-end vacuum control system. Such a control system could be optimized in the long run in a way that individually for each animal, under consideration of cattle breed, udder condition, cow's health condition and lactation stadium, for each cow the optimal vacuum application will be calculated and afterwards gener-

ated. Many data for a good adjustment of the milking plant are given in ISO 6690 (2007) and protect farmer and cow. But these guidelines don't react to the individual daily situation of the animal. A control system can do this. The vacuum application at the teat end, which is optimal for the economic situation of the farm, is not found yet and the optimal vacuum application for each teat and cow can only be measured, if first a precise teat-end vacuum measurement in or near the teatcup will be developed and if second the evaluating of the animal data by computer can be done automatically.

Aim of this study was to develop a first technical solution for a permanent inserting of a pressure sensor. The inserted pressure sensor has to be able to memorize the milking vacuum during the whole milking time. Furthermore, it should be found out, if an inserted pressure sensor has measuring deviations in comparison to a conventional teat-end vacuum control device and if they are relevant for creating the vacuum control system.

2 Materials and methods

The basic test set-up of the two in this study filled out test series A and B is shown in **figure 1**. At test series A, the measuring deviation between the vacuum control device (M) and the permanent inserted pressure sensor (S) was measured. At test series B the measuring deviation between two sensors (M1, M2) of one measuring device was measured to compare both measurements. The two sensors have been connected with the milk tube by measuring needles, 30 mm below the end of the teatcup. The exact way of connection is shown in **figure 1**. Measuring needles are metal cannulas with an obtuse end and with an inner diameter of 2 mm. They are usually used in human medicine. The needles are put direct to the measuring sensors with the help of a 10 mm long thin tube.

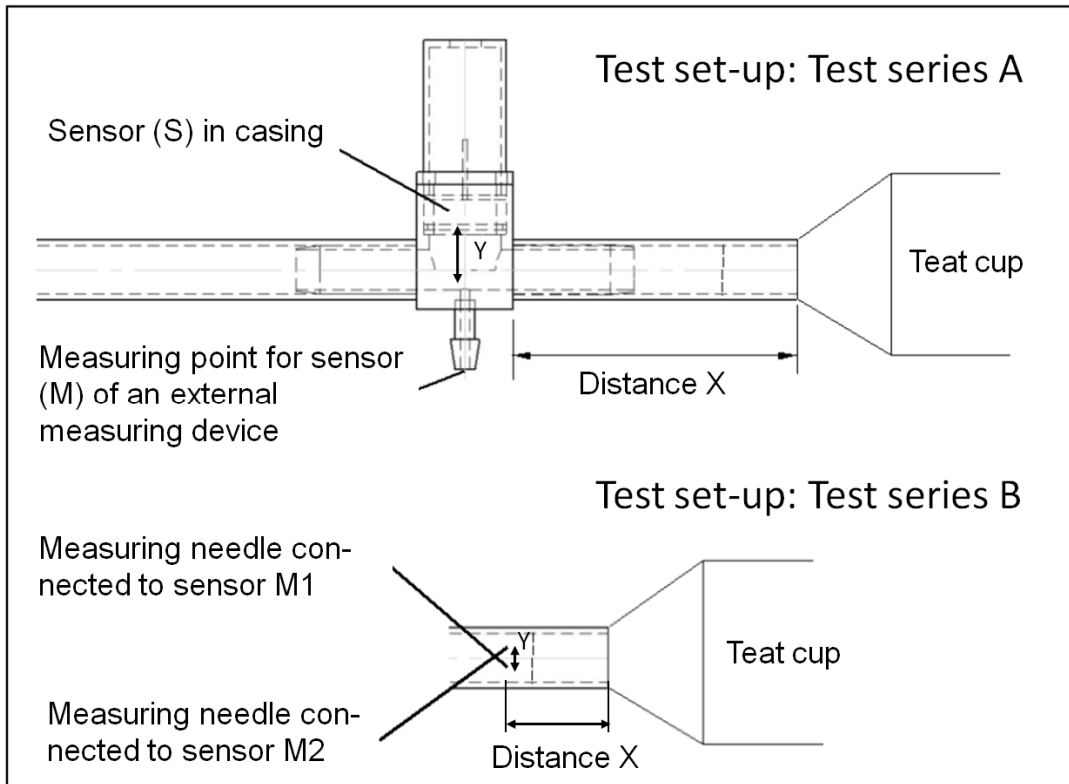


Figure 1: View of the test set-up: Sensor casing at the end of the teatcup (Test series A) and measuring with two measuring needles (Test series B)

The test set-up for both sensors in test series A was as follows: The piezoresistive sensor (S) was put permanently in a sensor casing developed especially for this purpose. The sensor (M) of the measuring device was at the opposite side connected by a short tube with 2 mm diameter (**Figure 1**). The opening for the pressure measurements at the sensor casing are for both sensors parallel to the streaming direction in the milk tube. The inner diameter of the milk tube is not narrowed from the inserted sensor casing. However, it is as big as the inner diameter of the milk tube and amounts 10 mm. The permanently integrated sensor in the sensor casing is a high quality, calibrated piezoresistive pressure sensor (KELLER GES. FÜR DRUCKMESSTECHNIK MBH 2008).

During test series B both sensors were connected with measuring needles to the milk-tube, as schematic shown in **figure 1**. The ends of the measuring needles with air-inlet at the needle points have been pierced into the milk-tube 30 mm below the teat end and being located with a distance (Y) of 6 mm to each other. In **Table 1**, the set-up data of both test series are summarized represented. Test series B helps to determine which measuring deviation between the two sensors may occur, by performing the measuring method with measuring needles.

Table 1: Details of the test set-up at test series A and B.

Test series	Sensor 1	Sensor 2	X in mm*	Y in mm**
A	S	M	140	12
B	M1	M2	30	6

* Distance X between measuring point and the end of the teatcup

** Distance Y between the air-inlet of both used sensors

The pressure sensors M, M1 and M2 are sensors at the vacuum control device Milko-Test MT52 (Company SystemHappel). According to manufacturers instruction amounts the measuring accuracy of the sensor (S) from Keller GmbH 0.5%. The maximum measuring frequency is 2.0 kHz. At the vacuum control device MilkoTest MT52 the measuring accuracy of the sensors (M) amount 0.5% too. The maximum measuring frequency is here 1.0 kHz.

The measurements took place at a measuring frequency of 500 Hz. The sensor (S) in the casing was connected to an analog-digital converter, which was connected by an interface to a computer. For data recording the software LabView was available on the computer (National Instruments).

All the vacuum measurements were carried out according to the wet-test method ISO 6690, (2007). Here the milking process is simulated with the help of a flow meter for liquids and with artificial ISO-teats (ISO 6690, 2007). All the measurements were performed at a quarter of an individual milking system. So far, this system is the only quarter individual system, which can be used in milking parlours. It disposes of periodical air-inlet and should work by low level vacuum of 35 kPa. All the measurements were carried out at the same udder quarter. At each test series at least two repetitions were carried out. As test liquid water was used. For determination of the suitability of the sensor inserting with casing, the average percentage measuring deviation between both measuring systems was calculated for each test. The measuring deviation is used in the results of this study, as a value for the measuring difference between two used sensors, for the whole measuring time.

The calculations of the results were carried out by calculating the difference between each pair of values first in kPa (at the minimum 7000 pairs of values at a measuring frequency of 500 Hz were measured). Furthermore the mean of the vacuum of both used sensors was calculated. Then the percentage measuring deviation always related to the mean of sensor M was calculated. For measuring deviation and percentage measuring deviation the means and standard deviations of each test was calculated.

This calculation has been done for all the performed measurements. For a statistical analysis of the results the statistical software SAS version 9.1.3 with service pack 4 was used.

Results and discussion

The present study shows that generally the measuring with in casing inserted pressure sensors is possible. The installation of pressure sensors into the milk tube can take place with the constructed casing in a cost-efficient way.

Furthermore it was found, that the mean of the percentage measuring deviation at test series A, at each flow rate lays fewer than 3.5% (**Figure 2**). The mean of the percentage measuring deviation at the two lower flow rates is fewer than 2.2%. The standard deviations at all flow rates are high. So it is shown, with higher flow rates there are higher maximum values for the measuring deviation. Moreover the standard deviation is higher than at low flow rates.

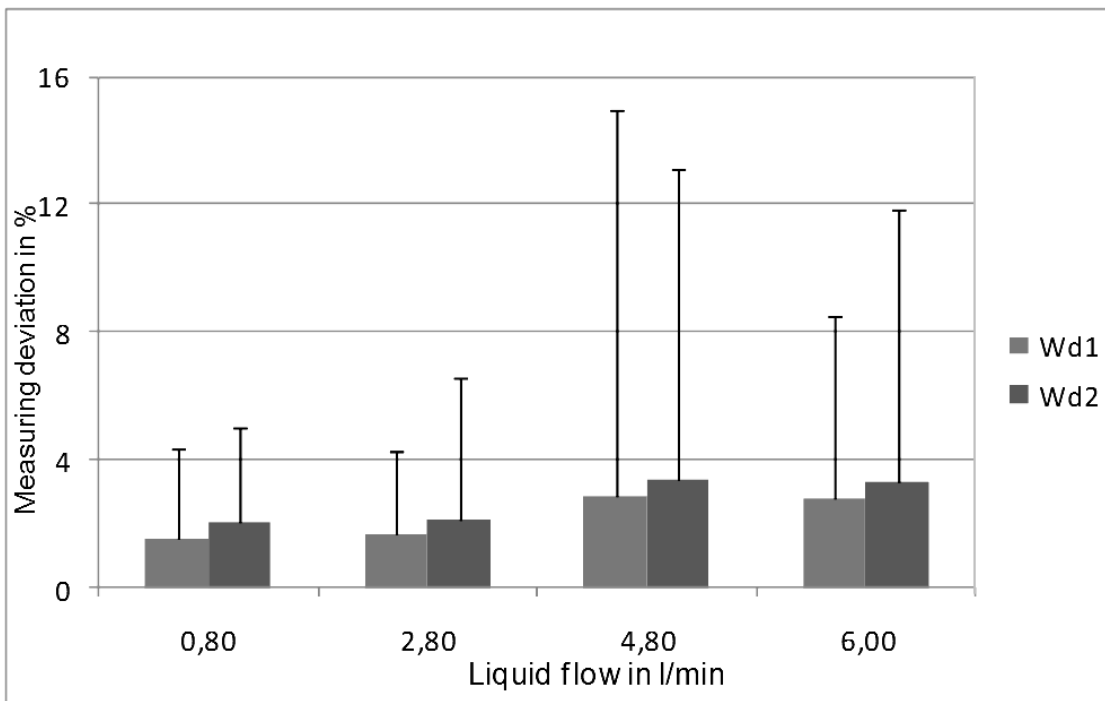


Figure 2: Percentage measuring deviation on the test set-up of test series A at different flow rates

Test series A compared with B shows that at test series B higher means of percentage measuring deviation occur than at test series A. By adjusted flow rates between 0.8 and 2.8 l/min, the mean of the percentage measuring deviation amount between 4.2% and 5.0%. For the higher flow rates 4.8 to 6.0 l/min the value amount between 8.3% and 8.8%. Over all tests, the values of the repetitions fit very well together with the original data. Another found fact is, that with the prevalent measuring method (B), there was found a percentage measuring deviation, which is almost twice as high as during the measurement with two sensors at the casing (A).

One explanation for the found result could be, that the needles are very sensitive against measuring errors, because the holes in the needles have an inner diameter of only 2 mm and the needles can move a little bit during the measuring process and it is not possible in the tube, to find for both needles exact the same position. The measuring deviation at the test series A is therefore clearly lower than at the reference measurement in test series B. So for sure the sensor and casing showed in test series A are usable for development of the vacuum control system.

ROSE *et al.* (2005) found out, that at some conventional milking clusters the vacuum reduction can rise up to 28% in relation to the main vacuum. If there is a measuring deviation of three or four percent between the tested sensor and the reference, the result is good enough for beginning with the development of a permanent, online, teat-end vacuum control system. Even with the found out measuring deviation a big share of the vacuum reduction can be prevented with a vacuum control system and so the main vacuum level can be adjusted to a lower level. As well the study and the researched literature helped to learn more about the planned vacuum control system. One aim is now to produce lower vacuum fluctuations with the planned vacuum control system than ÖZ *et al.* (2010) found in the conventional milking cluster in the mentioned study. For the vacuum reductions the aim is to reach values like RASMUSSEN & MADSEN (2000) stated for milking at low vacuum. Additionally the control system should be realized in a way that the teat-end vacuum is much lower at low milk flow rates and in d-phase in comparison to b-phase vacuum, because machine-on time will only slightly increase during milking at low vacuum, if the low vacuum is especially produced by very low vacuum, in the mentioned time-intervals of the milking process.

Conclusions

There are many arguments for a presently development of a vacuum control system for all milking machines. The mean percentage measuring deviation at test series A amounts at different flow rates 3.5% and less. The lower the flow rate, the lower is the measuring deviation in test series A. To improve this correlation, more measurements have to be carried out. The recorded measuring deviation for this study should be a bit lower for developing a vacuum control system, but the data built a good foundation to improve the measurement with permanent inserted pressure sensors. There was found as well, that the measuring deviation is low enough to decrease the vacuum reductions of the milking systems at high liquid flow rates.

Further research is needed to find out, which measuring deviation exists between teat end and the end of the teatcup. This can be found out analog to this study, with the same statistical method. Those results are definitely necessary too, for developing a vacuum control system. If there is only a pour measuring deviation between the two measuring points then the control system can be developed more easily.

Actually the data transfer from the sensor at the casing to the computer can be realized by a wireless data connection. In fact there are many working steps to do to develop the vacuum control system. With a good adjusted vacuum control system the comfort of our milking systems and the udder health of our cows will improve soon. The research for a vacuum control system should be pursued with the casing developed for this study, because there are different ways to improve the measuring results, for example with a mathematical error reduction.

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Evaluation of milk quality by quarter individual milking

Beurteilung der Milchqualität beim viertelindividuellen Melken

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Abstract: *Introduction of automatic milking has on an average not improved milk quality, but there are large potentials and especially by inclusion of information at the quarter level. Milk quality covers the hygienic, compositional and aesthetic quality of milk. Clinical mastitis has the main influence on milk quality and consequently, detection of cows with clinical mastitis and diversion of abnormal milk are in focus in this paper. Measurement of electrical conductivity for each quarter has been used as the main source of information, but additional input to the algorithms are needed when used for automatic diversion. Use of decision-tree models and especially measurement of quarter somatic cell count shows benefits.*

Keywords: *Quarter milking, automatic milking, mastitis, abnormal milk, milk quality*

Zusammenfassung: Die Einführung des automatischen Melkens hat prinzipiell nicht zur Verbesserung der Milchqualität beigetragen, dennoch bieten sich große Potenziale insbesondere unter Einbeziehung der Informationen auf Viertelniveau. Milchqualität umfasst die hygienische, inhaltliche und ästhetische Qualität von Milch. Klinische Mastitis hat den Haupteinfluß auf die Milchqualität, infolgedessen stehen die Erkennung von Kühen mit klinischer Mastitis und Absonderung der abnormalen Milch im Fokus des Beitrags. Die Messung der elektrischen Leitfähigkeit für jedes Viertel ist bisher als Hauptinformationsquelle genutzt worden, jedoch sind zusätzliche Informationen für die Algorithmen erforderlich, wenn die Milch automatisch abgesondert werden soll. Die Nutzung von Entscheidungsbaum-Modellen und insbesondere die viertelindividuelle Zellzahl können dabei hilfreich sein.

Schlüsselwörter: Viertelindividuelles Melken, automatisches Melken, Mastitis, veränderte Milch, Milchqualität

Introduction

There is a growing demand for high quality dairy products. Parallel to this there is a trend of farms increasing in size and production and that the dairy farmers are using

less manual time per cow. This requires improved efficiency at the dairy farms and that farmers mechanize and automate processes of their daily routines. Automatic milking systems (AMS) was introduced in The Netherlands in 1992, but this technological break through was not followed by an improvement of the milk quality. Although many farms with automatic milking deliver milk of excellent hygienic quality, total bacterial count and somatic cell count of bulk milk is on an average still higher of AMS herds than of conventional herds at least for Danish conditions. About 20% of the milk in Denmark is from AMS herds which stress the importance of obtaining an excellent milk quality along with development of automation of the milking process. Denmark and Iceland are the countries with the highest proportion of AMS farms but most of the western countries are seeing a similar development. Moreover, conventional farms are adapting technologies invented for fully automation of the milking process. The requirements and standards we impose on automatic milking then become very important for the trends in milk quality.

Milk quality is a very broad term that covers the hygienic, compositional and aesthetic quality of milk. We expect that good quality healthy milk comes from healthy cows kept in a clean environment. Total bacterial count of the milk reflects to some degree this image and is influenced by cleanliness of the teats at attachment, cleanliness of the milking equipment, sufficient cooling and in some cases the udder health. There have been attempts to measure or score the cleanliness of teats at the automatic attachment of the teat cups but there are not published papers on this matter or commercial systems available. The general trend has been to keep cows in a dry and clean environment which minimise the contamination of teats with manure and bedding material and then count on that the time used for automatic teat cleaning is sufficient to leave the teat visible clean at attachment. HOVINEN *et al.* (2005) evaluated the efficiency of brushes and cleaning cups and found that 80-85% of the teats were correctly positioned in the cleaning device. The devices sufficiently cleaned 73-80% of the visible dirty teats. The teat sensing devices and mechanical parts have improved for several of the AMS models since then and a higher success rate can be expected today. Although there is a correlation between dirtiness of the teats at attachment and bacterial count of the milk, visible clean teats are not a guarantee of low bacterial counts in milk. Clean teats add to the image of an aesthetic milk production and this should be solved through a general high hygienic standard rather than fixing an acute problem at attachment.

The main development of sensors for automatic milking associated with milk quality has been in relation to udder health and detection of cows and quarters with clinical mastitis. BRANDT *et al.* (2010) presented an overview of sensors and their application area for in-line measurements of milk (**Figure 1**). This paper focus on detection of abnormal milk and automatic sorting at the time of milking.

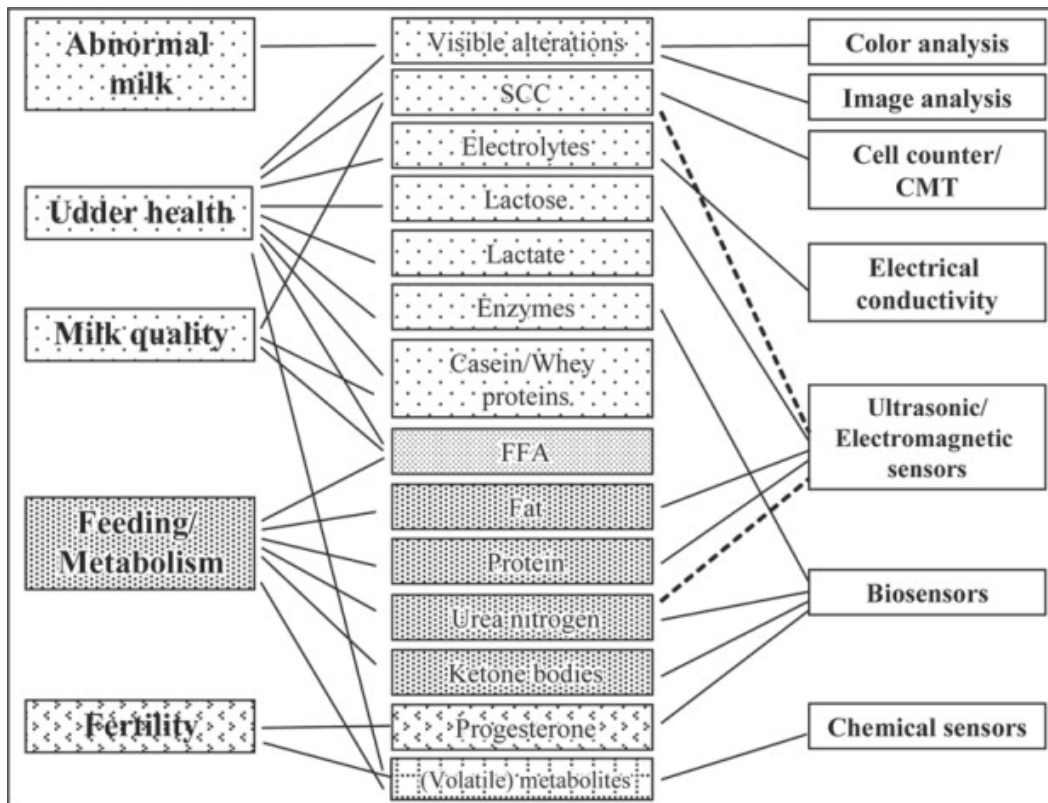


Figure 1: Indicators in milk, their application areas, and key sensing techniques. CMT = California Mastitis Test; FFA = free fatty acids. (BRANDT *et al.* 2010)

Definition of abnormal milk

There are several reasons for appointing quarters suffering from mastitis and the ultimate goal is to divert abnormal milk at the time of milking. Most of the detection systems were originally set up to produce an alarm list and were not specified towards appointing subclinical mastitis, clinical cases, abnormal milk, cows for culling or the need for antibiotic treatment. In order to test systems for their ability to divert abnormal milk a definition has been developed and included in an ISO standard (ISO 20966, 2007). Double standards are not appreciated by farmers and consequently, the definition of abnormal milk in ISO 20966 is based on standards for what should be detected visually during conventional milking. The definition of abnormal milk is according to the ISO standard milk which is visibly changed in homogeneity or coloured by blood. Additionally the standard includes definitions for undesirable and withheld milk. Undesirable milk means milk which, prior to the milking of the animal, is expected to be unsuitable for dairy processing (typically milk from cows with high cell counts). Withheld milk means milk which, prior to the milking of the animal, is known to be unfit for human consumption (typically milk from cows treated with antibiotics). The Annex C of ISO 20966 (2007) describes one method to detect blood in milk and one method to detect changes in homogeneity.

The detection of blood in milk is based on the work of RASMUSSEN & BJERRING (2005) finding that 65% of samples with about 1% blood in the milk will be scored as normal in a black strip cup whereas only 2% of the samples will be scored as normal milk if the blood content is 2%. Consequently, milk with 2% or more blood should be detected and diverted by the automatic system.

Detection of clots in milk is based on the work of RASMUSSEN (2005) which showed a high sensitivity and specificity using a filter method. The filter can have a pore size of 0.05 to 2 mm but size 0.1 mm was the easiest to read. The ISO test recommends that findings of clots in milk are supported by an increase in cell count or CMT-score. Cows with clinical mastitis may not show clots in the milk at every milking, but the milk will still not be suitable for human consumption. MEIN & RASMUSSEN (2008) analysed data from herds with clinical mastitis and concluded that the milking system should divert abnormal milk if clots were found in two out of three consecutive milkings and in this case the additional information of high cell counts did not improve sensitivity.

Blood in milk

Detection of milk coloured by blood can be done automatically and with a high sensitivity and specificity. OUWELTJES & HOGVEEN (2001) used a colour sensor based on reflection of the light generated by a Light Emitting Diode (LED) to measure the colour of the milk. Three different wavelengths were used to measure reflections in the red, green, and blue area and they were all set at a value of 100 for normal milk. Milk samples with 0.0025% blood showed a slight decrease in colour values but appeared visually normal. Milk samples with 0.05% blood were denoted slightly pink and had a 21% reduction in the blue colour. A sample with 1% blood was visually pink and had clearly reduced colour values in all three wavelengths. ESPADA & VIJVERBERG (2002) used the same colour sensor to detect clinical mastitis, colostrum, and blood in milk. About 1% of the measurements done by ESPADA & VIJVERBERG (2002) were below the value 86 in the blue range corresponding to the colour reading of a milk sample with 0.03% blood interpolated from the data of OUWELTJES & HOGVEEN (2001).

The red colour of blood and haemoglobin is due to the heme part where four heme molecules unite with globin to form haemoglobin. Measurement of haemoglobin or counting of red blood cells will be highly correlated with the colour of blood and a better indicator since the number of red blood cells in cattle blood differs from cow to cow. WHYTE *et al.* (2004) developed an in-line sensor based on optical measurements of the colour of milk to detect the presence of blood. All six samples with >10 mill. red blood cells per mL were identified (sensitivity 100%) and out of 475 samples with a lower count, 473 were correctly identified as negative (specificity 99.6%). The 10 mill. red blood cells per mL correspond to about 0.15% blood in the milk.

The performance of the tested systems is much better than what can be expected from manual detection of milk coloured by blood. All systems on the Danish market have

been tested according to Annex C of ISO 20966 (2007) and all came out with a sensitivity and specificity of 100% (RASMUSSEN 2006). The room for interpretation is wide and the technical performance of the systems so specific that detection can be based on composite milk as well as milk from individual quarters.

Detection of clinical mastitis based on conductivity

Electric conductivity is the most common method for on-line detection of cows and quarters with mastitis (BRANDT *et al.* 2010). Some of the early findings were very promising. All clinical mastitis cases were detected by a 15% increase in conductivity relative to the lowest quarter at the actual milking and a 20% increase over the last two milkings (MAATJE *et al.* 1992). The sensitivity for diversion of abnormal milk was 100%, but the specificity only 85% which would have discarded a lot of milk if these criteria had been used to divert milk automatically. NIELEN *et al.* (1995) used models based on the highest conductivity values and variation within the first, middle, and last minute of milking and found a sensitivity of 84% and a specificity of 97%. MAATJE *et al.* (1997) found a sensitivity of 90% for detection of clinical mastitis and 76% for subclinical mastitis and a specificity of 98% for healthy quarters (no bacteria present and SCC <500,000 cells/ml) by the use of time series analysis and Kalman-filters.

There have been several attempts to improve the algorithms, but it can be concluded that measurement of conductivity by it self is not enough to ensure an adequate sensitivity and specificity for diversion of abnormal milk. RASMUSSEN (2006) tested all systems on the Danish market according to the Annex C of ISO 20966 (2007). The best system had a sensitivity of 50% and a specificity of 99%. A system based on measuring conductivity in composite milk had a sensitivity of 13% and specificity of 87%, which is no better than random sampling. Further development of the systems is based on combination of information from different sensors and management programs.

Detection of clinical mastitis based on combination of sensors

There seems to be a possibility of using colour scanning of milk as an aid in the differentiation between normal and abnormal appearance of milk (OUWELTJES & HOGVEEN 2001, ESPADA & VIJVERBERG 2002). KAMPHUIS *et al.* (2008b) developed a flow diagram to systematically describe the steps involved in the transformation of within quarter milking measurements into variables that potentially predict abnormal milk and clinical mastitis. The most important variables came from the sensors for electrical conductivity and the colours blue and green. Variables describing the variability and shape of the measurement patterns were as important as mean and maximum values, and should be included in future modelling.

MOTTRAM *et al.* (2007) found an improvement over conductivity by the use of an electronic tongue. Sensitivity and specificity reached 93 and 96%. These results are rather

promising since measurements were not done during milking and only in some cases milk from different quarters within cow were compared. The authors state that the system needs to be tested on fresh milk samples to determine its potential as on-line measurement system.

Further combination of conductivity and colour measurement with information of the milking performance of each quarter resulted in a sensitivity of 83% and specificity of 99.4% (SONG *et al.* 2010). The study used four days as the time window and showed a clear advantage for including historical data of cows and quarters. Long time windows normally improves sensitivity, but will be on the cost of sensitivity when the target is diversion of abnormal milk at a specific milking.

Individual quarter cell count

The EU hygiene regulation impose that bulk milk SCC should be lower than 400,000 cells/ml. Most dairy factories got premiums for herds with low bulk milk SCC. There is an economic incentive to discard milk from cows with high SCC and especially if a payment threshold is passed. Cow SCC is a function of quarter SCC multiplied by quarter milk yield. Normally only one or two quarters experience clinical mastitis at the same time and measurement of individual quarter SCC could make it possible to divert high SCC milk only and deliver the milk from healthy quarters. KAMPHUIS *et al.* (2008a) conclude that detection of clinical mastitis is improved by in-line monitoring of SCC mainly through decrease of the false alert rate. FORSBÄCK *et al.* (2009) conducted an interesting study where cows were divided into three groups according to cow SCC. About 30% of the cows having cow SCC <100,000 cells/ml were discovered to have individual quarters with high SCC and decreased milk quality. The changes in SCC between quarters of obviously healthy cows were large and authors conclude that the effect of quarter separation on bulk milk needs further studies.

MOLLENHORST *et al.* (2010) collected data from three farms over 3-4 days and captured 12 cows with 19 quarters where foremilk was scored as visually abnormal. Samples of 20 ml of milk from each quarter were taken by the AMS from the first milk and analysed with an on-line SCC sensor. Milk meters were used to collect milk samples for each individual quarter and of the composite milk and samples were analysed for SCC. The correlation between log values of foremilk SCC and quarter SCC were only 0.47 and higher counts of foremilk than of quarter milk and visa versa were experienced. Differences in milking interval, emptiness of the quarter and placement of an infection in the udder may account for much of the difference. We expect foremilk SCC to discriminate best between mastitic and healthy quarters, but the quarter SCC will be a better measurement of milk quality in relation to bulk milk SCC. MOLLENHORST *et al.* (2010) found that sensitivity and specificity for appointing quarters with abnormal milk using quarter SCC was superior to cow SCC both in combination with measurement of quarter conductivity. There will be benefits of measuring quarter SCC in relation to milk quality al-

though it requires more complicated techniques especially in comparison with the measurement of conductivity.

Decision tree models and additional information

The main complaints from farmers regarding alert lists are directed towards false positives i.e. healthy cows that by the AMS is suspected to be mastitic. Inclusion of a decision-tree model has the potential to reduce the number of false alerts by more than 50% (KAMPHUIS *et al.* 2010b). The authors give an example of a decision tree including three nodes starting with quarter conductivity, adding colour measurement and ending with milk flow. The included variables should be independent and then improves classification into healthy or diseased. Inclusion of costs for false negatives improved the classifications (KAMPHUIS *et al.* 2010a) and decision-trees as such show potential for detecting clinical mastitis.

Inclusion of milk yield has been less successful in appointing cows with clinical mastitis. The main reason being that the daily fluctuations in milk yield are large and additionally, variation in milking interval has a direct influence on obtained milk yield. Lack in technical performance of the first models of AMS increased the variation in cow milk yields and especially of quarters when attachment was less successful. The variation in quarter milk yield from milking to milking is still large, but holds potentials for historic evaluations. **Figure 2** shows a plot of average quarter milk yield of healthy quarters and quarters treated for clinical mastitis. Treated quarters lost about 20% of their milk yield whereas a slight increase was seen for healthy quarters.

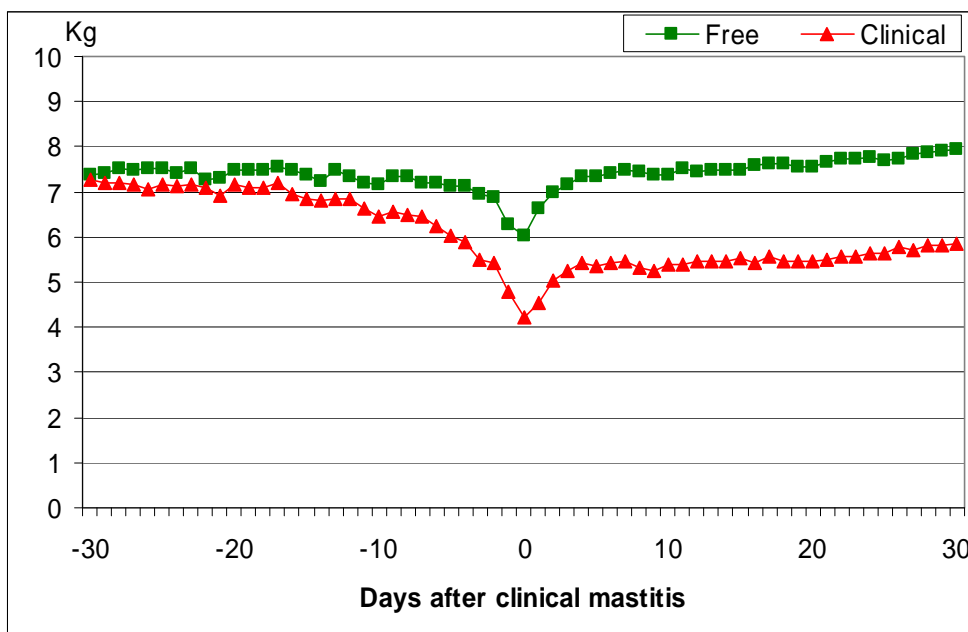


Figure 2: Daily milk yield of quarters free of infection (free) or being treated for clinical mastitis (clinical) at day 0 (Rasmussen *et al.* unpublished results)

Concluding remarks

Detection of clinical mastitis of cows milked automatically is mainly based on different interpretations and calculations of electrical conductivity. However, sensitivity and specificity of such systems are not high enough to be used for automatic diversion of abnormal milk. Milk quality can be improved by inclusion of additional measurements of which quarter SCC may have the largest potential. MAASSEN-FRANCKE *et al.* (2004) presented a prototype for diversion of abnormal milk based on measurement of the homogeneity. Such sensors will be directly correlated with the visual gold standard of abnormal milk and can be expected to match the required sensitivity and specificity for diversion of abnormal milk. We are still waiting for the first commercial version.

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Examination of milk flow traits in conventional and quarter-individual milking systems

Untersuchung von Milchflusseigenschaften bei konventionellen und viertelindividuellen Melksystemen

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Abstract: *Milk flow curves provide important information about the cow's response to the milking system and to the milking conditions. They also indicate physiological factors like parity, stage of lactation and status of udder health. Machine milking with conventional clusters often results in a damaging of the udder and teat because of detrimental forces. Against this background, a new quarter-individual milking system (MultiLactor[®], Siliconform GmbH, Türkheim, Germany) was developed. The milking technique comprises milking with a single tube guiding system and low vacuum level (37 kPa). A comparative study was performed to evaluate the differences in milk letdown between dairy cows that were milked by quarter-individual milking system (MUL) and dairy cows that were milked by conventional milking system (CON) in two tandem parlours. The milk flow curves were recorded every other week by using a LactoCorder[®] (WMB, Balgach, Switzerland). It was found out that between both milking systems there were no differences in duration of decline phase within main milking phase at primiparous and multiparous dairy cows. In contrast to tAB, tAN was shorter for MUL and showed significant differences between conventional and quarter-individual milked cows in all lactations. Correlation coefficients calculated for MUL ($r = 0.80$) and CON ($r = 0.65$) indicated that tMGG had a high positive correlation with tPL and was moderately positively ($r = 0.47$ for MUL and CON) related to tAB. In conclusion, primiparous cows, second-lactation cows and multiparous cows were not affected by the used milking system in regard to decline phase. In contrast to CON, MUL cows in all lactations showed a full milk ejection shortly after attaching the teat cups indicating a better pre-stimulation by actuator usage. In our opinion, quarter-individual milking is not only an advantage of automatic milking systems (AMS). With the usage of the MultiLactor[®] it exists also a possibility for quarter-individual milking in milking parlours.*

Keywords: *dairy cow, quarter-individual milking, conventional milking, milk flow, incline phase, plateau phase, decline phase*

Zusammenfassung: Milchflusskurven liefern wertvolle Informationen zur Reaktion der Milchkühe auf das Melksystem und die Melkroutine. Das Melken mit konventionellen Melkzeugen führt durch ungünstige Kraffteinwirkung oftmals zur Schädigung des Euters und der Zitzen. Aus diesem Grund wurde ein neuartiges viertelindividuelles Melksystem (MultiLactor[®], Siliconform GmbH, Türkheim, Deutschland) entwickelt. Diese Melktechnik ermöglicht das Melken mit Einzelschlauchführung bei niedrigem Vakuum (37 kPa). Um mögliche Unterschiede bezüglich der Milchabgabe zwischen viertelindividuell (MUL) und konventionell (CON) gemolkenen Kühen zu bewerten, wurde eine vergleichende Studie durchgeführt. Die Milchflusskurven wurden alle zwei Wochen mit LactoCordern[®] (WMB, Balgach, Switzerland) aufgezeichnet. Es konnte gezeigt werden, dass sowohl bei erstlaktierenden als auch bei mehrfachlaktierenden Kühen zwischen beiden Melksystemen hinsichtlich der Dauer der Abstiegsphase keine Unterschiede bestanden. Im Gegensatz dazu war die Anstiegsphase bei MUL kürzer und wies in allen Laktationen signifikante Unterschiede zwischen den konventionell und viertelindividuell gemolkenen Kühen auf. Die Korrelationskoeffizienten (MUL: $r = 0.80$ und CON: $r = 0,65$) zeigten, dass die Melkdauer eng mit der Dauer der Plateauphase und mittelmäßig hinsichtlich der Dauer der Abstiegsphase verbunden war ($r = 0,47$ bei MUL und CON). Zusammenfassend kann gesagt werden, dass die Kühe in allen Laktationen bezüglich der Dauer der Abstiegsphase nicht vom eingesetzten Melksystem beeinflusst wurden. Im Gegensatz zu CON, zeigten die MUL-Kühe in allen Laktationen eine vollwertige Milchejektion kurz nach dem Ansetzen der Melkbecher. Dies deutet auf eine verbesserte Vorstimulation durch Aktuatoreinsatz hin. Nach unserer Ansicht ist viertelindividuelles Melken nicht nur ein Vorteil von automatischen Melksystemen (AMS). Mit dem Einsatz des MultiLactors[®] gibt es auch in Melkständen die Möglichkeit Kühe viertelindividuell zu melken.

Schlüsselwörter: Milchkuh, viertelindividuelles Melken, konventionelles Melken, Milchfluss, Anstiegsphase, Plateauphase, Abstiegsphase

Introduction

Milk yield, milk quality and udder health influence the economic efficiency of dairy farms very much (BOCKISCH & ORDOLFF 2006). Mechanical milking requires complete and fast removal of milk from the udder under optimal technical and hygienic conditions to maintain animal health (BRUCKMAIER & HILGER 2001). The technical condition of milking equipment has a considerable effect on the milk gland health status and milk quality.

The production level of cows had no influence on the course of milk flow (WELLNITZ *et al.* 1999). Therefore the milk flow of high-yielding cows is mainly characterized by a prolonged milking time, but not by an increase of peak and average milk flow rates. Total milking time was significantly longer in rear than in front quarters independent of the milk production level caused by uneven distribution of quarter milk yields (SCHÖNE *et al.* 1994, WELLNITZ *et al.* 1999). That fact led to unavoidable over-milking in the quarters with less milk yield which tended to be numerically longer in high-yielding cows and sig-

nificantly longer in lower-yielding cows (WELLNITZ *et al.* 1999). The duration of the decline phase at the udder level indicates the over-milking of one or more quarters and the reduction of both milk flow traits seem to be important for good milking process (TANČIN *et al.* 2007b). Milking with pre-stimulation resulted in a reduction of milking time, duration of the incline and decline phase of milk flow, but it increased the peak flow rate as compared to milking without pre-stimulation (TANČIN *et al.* 2007a). Pre-stimulation positively influences milk letdown and therefore the efficiency of milking.

ZUCALI *et al.* (2009) supported a close relationship among high peak milk flow, short duration of plateau phase and high milk SCC (somatic cell count) in primiparous cows at the beginning of lactation. Quarters with long decline phase had higher SCC compared to quarters with short decline phase (TANČIN *et al.* 2007b). On-line measurements of milk samples from each quarter could be one easy way of detecting an increase in SCC at an early stage of inflammation (BERGLUND *et al.* 2002). Milking systems using quarter-individual milking, like automatic milking systems or the MultiLactor[®], could offer such possibility to collect and analyse foremilk from each quarter. Bimodality had no effect on the decline phase at the udder level, but resulted in a longer decline in bimodal milk flow curves at the quarter level (TANČIN *et al.* 2007b). Over-milking had no immediate effect on SCC (WELLNITZ *et al.* 1999). But still, long-term effects on mastitis susceptibility due to unavoidable overmilking of single quarters cannot be excluded.

Material and method

Animals and management

The experiment was carried out at a dairy farm located in Thuringia (Germany) between June and December 2009. 84 primiparous and multiparous Holstein cows were randomly divided into two test groups. Only dairy cows till the 120th day of lactation and free of clinical symptoms of mastitis were investigated during the trial period. Both groups were housed in the same cubicle barn and got the same dairy feedstuff ration including additional concentrates. All cows were milked twice daily at 0630 and 1830 h in a tandem parlour; group one with a conventional (CON) and group two with a quarter-individual (MUL) milking system. Milking operations were performed by two milkers in each group. In both experimental groups premilking procedures included: forestripping and cleaning of the teats with disinfection tissues as well as teat dipping at the end of milking. After this short preparation, the teat cups were immediately attached.

Milking systems

During the experiment, a conventional milking system (CON) (Westfalia[®] manufactured by GEA, Bönen, Germany) and a quarter-individual milking system (MUL) (MultiLactor[®]) manufactured by Siliconform GmbH, Türkheim, Germany) were examined in regard to milking performance. Both milking parlours had a low level milk line and were equipped

with milk meters. Milking vacuum was set at 37 kPa (MUL) and 41 kPa (CON). Pulsation ratio was 60:40 (CON) and 65:35 (MUL); both with a pulsation rate of 60 cycles/min. The MultiLactor[®] had a single tube guiding system with silicon liners and this system allowed periodic air inlet to the pulsation chamber of the teat cups (BioMilker[®]). Furthermore, the system used a new type of pulsation - sequential pulsation. In each liner, pulsation started successively with 25% out of phase. This technical characteristic provided a steady draining off milk from the four teat cups. MUL applies a special pre-stimulation with a mechanical actuator stimulating each teat and the whole udder with vibrating movements of the long milk tubes.

Milk flow measurements

Milk flow curves of the whole udder from all test animals were recorded exclusively during the evening milking with a continuous electronic milk flow meter (LactoCorder[®], WMB, Balgach, Switzerland). Measurements have been realized every other week for each experimental group. The LactoCorder[®] measured milk yield, several milking time traits and electrical conductivity. The main milking phase was divided into three phases:

1. incline phase (milk flow rate > 0.5 kg/min until start of plateau phase)
2. plateau phase (phase of steady milk flow)
3. decline phase (from end of plateau phase until milk flow rate < 0.2 kg/min)

In **table 1** some milkability traits describing the milk letdown are listed:

Table1: Traits characterizing milking

Merkmale der Milchabgabe

Abbreviation	Unit	Trait
MGG	kg	Total amount of milk
tMGG	min	Duration of whole milking
tAN	min	Duration of increase phase
tPL	min	Duration of plateau phase
tAB	min	Duration of decrease phase
tMHG	min	Duration of main milking phase
HMF	kg/min	Maximum milk flow per minute
DMG	kg/min	Average milk flow per minute of whole milking
DMHG	kg/min	Average milk flow per minute within main milking phase

Statistical analysis

For the calculations of correlations the CORR procedure was used (SAS 9.1, SAS Institute Inc., Cary, NC, USA). The evaluation of the data and comparison of the two different milking systems was made using a mixed linear model (MIXED procedure). The model was:

$$y_{ijkl} = \mu + MS_i + CW_j + Dx + Mz + K_k + e_{ijk}$$

$$(i=1,2; j=1,\dots,14; k=1,\dots,84)$$

with y : expected value of target variable;
 μ : general mean;
 MS_i : fixed effect of the i -th milking system;
 CW_j : fixed effect of the j -th comparative test weeks;
 D : covariable (lactation day x);
 M : covariable (milk yield z);
 K_k : random effect of k -th cow;
 e_{ijk} : residual error.

Results

Influence of milking system

The differences of least square means were calculated for the fixed effect milking system and considered for several parities. Independent of the lactation number, level of milking system had no influence on tAB within main milking phase. Estimated values for tAB were numerically higher in cows milked quarter-individually. In view of tAN, there were significant differences between conventional and quarter milked cows in all lactations. All values showed that tAN was considerable lower in the MUL, especially for primiparous cows. With regard to tPL, significant differences existed between CON and MUL in the 1th and $\geq 3^{\text{th}}$ parity. Duration of main milking phase took numerically longer for MUL-cows in all investigated lactations. But only cows with three or more lactations showed significant differences in tMHG between both milking systems

Table 2: Least square means (LSM), standard error (SE) and influence of milking system as fixed effect upon milk flow traits of main milking phase

Schätzwerte mit den kleinsten quadratischen Abweichungen (LSM), Standardfehler (SE) und Einfluss des Melksystems als fixen Einflussfaktor auf Milchflusseigenschaften der Hauptmelkphase

Lactation	Effect	Level	tAN [min]		tPL [min]		tAB [min]		tMHG [min]	
			LSM	SE	LSM	SE	LSM	SE	LSM	SE
1 th (n=397)	MS	CON	0.90 ^a	0.06	3.09 ^a	0.50	2.40 ^a	0.24	6.51 ^a	0.62
	MS	MUL	0.37 ^b	0.06	5.33 ^b	0.54	2.51 ^a	0.25	8.12 ^a	0.67
2 th (n=393)	MS	CON	0.91 ^a	0.07	2.65 ^a	0.34	2.78 ^a	0.23	6.49 ^a	0.47
	MS	MUL	0.66 ^b	0.05	3.21 ^a	0.28	2.94 ^a	0.19	6.71 ^a	0.38
≥3 th (n=263)	MS	CON	0.97 ^a	0.06	2.10 ^a	0.36	3.07 ^a	0.27	6.19 ^a	0.41
	MS	MUL	0.44 ^b	0.06	4.60 ^b	0.38	3.16 ^a	0.28	8.15 ^b	0.43

^{a, b} different small letters within fixed effect indicated significant differences at $\alpha = 0.05$

Relationships between milkability traits

The **table 3** and **4** shows Spearman correlation coefficients between selected milkability traits of the milk flow curve for MUL and CON. Spearman correlation coefficients calculated for MUL indicated that tMGG had a high positive correlation with tPL and was moderately negative related to tAN as well as positive to tAB. Furthermore, tAN was strong negatively related to tPL which means that a short increase of milk flow until reaching tPL causes a longer duration of steady milk flow. Similar results were found for estimate values calculated for CON. Only the positive correlation between HMF and tAN was considerable lower in comparison with MUL. Also the relationship between tAN and tPL were not so marked, although the two milkability traits largely influence the milk let-down.

Table 3: Correlations between selected milk flow parameters for quarter-individual milking system (n=556)

Korrelationskoeffizienten zwischen ausgewählten Milchflussparametern bei viertelindividuell gemolkenen Kühe (n=556)

Parameter	HMF	tMGG	tAN	tPL	tAB
MGG	0.36	0.36	0.27	0.24	0.24
HMF		-0.60	0.71	-0.69	-0.07
tMGG			-0.44	0.80	0.41
tAN				-0.59	-0.07
tPL					-0.05

* ($P > 0.05$)

Table 4: Correlations between selected milk flow parameters for conventional milking system (n=497)

Korrelationskoeffizienten zwischen ausgewählten Milchflussparametern bei konventionell gemolkenen Kühe (n=497)

Parameter	HMF	tMGG	tAN	tPL	tAB
MGG	0.45	0.47	0.06	0.32	0.24
HMF		-0.37	0.29	-0.53	-0.01
tMGG			-0.17	0.65	0.47
tAN				-0.31	-0.11
tPL					-0.11

* (P > 0.05)

Discussion and conclusions

For Holstein cows, DODENHOFF *et al.* (1999) were able to show that the fixed effect of parity had a significant influence on the following milkability traits: HMF, tPL and tAB. According to that, tPL decreased and tAB increased with rising lactations (DODENHOFF *et al.* 1999) which was confirmed with our own experiments. TANČIN *et al.* (2006) found out that second-lactation and multiparous cows had higher MGG than primiparous cows. However, parity did not influence HMF or tAN at udder or quarter level.

For all lactations, the milking system (MUL and CON) had an influence on tAN which was significantly smaller for cows milked quarter-individually. For this reason, it is justified to assume that primiparous as well as multiparous cows did not have any problems caused by adaptation to the new quarter-individual milking system (MUL). The tPL and tAB are the two major time traits within the milking process and the lion's share of milk was yielded during this period. Against this background, the present study demonstrated that the used milking system did not have any influence on tAB no matter which number of lactation the cows were in. With regard to tPL, primiparous MUL-cows as well as MUL-cows with three and more lactations had a significant longer duration of steady milk flow compared to CON-cows. According to DODENHOFF *et al.* (1999), dairy cows with longer tPL had lower somatic cell counts, but the proven correlation between both traits was only weak negative ($r = -0.16$). Thus, somatic cell count can be reduced by prolongation of tPL (DODENHOFF *et al.* 1999). In contrast to that NAUMANN *et al.* (1998) showed that tPL did not have any effect on somatic cell content. Therefore tAB and the ratio of tPL and tAB had a significant influence on SCC. According to GÖFT *et al.* (1994), a long plateau phase did not entail a short duration of decrease phase.

The relative high negative correlation between HMF and tPL (-0.53 till -0.69) were in conformity with the results of DODENHOFF *et al.* (1999). Present study and earlier results (DODENHOFF *et al.* 1999, NAUMANN *et al.* 1998) showed no or only a very weak and negative correlation between tAB and tPL as well as HMF. The noticeable high correlation (MUL: $r = 0.89$ and CON: $r = 0.87$) between average milk flow within main milking

phase and HMF suggested that the aim to breed Holstein cows with a high average milk flow led to increasing HMF (GÖFT *et al.* 1994). The results of LEE & CHOUDHARY (2006) showed that HMF had medium negative correlations with tMGG ($r = -0.37$ till -0.60) indicating that an increase in milking speed will decrease the milking time. In the authors' view, milking speed should be high to save labor time and money, but otherwise high milking speed encourages the occurrence of bovine mastitis because the risk to damage the is higher under these conditions (BOETTCHER *et al.* 1998). Furthermore, high milking speed may lead to overmilking. Overmilking can causes damages, especially to the quarter that has milked out early (LEE & CHOUDHARY 2006).

In our opinion, quarter-individual milking is not only an advantage of automatic milking systems (AMS). With the usage of the MultiLactor[®] it exists also a possibility for quarter-individual milking in conventional parlours. Further research is needed to evaluate the influence of the new milking system on udder health and teat condition.

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On-farm analysis in quarter individual milking

On-farm Analyse beim viertelindividuellen Melken

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Abstract: *On-farm analyses of milk components are possible today using stand-alone instruments and in-line techniques. These techniques make measurements of milk at bulk tank, cow or udder quarter level possible on the farm. In addition, they allow more frequent analysis of milk than the monthly official milk recording. A prerequisite when analysing milk components is to know the day-to-day variation, which is known to differ between parameters, but the variation within parameters is similar between udder quarters of healthy cows. This makes within-udder comparisons valuable when detecting abnormalities in milk composition and udder health. It has been shown that udder quarters with altered milk composition and elevated SCC can be masked when milk is analysed at cow level. This suggests that recordings of udder quarter milk sample will be a valuable tool for detecting alterations in milk composition and udder health. On-farm analysis is one way to analyse milk at udder quarter level.*

Keywords: *On-farm analysis, udder quarter, milk composition, somatic cell count (SCC), day-to-day variation*

Zusammenfassung: On-farm Analysen von Milchinhaltsstoffen sind heutzutage mit stand-alone Geräten und in-line Technik möglich. Mit diesen Techniken sind Messungen von Tankmilch sowie pro Kuh und Euterviertel im Betrieb machbar. Zusätzlich erlauben sie die häufigere Analyse von Milch als die monatliche Milchkontrolle. Eine Vorbedingung bei der Analyse von Milchinhaltsstoffen ist, die Alltagsveränderung zu kennen, die sich bekanntermaßen zwischen den einzelnen Parametern unterscheiden. Jedoch ist die Veränderung innerhalb der Parameter zwischen Eutervierteln von gesunden Kühen ähnlich. Dies gibt die Möglichkeit, durch den Vergleich der Euterviertel Abweichungen zu erkennen und Rückschlüsse auf Milchinhaltsstoffe und Eutergesundheit ziehen zu können. Es hat sich gezeigt, dass Euterviertel mit veränderter Milchezusammensetzung und erhöhten Zellzahlen bei einer Analyse auf Euterebene unentdeckt bleiben. Das lässt vermuten, dass die Erfassung von Euterviertel-Milchproben ein wertvolles Werkzeug für die Entdeckung von Änderungen in der Milchezusammensetzung

und der Eutergesundheit sind. On-farm Analyse ist eine Möglichkeit die Milch auf Euterviertelniveau zu analysieren.

Schlüsselwörter: On-farm Analyse, Euterviertel, Milchinhaltsstoffe, somatische Zellzahl (SCC), Tagesabweichungen

Introduction

With technical development and progress in dairy production, it is now possible to analyse milk at farm level with either stand-alone instruments or with in-line techniques (for review see BRANDT *et al.* 2010). Stand-alone instruments are available on the market for analyses of milk composition and milk somatic cell count (SCC). For in-line analyses during milking, parameters such as SCC, electrical conductivity, blood in milk, progesterone, lactate dehydrogenase, β -hydroxybutyrate and urea are available. On-farm analyses make it possible for the farmer to analyse the milk at tank level, cow level or udder quarter level as frequently as required. The results of the analyses can be used for different purposes such as breeding, feed management and udder health. Some previous studies have scrutinised the importance of monthly versus daily milk recordings on cow composite milk, but studies dealing with the importance of on-farm analyses at udder quarter level are sparse, despite techniques being available for such analyses.

Irrespective of whether the milk analyses are performed with stand-alone instruments or in-line equipment, the accuracy of the analyses must be lower than the day-to-day variation for the natural biological variation in the components to be analysed. A prerequisite for functional analytical equipment at farm level is that it must be robust, easy to handle, able to withstand the rather tough milking parlour environment and easy to calibrate.

The aim of this paper is to discuss the possibilities and relevance of on-farm analysis in quarter individual milking.

Why frequent on farm milk analyses?

As milk SCC and milk composition are affected by various factors, such as breed, feeding, lactation stage, lactation number, stress and season, it can be difficult to decide from occasional values whether the milk is normal and the cow is healthy (HARMON 1994, WALSTRA *et al.* 1999). For example, fat and protein content are influenced by feeding, breed, stage of lactation, milking procedure and season (JOHANSSON *et al.* 1952, SUTTON 1989, SVENNERSTEN *et al.* 1991, WALSTRA *et al.* 1999, WEISS *et al.* 2002). Milk SCC can be influenced by stage of lactation, milking interval and management system, for example use of grazing (COULON *et al.* 1998, FOX & SCHULTZ 1985, HARMON 1994, WREDLE *et al.* 2008, LAKIC *et al.* 2009). Milk composition profiles for individual cows would therefore be preferable in early detection of, for instance, changes in udder

health. This would require frequent analyses of the milk and information about the day-to-day variation. Deviations from the 'normal' variation can be used to signal an alarm situation (for review see SVENNERSTEN-SJAUNJA *et al.* 1997).

Milk in bulk tanks is routinely analysed weekly for its composition at central laboratories for payment purposes, while milk from individual cows is analysed monthly for breeding purposes and management decisions. Monthly milk analyses are probably adequate for breeding, but it is questionable whether the frequency of monthly analyses is optimal for management decisions and health control. Furthermore, the time lag between taking the milk sample and receiving the results can vary and the results can be delayed for up to a week before they reach the farmer. For decision making or for information about udder health status the time lag ought to be short, so on-farm analyses could be an alternative or complement to analyses at central laboratories. Another aspect is that when a potential problem is detected, it is important to investigate this as soon as possible. The wait for the monthly milk recording can be too long for early detection and treatment of potential problems. On-farm analyses also give the farmer opportunities to select whether the milk samples should be taken at bulk tank, cow or udder quarter level. On-farm analysis of milk components could consequently be a completion to the conventional monthly recordings.

Day-to-day variation in milk components at udder quarter level

Several studies have been performed on day-to-day variation in composite milk samples from individual cows (SYRSTAD 1977, SJAUNJA 1986, SVENNERSTEN-SJAUNJA *et al.* 2005, ČANDEK-POTOKAR *et al.* 2006, QUIST *et al.* 2008). The day-to-day-variation differs between the different milk components, and is generally higher for fat content and milk yield than for lactose and protein content. The day-to-day variation of milk yield, fat content, lactose content and protein content have been reported to be 6-8%, 5-8%, 1% and 1.5-2%, respectively. However, information about day-to-day variation in milk from separate udder quarters is sparse (LINZELL & PEAKER 1972).

In a recent study where samples were taken from each separate udder quarter at every milking during a three-week period, the day-to-day variation in milk components and SCC of healthy cows was found to be low and equal within the four udder quarters (FORSBÄCK *et al.* 2010) (**Figure 1**). Day-to-day variation in healthy cows in udder quarter milk was 0.9% for lactose and 2.0% for SCC. The variation in composite milk and udder quarter milk was almost similar. Within-udder comparisons were indicated to be a useful method to detect deviations or abnormalities (**Figure 2**). As shown, both SCC and lactose deviated markedly in the affected udder quarter, which also had bacterial infection. Results reported by ÅKERSTEDT *et al.* (2010) and FORSBÄCK *et al.* (2010) confirm the findings by LINZELL & PEAKER (1972) that the day-to-day variation in milk components is equal within the four udder quarters of healthy cows. When a component differs, this

can be related to clinical mastitis (LINZELL & PEAKER 1972) or elevated SCC (FORSBÄCK *et al.* 2010).

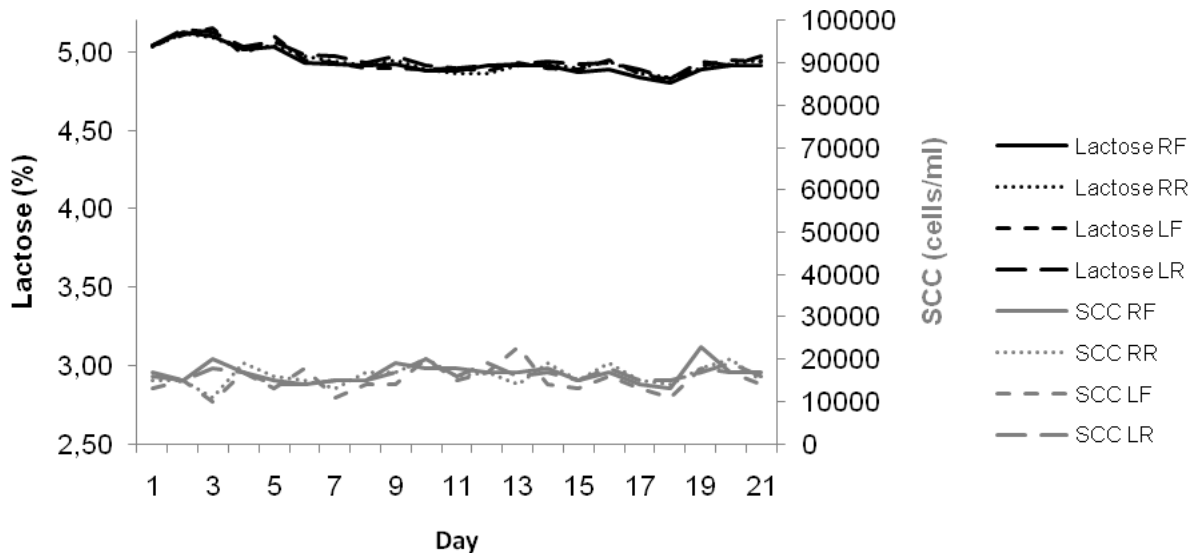


Figure 1: Somatic cell count (SCC) and content of lactose in milk from a healthy cow during 21 consecutive evening milkings. RF = right front udder quarter, RR = right rear udder quarter, LF = left front udder quarter and LR = left rear udder quarter.

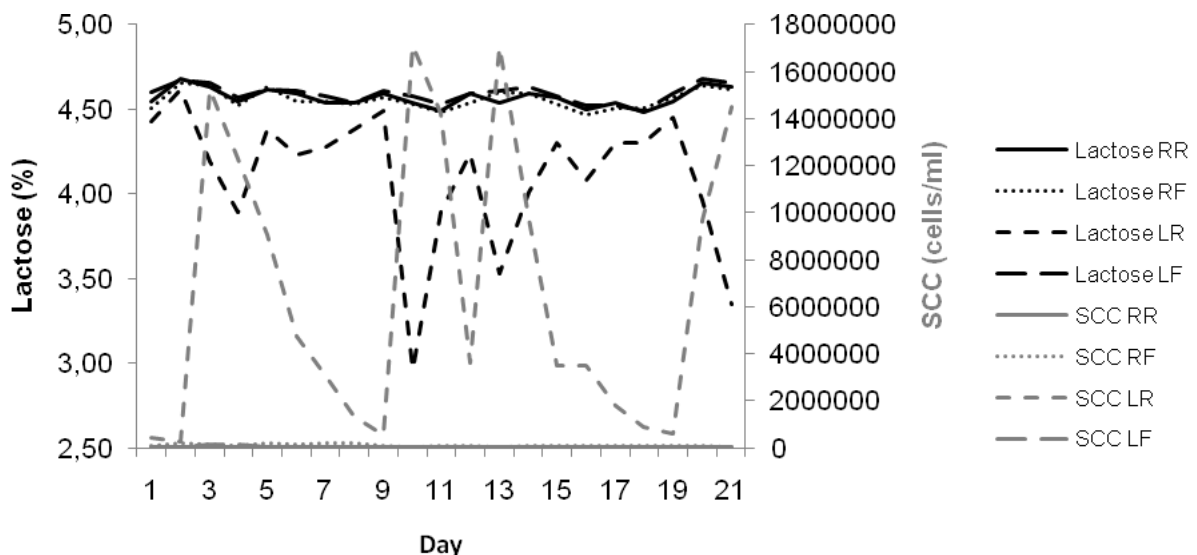


Figure 2: Somatic cell count (SCC) and content of lactose in milk from a cow with subclinical mastitis in her left rear udder quarter during 21 consecutive evening milkings. RF = right front udder quarter, RR = right rear udder quarter, LF = left front udder quarter and LR = left rear udder quarter.

Interestingly, we also observed generally higher day-to-day variation in the biomarkers for udder health: LDH, NAGase, serum amyloid A and alkaline phosphatase

(ÅKERSTEDT *et al.* 2010) compared with the compositional parameters (FORSBÄCK *et al.* 2010). The day-to-day variation of the biomarkers for udder health ranged between 8-50%. The differing day-to-day variation between milk components and biomarkers indicates that the demands on analytical accuracy for the different components are not the same. The analytical accuracy must always be lower than the biological variation, since otherwise the results can be masked by the analytical error (SJAUNJA 2005).

However, as mentioned above, the level of the different milk components differs naturally between individual cows due to lactation number, lactation stage, feeding and management. Using a cut-off value can therefore be misleading, since each cow has its own level. For example, FORSBÄCK *et al.* (2010) found that a cow with quite a high lactation number (7) had slightly higher SCC (mean value of the four udder quarters was 84 000 cells/ml) than the other cows, but the day-to-day variation in SCC and in other milk components of the four udder quarters was low and no bacteria were found in the udder quarters, indicating that this cow was healthy. In general, the mean composition and variation in the four udder quarters of healthy cows are similar. This suggests that analysing milk at udder quarter level, especially with repeated measurements, is a sensitive method for detecting deviations that can be related to udder health and milk composition disturbances. Repeated measurements at udder quarter level with equipment available at the farm can therefore be justified. However, the instruments used must be rather cheap, easy to handle and environmentally friendly. Laboratory equipment that is expensive and more difficult to use is not suitable at farm level.

Detection of udder health and milk composition alterations is the only application where udder quarter milk samples are worthwhile. In other recordings, *i.e.* for breeding and feed management, as far as we know today, no further information can be obtained using udder quarter milk samples compared with cow composite milk samples.

Are udder quarters with deteriorated milk composition common?

Altered milk quality due to subclinical mastitis often occurs in only one of the four udder quarters, since it is very seldom that all quarters are affected (BARKEMA *et al.* 1997). Due to the anatomical construction of the udder, milk cannot pass from one udder quarter to another. Furthermore, milk with deteriorated quality from one quarter cannot pass to another. During recording at cow level, problem milk from individual udder quarters can be masked due to the dilution effect.

In our own studies in cows that were considered healthy, we observed that in cow composite milk samples with less than 100 000 cells/ml, around 30% of the cows had one or more quarters with elevated SCC and altered milk composition. The total protein, whey protein, casein number, lactose and SCC were significantly different in affected udder quarters compared with contralateral healthy udder quarters (FORSBÄCK *et al.* 2009). This is in agreement with BERGLUND *et al.* (2004), who also found elevated SCC in milk at udder quarter level when cow composite milk exhibited SCC < 100 000 cells/ml milk.

In 50% of the quarters with elevated SCC, the udder quarter was infected by a mastitis pathogen. Consequently, milk recording ought to be performed at udder quarter level in order to detect cows with subclinical mastitis and deteriorated milk quality.

Cows with elevated SCC in composite milk presumably have udder quarters with low SCC containing milk that is not altered. FORSBÄCK *et al.* (2009) observed that cows with elevated SCC in composite milk had one or more udder quarters with SCC < 100 000 cells/ml in the milk. These results suggest that cows with elevated SCC in composite milk samples most likely have udder quarters with low SCC and normal milk composition.

Separation of mastitic milk?

The greatest and most costly problem in dairy production is mastitis. It is a well known fact that mastitis alters milk composition and causes increased activity in lipolytic and proteolytic enzymes whereby the quality of raw milk delivered to the dairy can be impaired (TOLLE *et al.* 1971, KITCHEN 1981, MUNRO *et al.* 1984, AULDIST & HUBBLE 1998, HORTET & SEEGERS 1998, HAMANN 2002). It has been questioned whether it is economically viable to avoid delivering milk from cows with elevated SCC to the dairy or whether to separate the mastitic milk before it enters the bulk tank at the farm.

In a study examining the effect of excluding milk from individual udder quarters with elevated SCC at cow level, it was observed that the total protein and whey fraction contents were lower and the content of lactose was higher in the milk when udder quarter milk with elevated SCC was excluded. Although the number of cows in this study was only 11, the results give an indication that there are some improvements in milk quality, at least at cow level, when milk from individual udder quarters with elevated SCC is excluded (FORSBÄCK 2010).

Calculations on excluding milk from individual udder quarters with high SCC showed that the bulk tank SCC could be decreased from 274 000 cells/ml to 135 000 cells/ml by only excluding milk from four udder quarters having a SCC of 18 433 000, 14 388 000, 11 976 000 and 5 113 000 cells/ml, respectively. However, the milk composition showed no changes. The small amount of milk excluded and the lower bulk tank SCC would probably lead to some increase in the payment for that milk (FORSBÄCK *et al.* 2009). This was only a calculation, and the issue needs to be studied in practice to fully evaluate the effects.

NIELSEN (2009) simulated discarding milk with high SCC and found it never to be profitable, with none of the simulated scenarios giving any beneficial effect on the net return per cow-year. The problem is that the higher milk quality achieved does not pay enough to compensate for the lower amount of milk supplied. The quality of milk supplied has a lower impact on income for the farmer than the amount of milk supplied. However, the simulation by NIELSEN (2009) represented sorting of milk at cow level and this may have

involved milk of good quality being discarded, since we know that it is very seldom that all four udder quarters of a cow are infected. Separation of milk at cow level would contribute to higher amounts of milk being discarded than separation of milk at udder quarter level, so the question is whether it is justifiable to separate milk at udder quarter level.

Future studies on the impact of excluding milk at udder quarter level on the bulk milk tank will confirm whether it is worthwhile for the overall milk quality to introduce separation of milk at udder quarter level.

When discussing the possibilities to separate milk at udder quarter level in order to improve bulk tank milk, it is also important to consider the possibilities to deliver the milk from those low SCC udder quarters in cows with high SCC in composite milk. It is a waste of resources to discard all milk from these cows, whereas sorting milk at udder quarter level could be worthwhile. However, the European Union Directive 853/2004 states that milk from any cow presenting organoleptic or physico-chemical abnormalities is not permitted for use for human consumption (EC 2004). This can be interpreted as meaning that all milk from cows presenting abnormalities in milk should be discarded, which will prevent farmers excluding only milk from individual udder quarters.

Conclusions

Since the relative day-to-day variation is the same in all four quarters in a healthy udder, deviations in milk components can indicate udder health disturbances. Analyses on udder quarter level on the farm can be a valuable tool for early detection of udder quarters with mastitis or elevated SCC. Whether milk should then be separated and excluded at udder quarter level is debatable. However, at least at cow level, there are signs that the exclusion of milk from udder quarters with elevated SCC can improve milk quality.

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Automatic milking: management and milk quality

Automatisches Melken: Management und Milchqualität

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Abstract: *Almost twenty years ago the first automatic milking systems were installed on commercial farms in The Netherlands. No other new technology since the introduction of the milking machine, has aroused so much interest and expectations among dairy farmers and the periphery. Reduced labor, a better social life for dairy farm families and increased milk yields due to more frequent milking are generally recognized as important benefits of automatic milking. Without doubt automatic milking changes many aspects of farm management since both the nature and organization of labor is altered. Manual labor is partly replaced by management and control, and the presence of the operator at regular milking times is no longer required. Visual control on cow and udder health at milking is, at least partly, taken over by automatic systems. Facilities for teat cleaning and separation of abnormal milk are incorporated into the automatic system and several adaptations are needed to accommodate continuous milking. Cow management including routing within the barn, the opportunity for grazing and the use of total mixed rations is altered. A high level of management and realistic expectations are essential to successful adoption of automatic milking. Results from commercial farms indicate, that milk quality is somewhat negatively affected, although bacterial counts and somatic cell counts remain well below penalty levels. In terms of quality control, AM systems offer extra means to assure milk quality and food safety. No adverse effects of the transition have been found for body condition, lameness or teat condition. Automatic milking has gained widespread acceptance and is estimated to be in use on approximately 10000 farms in over 25 countries worldwide at the end of 2010.*

Keywords: *automatic milking, milking robot, barn layout, milk quality, animal health, farm economics*

Zusammenfassung: In 1992 werden die ersten automatischen Melksystemen auf kommerziellen Farmen in den Niederlanden installiert. Keine andere neue Technologie seit der Einführung der Melkmaschine, hat so viel Interesse geweckt und Erwartungen unter den Milchbauern und der Peripherie, wie Roboter Melken. Geringere Arbeitskosten, eine besseres soziales Leben für Familien und erhöhte Milchleistung wegen

häufiger melken der Kühe, werden allgemein als wichtige Vorteile des Roboter Melken anerkannt.

Roboter Melken verändert ohne Zweifel viele Aspekte der Betriebsführung, da sowohl die Art und Organisation der Arbeit verändert. Manuelle Arbeit wird teilweise durch Verwaltung und Kontrolle ersetzt, weil die Anwesenheit des Betreibers in regelmäßigen Melkzeiten nicht mehr erforderlich ist. Visuelle Kontrolle von die Kuh und die Eutergesundheit beim Melken ist, zumindest teilweise übernommen durch automatische Sensorsystemen. Melkroboter haben Geräte und Anlagen für die Zitzenreinigung und Trennung von abnomaler Milch. Diese Geräte und Anpassungen sind notwendig für kontinuierliches Melken.

Auch das Tier-Management, das Kuh-Verkehr, Beweidung und die Fütterung ändern wesentlich. Ein gutes Management und realistische Erwartungen sind unerlässlich für eine erfolgreiche Einführung das Roboter Melken.

Ergebnisse von Roboterbetrieben zeigen, dass die Milchqualität etwas negativ beeinflusst wird, obwohl die Keimzahlen und Zellzahlen deutlich unter die maximal Werten bleiben.

In Bezug auf die Qualitätskontrolle, bieten AM systeme zusätzliche Mittel um die Milchqualität und Lebensmittelsicherheit zu gewährleisten. Keine negativen Auswirkungen des Übergangs sind gefunden für Body Kondition, Lahmheiten, Eutergesundheit und Zitzen Kondition. Roboter Melken ist weithin anerkannt und wird geschätzt zum Ende des Jahres 2010, im Einsatz zu sein auf 10000 Betriebe in über 25 Ländern weltweit.

Schlüsselwörter: Automatisches Melken, Melkroboter, Stallplan, Weiden, Milch Qualität, Tiergesundheit, Ökonomie

Introduction

The main reason to start the development of automatic milking in the eighties of the last century, was the need for improved labor efficacy due to the growing costs of labor in many dairy countries (ROSSING *et al.* 1985, ROSSING & HOGWERF 1997, LIND *et al.* 2000). Milking is on many dairy-farms a time consuming activity, which takes about 25 to 35% of the annual labor demand. The development of AM systems started with the development of equipment for automatic attachment of the teat cups (ROSSING & HOGWERF 1997). However automatic milking requires more than automatic teat cup attachment. An AM system has several main modules, like the milking stall itself, the teat cleaning system, the teat detection system, a robotic arm device for attaching the teat cups, a control system including sensors and software and of course the milking machine. Apart from substituting manual labor by technology, robotic milking affects the whole farming operation. The farmer's presence at regular milking times is no longer required. The nature and organization of farm labor changes such that manual labor

dealing with milking is largely replaced by management and control activities. Regular visual checks of cow and udder health during milking is, taken over by automated monitoring using smart sensor technology. An automatic milking system (AM system) is in use for 24 hrs a day, which requires a high reliability of the system as well as the adaptation of cleaning and cooling systems. Permanent access to the milking system may require specific cow routing within the barn and is likely to affect the possibilities of grazing. Although less than with conventional milking systems, many AM-farms are able to apply (partly) grazing. Reduced labor demand and better social circumstances for the dairy farmers are the attractive benefits of AM systems. Other potential benefits are improved animal health and well being and increased milk yields.

Automatic milking strongly relies on the cow's motivation to visit the AM system voluntarily. The main motive for this is the supply of concentrates dispensed in a feed manger in the milking box during the milking process. An automatic milking system has to take over the 'eyes, ears and hands' of the milker. Therefore such a system is equipped with electronic cow identification, cleaning and milking devices and computer controlled sensors to detect abnormalities in milk, in order to meet international legislation and hygiene rules from the dairy industry. Teat cleaning systems include brushes or rollers, inside teat-cup cleaning or a separate 'teat cup like' cleaning device. Several trials showed that cleaning with a device is better than no cleaning (SCHUILING 1992, KNAPPSTEIN *et al.* 2004), although these systems are not as good as manual cleaning by the herdsman. AM systems apply quarter-individual milking including individual quarter take off. AM systems are also equipped with sensors to observe and to control the milking process. Data are automatically stored in a database and the farmer uses a management program to control the settings and conditions for cows to be milked. Attention lists and reports are presented to the farmer by screen, printer or text messaging to a mobile phone.

World-wide development of automatic milking

The first AM systems on commercial farms were implemented in The Netherlands in 1992. Increasing costs of inputs while milk prices decreased, forced farmers to increase their output per man-hour. After the introduction of the first AM systems in 1992, adoption went slowly, until the end of the nineties. From 2000 automatic milking became an accepted technology in the Netherlands and other European countries, but also Japan and North America. At the end of 2010, worldwide approximately 10000 commercial farms use one or more AM systems to milk their cows (**figure 1**). The majority of farms are family run with 1 to 3 milking boxes, however also operations with more than 10 units can be found. More than 90% of the world's AMS farms are located in north-western Europe. The largest number AM farms is found in the Netherlands with over 2000 farms, however as a percentage of the national number of farms the greatest adoption can be found in the Scandinavian countries. To date, adoption of AMS has taken place in areas where there is a fairly high density of dairy production. Since AMS

systems have a fairly high requirement for technical support, this has made servicing these systems manageable. In view of the importance of continuous operation, future adoption in less intense dairy production areas will result in new challenges regarding maintenance services.

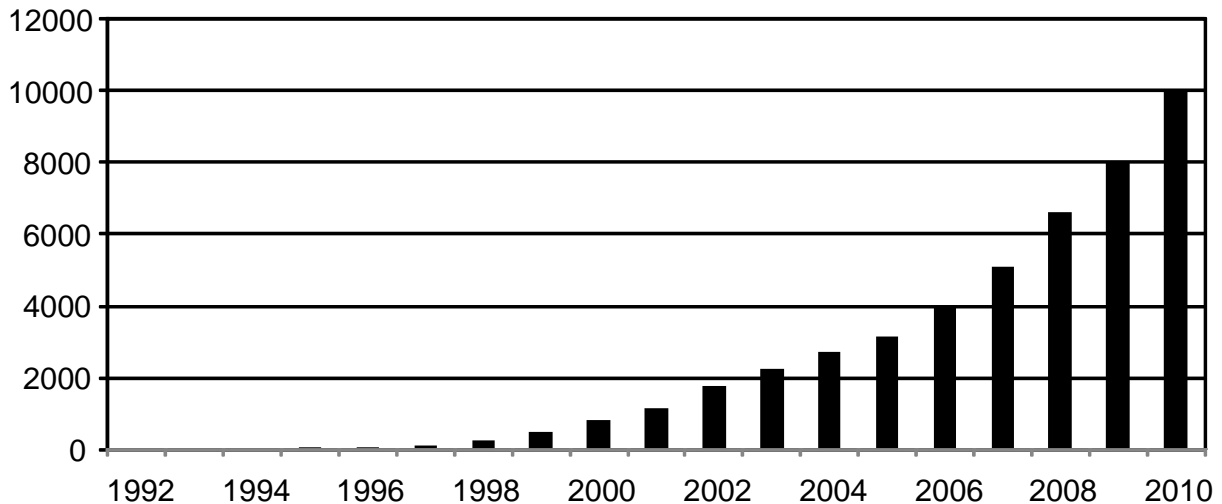


Figure 1: development of number of farms with an AM system worldwide (De Koning, WUR Livestock Research)

Management aspects of automatic milking

Switching from a milking parlor to automatic milking results in big changes for both the herdsman and the cows. Although with AMS immediate supervision of milking is eliminated, new labor tasks appear (SCHÖN *et al.* 1992, LIND *et al.* 2000, DE KONING *et al.* 2002). They include control and cleaning of the AM system, twice or three times a day checking of attention lists including visual control of the cows and fetching cows that exceeded maximum milking intervals. Compared with the conventional twice daily milking there is an average of 20% -30% reduction in total labor, but large variations between farms can be found. Especially in the first transition year, automatic milking might take extra time.

The biggest change without doubt lies in the nature of the labor. The physical work of machine milking, is replaced with management tasks such as frequent checking of attention lists from the computer and appropriate follow up. This work is less time bound than parlor milking, so the input of labor is more flexible. This is attractive on family farms. But because milking is continuous, and system failures can occur anytime there must be a person “on call” at all times. System failures and associated alarms typically occur about once every two weeks although this varies with the level of maintenance and management. In terms of the impact on cows, the AM system is not suitable for all cows. Poor udder shape and teat position may make attachment difficult and some

cows may not be trainable to attend for milking voluntarily. In new installations, the number of cows found to be unsuitable is generally reported to be less than 5% (DE KONING & RODENBURG 2004). In the transition from conventional to automatic milking, cows must learn to visit the AM system at other than traditional milking times. Training and assistance in the first days after transition to the AM system should involve quiet and consistent handling, so the animals adapt quickly to the new surroundings and milking system.

Milking frequency

In practice, the average number of milkings per cow day varies from 2.5 till over 3.0 milkings per day, but rather big differences in milking intervals are reported by commercial farms. A typical figure is presented in **figure 2**. Almost 10% of the cows realized a milking frequency of 2 or lower over a two year period milking with a single stall AM system. This occurred even though cows with a too long interval were fetched three times per day. Such cows will not show an increase in yield or may even show a production loss. By changing the milking parameters of the AM system, it is quite easy to prevent cows from being milked at low yields or short intervals. But it is much more difficult to prevent cows from being milked with long intervals. This means it will be necessary to manage the intervals by fetching cows that have exceeded a maximum interval. Usually this is done several times per day at fixed times around the cleaning procedures of the AM system.

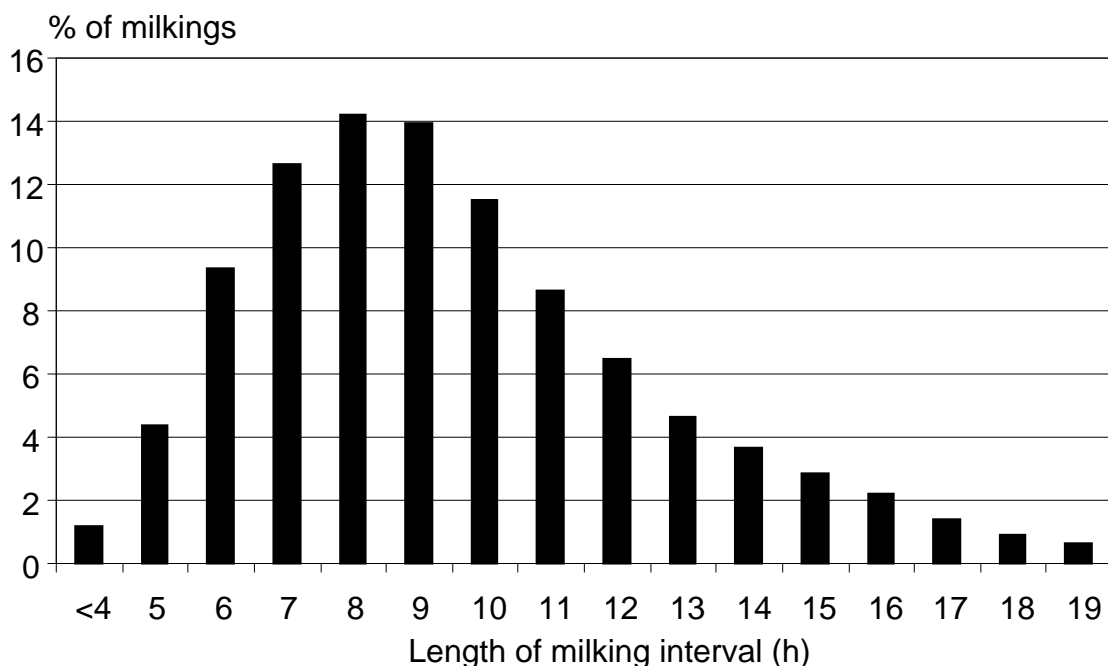


Figure 2: Frequency distribution of milking intervals in hours over a 2-year period (data high-tech farm Waiboerhoeve)

Increase in milk yield

One of the benefits of automatic milking is increased milk yield from more frequent milking. An increase from 6 to 25% in complete lactations has been shown when milking frequency increases from two times to three times per day (ERDMAN & VARNER 1995). As can be deduced from **figure 2**, several cows are milked less than twice a day in automatic milking and may therefore produce less milk. Data from all over Europe indicate a production increase of 5-10% for herds milked automatically (DE KONING & RODENBURG 2004, BACH *et al.* 2007, BIJL *et al.* 2007), however large variations can be seen. In many larger US herds with highly automated conventional parlors, 3 times daily milking is commonplace. For 3x herds adopting automatic milking, a production decrease of 5 to 10% would be expected (DE KONING & RODENBURG 2004).

Capacity of the AM system

The capacity of an AM system is often expressed as the number of milkings per day. This number will largely depend on the configuration of the AM system, like the number of stalls and the use of selection gates, milking frequency, machine on time and herd size. Increasing the number of milkings per cow per day, does not necessarily contribute to a high output capacity in kg of milk per day. This is due to the more or less fixed handling time of the automatic milking system per milking and the decreasing amount of milk per milking. Studies (DE KONING & OUWELTJES 2000, ANDRÉ *et al.* 2010, HARMS & WENDL 2010) showed that especially milk flow rate has a large effect on the capacity of an AM system.

Sensor technology and data handling

AM systems are also equipped with sensor technology and integrated data management systems to observe and to control the milking process. Data are automatically stored in a database and the farmer has a management program to control the settings and conditions for cows to be milked. Attention lists and reports are presented to the farmer by screen or printer messages. With their sensors AM systems collect enormous amounts of data, which have to be processed with appropriate software (HOGEVEEN & OUWELTJES 2003, DE KONING & OUWELTJES 2004). The challenge for both manufacturers as end users is to detect in the data the abnormalities, so actions can be taken. Because abnormalities are rare this is called management by exception. Modern AM systems are equipped with various sensors ranging from sensors to control the milking process till sensors that analyze the milk quality in several ways, like milk composition, cell counts, blood detection, conductivity, progesterone, and so on. All these sensors require smart data handling solutions in order to help the farmer to make the right decision. Special guide lines for automatic milking were developed and approved for auto-

matic milking systems and involved sensor technology within the framework of the International Standards Organisation (ISO 20966, 2007).

Farmers attitude and expectations

One important factor in successful implementation of an AM system is the attitude and expectation of the dairy farmer (MATHIJS 2004, OUWELTJES & DE KONING 2004). Almost all manufacturers have had some customers switching back to conventional milking systems. While there is considerable variation in level of satisfaction with different types of systems, an estimated 5-10% of owners have switched back to conventional technology (DE KONING & RODENBURG 2004). In some cases expectations were not realistic, in others farmers were unable to adapt to the different management style, and in some cases a high rate of failures of the AM system discouraged the farmer to continue. However this figure seems to decrease in more recent years, showing that farmers improved their decision process before buying and also that hardware technology has been improved. During the start up period, automatic milking requires a high input of labor and management. Key factors of a successful implementation of AM systems are:

- Realistic expectations
- Good support by skilled consultants before, during and after implementation
- Flexibility and discipline to control the system and the cows
- Ability to work with computers
- Much attention to the barn layout and a good functioning cow traffic
- Good technical functioning of the AM system and regular maintenance
- Healthy cows with good feet and 'aggressive' eating behavior

Barn layout and grazing

Since automatic milking systems largely depend on voluntary attendance, a well laid-out free stall barn is essential for success (LIND *et al.* 2000). The main motive for a cow to visit the AMS is the concentrate provided in the manger of the milking box. Cows should have easy access to the milking stall and selection gates: long alleys, steps and other obstructions should be avoided. A central location for the AM system minimizes walking distances of the cows. In many countries regulations from the dairy industry require that the AM system has to be located close to the milking room and that the system is accessible to the operator or the service technician via a clean route.

Cow traffic

After visiting the milking system, the cow should have access to the feeding area. In “forced traffic” systems she has to pass the milking system in order to get access. In “controlled traffic” systems one-way-gates, with cow identification and selection capabilities, restrict cows to go directly to the feeding area only when the interval since the last milking exceeds the pre-set minimum. AM systems with a high occupancy rate and forced traffic may affect the number of visits to the roughage station or feeding fence. In “free cow traffic” systems access to the feeding area is unrestricted and only the concentrate fed in the AM system is used to attract cows. Forced traffic can improve the number of voluntary milkings, however it alters eating and lying behavior (DE KONING & RODENBURG 2004, HAMS 2004, BACH *et al.* 2009). This might even result in reduced intake of roughage and therefore also production losses. Free, semi-free and forced cow traffic have been tested in several studies. HARMS (2004) observed that free cow traffic resulted in lower milking frequencies and higher number of fetched cows due to long milking intervals. Milk yield did not differ much, but tended to be higher in the free traffic system. Unlimited access to feed is a prerequisite for cow traffic and milking visits. HARMS (2004) reported that in all tested traffic systems repeated lack of feed resulted in decreased number of milkings. There is general consensus that for animal welfare, (semi) free cow traffic is preferred. An example of the semi free cow traffic is the Feed-First principle which is used as a mix between controlled cow traffic and free cow traffic. The system also relies on the cows motivation to eat. Without doubt, a well-functioning cow traffic is a key-factor for successful automatic milking. This can be achieved when feed is available for 24h/day.

Grazing

In most European countries, grazing during summer time is common routine, in some Scandinavian countries like Sweden even compulsory. Moreover, from an ethological point of view, many consumers in North Western Europe believe grazing is essential for cows and several Dutch dairies pay a premium for milk from grazed herds. In the Netherlands grazing is common practice (>80%). The basic principle of grazing cows is that they need to walk at least twice a day to a barn with a milking parlor to be milked. This is faced with problems. The development of large-scale farms and the related large dairy herds lead to long walking distances, increased labor demands and, in many cases, milk production losses. Often the allocation of land makes grazing impossible or leaves too little area for the purpose, causing high leaching potentials due to large urination and defecation surplus.

In The Netherlands only about 52% of the farms with an AM system apply grazing, showing on one hand that grazing in combination with AM is less common, but on the other that it is still possible (VAN DER VORST & OUWELTJES 2003, MATHIJS 2004). Overcapacity of the AM system, e.g. fewer cows per AM system can partly compensate but this

solution is inefficient due to the increased fixed costs of the robots. In respect of capacity use of the milking system and percentage of cows to be fetched, restricted grazing systems perform better than unrestricted (VAN DOOREN *et al.* 2004). Walking distances of up to 500 meters seem to be of little influence on the frequency of robot visits, however longer distances show a negative effect. Moreover the natural synchronized behavior of the cows when moving to the milking unit in the barn causes cueing in front of the AM system and also ineffective feeding. Several solutions are available to overcome (partly) the disadvantages. Smart pasture gates or selection boxes that control the cow traffic to and from the pasture can be a very helpful tool to the farmer. Only those cows that have recently been milked are sent outside, while the cows that still need to be milked, have to stay inside. Cows have to be attracted to go outside and inside the barn. Grass quality, walking distances, cow health, weather conditions and water supply are important factors within a grazing system. It is widely accepted that water supply should not be limited, nor be used as a motivation for cow to return to the barn. Grazing is critical to low cost milk production in Ireland, Australia and New Zealand. Research and experiences from New Zealand and Australia show that automatic milking in 100% grazing systems under very different circumstances than those found in Europe is quite well possible (JAGO *et al.* 2004, ANONYMOUS 2010). A recent development is the introduction of mobile automatic milking systems in Denmark and The Netherlands (LENNISINCK & ZEVENBERGEN 2007, OUDSHOORN *et al.* 2008, HOUWELINGEN *et al.* 2009). First results show that such systems are capable to milk herds without much additional labour.

Economical aspects

Investment required for AM systems are much higher than for conventional milking systems and thus the fixed costs of milking are higher. However more milk with less labour means that the costs of milking per kg of milk will decrease. Theoretically, with an AM system more cows can be kept with the same labor force than with conventional milking, but this may involve additional investments in buildings, land or feed and perhaps in milk quota. On a farm with more than one full time worker the possibility exists to reduce labor input and thus costs. Quite often that does not happen and the time saved as a result of lower labor requirement is used for personal activities. MESKENS & MATHIJS (2002) found that two third of AM-farmers state social reasons for investing in automatic milking, such as increased labor flexibility, improved social life and health concerns. In parts of North America, with large-size herds and numerous milkers, it may turn out that savings on labor costs may become a decisive motive to implement automatic milking

Simulation models

Several simulation models have been developed to calculate the pure economic effect of investment in automated milking. The "Room for Investment" model computes the amount of money that can be invested in an AMS, without a decrease in net return

compared with conventional milking (ARENDZEN & VAN SCHEPPINGEN 2000). The RFI-value calculates the annual accumulated return from increased milk yield, savings in labor, and savings in not investing in a milking parlor and divides this by the annual costs of the AM system. The model can use farm specific factors and circumstances to calculate the RFI-value. **Figure 3** shows the results of a combined sensitivity analysis illustrating that increased milk yield and labor savings are essential factors regarding the economy of automatic milking. The RFI-value for the basic farm (700.000 kg milk, 8500 kg milk per cow per lactation, 82 cows, 75 hrs of labor per week) with 500 kg per cow yield increase, 0,75 hour net labor saving per day (~10% labor saving), compared with a automated milking parlor and 20% annual costs of the AM system amounts €137.000. In this example this would be sufficient for investment in a single box (investment ~ €120,000). Both labor saving and yield increase have a large effect on the RFI value.

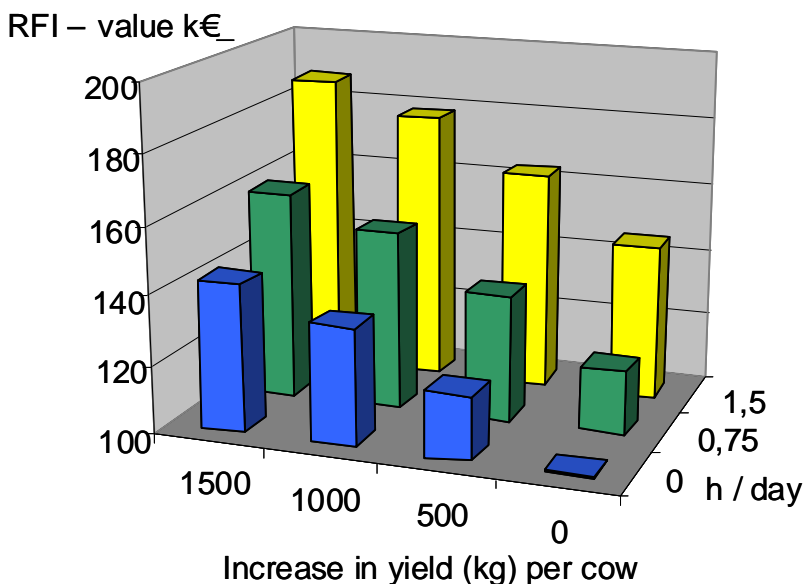


Figure 3: Room for Investment (RFI) due to labor saving and milk yield increase with annual costs for AM system of 25% of investment. Comparison made with an highly automated milking parlor.

American models (RODENBURG 2002, ROTZ *et al.* 2003) suggest that on large farms, as the hours of use of large automated milking parlors increase, their relative economic advantage over AM systems increases. These studies showed that on farms with 60 to 180 cows, capital investment in automatic milking is only slightly higher than in conventional milking systems, in part because of smaller space requirements than for parlors with large holding areas. Lower labor input for AM systems makes them competitive in this herd size range. For herds with more than 240 – 270 cows, extending the hours of use of conventional parlors, without additional capital investment made parlor milking much more efficient. It follows that in those regions in the world, where herds of 500 to

several thousand cows predominate, widespread adoption of automatic milking will not occur unless capital cost of these systems decrease or labor costs increase substantially.

Since both of these parameters are highly likely to trend in this direction, more widespread adoption of automatic milking in nearly all areas of the developed world would appear to be only a matter of time.

Economic results from commercial farms

Economic results from commercial farms show that the use of AM systems in general is profitable, although highly depending on the extra milk yield and labor savings. A Dutch case control study (BIJL *et al.* 2007) between farms with AM systems and farms with conventional milking systems showed no differences in margin, although fixed costs for the AM-farms were higher. AM-farms saved 29% labor and therefore when economical results were transformed to full time equivalents (FTE), AM-farms in the case control study had greater revenues, margins, and gross margins per FTE than the farms with conventional milking systems. So when deciding between investment in an AM system or in a conventional milking system, dairy farmers must weigh decreased labor needs for the AM system against the increased fixed costs of milking with an AM system. Therefore in many cases adoption of an AM system is for many dairy farmers a socio-economic decision, rather than just a purely economic decision (MATHIJS 2004, BIJL *et al.* 2007).

Animal health

Within a large EU project Automatic Milking carried out between 2000 and 2004, special attention was paid to animal health. In Denmark, The Netherlands, and the UK, 15 herds each were selected for monitoring the impact of transition to automated milking on animal health (HILLERTON *et al.* 2004). The herds recruited represented the types of AMS marketed in each country. Each farm was visited at least twice before installation of the AMS and a minimum of twice, but often up to six times, after installation. On these visits assessments were made of at least half of the cows or fifty animals on body condition and locomotion, and forty cows for teat condition (on some farms in the Netherlands and UK only). Farm data including milk production, milk quality, animal records on individual cow milk cell count, fertility, animal treatments, animal movements, veterinary purchases were collected. HILLERTON *et al.* (2004) conclude that no major problems in converting from conventional milking to AM could be identified but equally none of the 45 farms has been found to achieve a substantial improvement in any aspect of cow health. The transition period to AMS comprises a period of higher risk to health that extends from weeks before installation when resources start to be diverted from cow management. The length of the transition will vary on individual farms related to many

unique factors. Several potential problems may develop in the longer term and anticipation of these is necessary.

Mastitis

A large study to risk factors related with automatic milking and mastitis in The Netherlands (NEIJENHUIS *et al.* 2009) showed that risk factors for mastitis are more or less comparable with those found at conventional milking. Results indicated that smaller farms with an AMS had, on average, a better udder health than larger dairy farms. Also the milk production level of cows was associated with udder health on farms with an AMS. A higher milk production was related to a better udder health. Overall farm management may play a role in this association. The main areas related with good udder health were hygiene of cows, and especially teats, proper milking technique of the AMS to ensure proper teat health (ringing of teat base and hemorrhages), use of a waiting area, preventive health care (e.g., controlling BVD) and time spent on health control of dairy cattle. The udder health status before introduction of AMS was an important factor explaining the udder health status when milking with an AMS. NEIJENHUIS *et al.* (2009) conclude that the professional skills of the farmer are an important contributory to good udder health on AMS farms.

Milk quality

Milk quality is a very important aspect of milk production and milk payment systems and consumer acceptance are, to a great extent, based on it. Moreover in dairy processing, milk quality can be a decisive factor for product valorization. Features in automatic milking like a 24 hour operation, more frequent milking at different intervals, different cleaning procedures and a complicated visual control, may influence milk quality.

Although automatic milking uses the same milking principles as conventional milking, there are major differences. The AM system is in use for 24 hours continuously. Visual control during the milking process is not possible. Cows will visit the AM system more or less voluntarily and this will result in a big variation in the milking frequency from cow to cow. All these aspects may influence the quality of the milk produced.

Milk quality parameters

Somatic cell count (SCC) and Total Bacterial Count (TBC) are, respectively, measurements of the number of white blood cells and the total number of bacteria present in a milk sample. A high SCC might indicate reduced udder health due to Mastitis (udder infection) and implies a lowered milk quality. The cleaning of the milking equipment and the cooling of the milk seem to be the most important factors regarding the increase in TBC. In general AMS herds consistently show slightly higher SCC and TBC values than

conventionally milked herds (KLUNGEL *et al.* 2000, RASMUSSEN *et al.* 2002, DE KONING *et al.* 2004). **Table 1** presents the results for 4 quality parameters (DE KONING *et al.* 2004).

Table 1: Milk quality results for farms before and after introduction of AM system (adapted: DE KONING *et al.* 2004)

	Conventional milking		Automatic Milking	
	Two times milking	Three times milking	Before	After
Bacterial count (*1000/ml)	8	8	8	12
Cell count (* 1000/ml)	181	175	175	190
Freezing point (°C)	-0,520	-0,521	-0,521	-0,516
Free fatty acids (meq/100 g fat)	0,44	0,54	0,41	0,59

In general differences are relatively small and far within the requirements of the dairy industry. Nevertheless with 24h operation, milk hygiene requires continuous attention from the herdsman. Special attention has to be paid to teat cleaning and the cleaning of the teat cups and the milking machine including transfer line to the bulk tank, Hygiene management should not only focus to the automatic milking system, but also to the general hygiene standards in cubicles and the floors in the barn.

Free fatty acids

Free Fatty Acids (FFA) in milk are formed as a result of hydrolysis of milk fat by milk lipase, also called lipolysis. The amount of lipase in milk is enough to cause a rapid hydrolysis causing high levels of Free Fatty acids. However since milk fat occurs in the fat globule that is surrounded by a membrane, the fat is protected from the lipase activity. Lipolysis can be initiated either by physical damage to milk fat globules during milking or pumping, stirring or cooling of milk (induced lipolysis) or by animal-related factors such as the cow's health status, lactation stage, the frequency of milking and dietary factors (spontaneous lipolysis). This type of lipolysis is related both with activating and inhibiting factors in milk. Lipase activating factors are associated with compounds leaking from blood (JELLEMA 1986). Feeding a too low energy diet, especially at the end of lactation, can also cause increased FFA levels.

It is generally known that the content of free fatty acids (FFA) in milk will increase with shorter milking intervals, all the more if the yield per milking is rather low. With automatic milking the milking frequency is on average 2.5 till 3.0 milkings per day. All studies with AM systems show a significant increase in FFA levels for AM systems (IPEMA & SCHUILING 1992, KLUNGEL *et al.* 2000, RASMUSSEN *et al.* 2002, DE KONING *et al.* 2004, SLAGHUIS *et al.* 2004, WIKING *et al.* 2005, RASMUSSEN *et al.* 2006, WIKING *et al.* 2006). SLAGHUIS *et al.* (2004) studied the effect of different milking frequencies using a conventional milking installation. Average milk yields per milking for 2, 3 and 6 times milking

per day were 16.9, 11.7 and 6.0 kg, respectively, and average FFA concentrations of milk 0.42, 0.71 and 1.23 mmol/100 g fat, respectively. The contents of fat, protein and lactose in milk were not significantly different. WIKING *et al.* (2006) studied the effect of milking cows 4 times daily on FFA in the milk compared with milking twice daily, using a conventional milking machine with an air inlet similar to that of an AM system [10]. The average concentration of FFA in milk produced with 4 milkings per day was significantly greater than that in milk produced with 2 milkings per day (1.49 vs. 1.14 mmol/100 g fat, respectively). Furthermore, the average diameter of milk fat globules was larger in milk produced with 4 milkings per day than in milk produced with 2 milkings per day. The increased milking frequency that is associated with automatic milking seems to have more effect on the FFA concentration of milk than the use of a AM system per se.

As already mentioned, the increase in FFA levels cannot be explained solely by the shorter intervals, because the increase of FFA with AM systems is even bigger than with conventional milking parlors milking three times per day. In a Danish study (RASMUSSEN *et al.* 2006) small but statistically significant differences in average FFA concentration of milk between five different brands were detected. Apart from differences in diameter or length of “short” milk tubes, the technical specifications of the AM systems could not explain these differences. It is known that excessive air intake increases lipolysis in raw milk. AM systems generally have about 3 to 4 times higher air intakes (air inlet) during milking than conventional milking clusters. The higher air intake of AM systems has been recognized as a factor that can partially explain higher FFA concentrations of raw milk. RASMUSSEN *et al.* (2006) also reported on visits to 55 farms with high FFA levels. For 31 conventional farms most frequent faults were air leakage (71% of the herds) and intake of too much air in the cluster (61%) and pumping and stirring faults occurred on 29% of the farms. The main faults for 24 AM system farms concerned stirring of milk at very low levels in the bulk cool tank (79%), pumping of milk (67%) and the cooling of milk (58%). Low milk yields and low-energy diets increase the FFA level of milk. However, many aspects of the role of nutritional factors in lipolysis and FFA levels are still unclear and require further investigations.

Concluding remarks

The number of farms milking with automatic milking has increased significantly in the past decade from 500 farms worldwide to approximately 10000 farms at the end of 2010. In areas where labor is expensive or in short supply automatic milking is a valid alternative to traditional parlor milking. However if labor is available, and particularly where herd sizes are large conventional milking, often with rotary or rapid exit parlors equipped with features to increase throughput per man hour will remain popular. The introduction of automatic milking has a large impact on the farm and affects all aspects of dairy farming. Both farm management and the lifestyle of the farmer is altered by automatic milking. Successful adoption of automatic milking depends on the management skills of the farmer and the barn layout and farming conditions. Animal health and

well-being is not negatively affected by automatic milking, but till now no particular benefits for the health of the cows have been found. Grazing is a common routine in many countries and although grazing with automatic milking requires extra attention from the herdsman, grazing is still profitable. New solutions like mobile milking systems might be an alternative for large herds. Improved sensor technology will help farmers to manage the individual cow within the herd.

With respect to milk quality and automatic milking, rather big differences among and within farms are reported. Some farms have excellent milk quality results after introduction of the AM system, some have a decreased milk quality, while others show incidental peaks in for example total bacterial counts. Milk quality, to a certain extent, is negatively affected when milking with an automatic milking system. Possible risk factors related with milk quality concern several general farm characteristics like animal health, AM system, cleaning and cooling, housing, management of the farmer and the hygiene on the farm. An increased milking frequency is not the only explanation of increased FFA levels. Especially cows in late lactation seemed to be a risk. Technical factors related to FFA mainly concerned the air inlet in the teat cups, bubbling (excessive air inlet) and a too long post run time of the milk pump.

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Fast mastitis detection during milking process for milk quality monitoring

Zeitnahe Mastitiserkennung und Überwachung der Milchqualität durch Partikelgrößenmessung im Melkprozess

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Abstract: *The quality of raw milk is mainly influenced by animal health. The udder disease mastitis leads to high economic losses in milk producing industries. An early detection of inflamed udder quarters is necessary to maintain high quality of raw milk and to allow the separation of the milk of affected udder quarters during the milking process. In automatic milking systems (AMS) a rapid sensor-based online detection method is required to allow early mastitis detection. The measurement of somatic cells by Coulter Counter method is previously described but a time-consuming fixation step is necessary to avoid an overlapping of fat particles and somatic cells. In this study, the fat was removed by centrifugation before measurement of somatic cells by Multisizer™ 3 Coulter Counter®. Milk samples obtained from infected udder quarters showed higher cell count in the range of 7-20 μm in comparison to healthy udder quarters. The detected cell size corresponds to the size of somatic cells. The somatic cell count obtained by Coulter Counter methods is comparable to the somatic cell counts obtained by the Fossomatic. The peak of somatic cells decreased with remitting mastitis. This study confirms the potential of fast mastitis detection by Coulter Counter measurements.*

Keywords: *Particle count, somatic cells, quarter individually milking*

Zusammenfassung: Die Qualität von Rohmilch wird im großen Maß durch die Tiergesundheit bestimmt. Jährlich führt vor allem die Euterkrankheit Mastitis zu großen finanziellen Verlusten bei den Milchproduzenten. Um eine hohe Rohmilchqualität zu gewährleisten sollte ein erkranktes Euterviertel möglichst frühzeitig erkannt und die gewonnene Milch ggf. unmittelbar beim Melkprozess abgetrennt werden. Für eine zuverlässige und frühzeitige Detektion einer Erkrankung besteht ein erhöhter Bedarf an geeigneter Sensortechnik, die auf Grundlage von effizienten, online- und sensorfähigen Analysemethoden arbeitet. Die Messung von somatischen Zellen mit dem Coulter Counter wurde schon mehrfach positiv auf die Eignung zur Früherkennung der Mastitis untersucht. Die

Aufbereitung der Milchproben nach IDF Standard 148 erfordert jedoch einen zeitintensiven Fixierungsschritt, um eine Messung von Fettpartikeln im Größenbereich der somatischen Zellen zu verhindern. In dieser Studie wurde daher das in dem Vorgemelk enthaltene Fett durch einen geeigneten Zentrifugationsschritt entfernt. Nachfolgend wurde die somatische Zellzahl im MultisizerTM 3 Coulter Counter® bestimmt. Diese Partikelzählung zeigte, dass Milchproben erkrankter Kühe im Partikelgrößenbereich von 7-20 µm eine erhöhte Partikelanzahl im Vergleich zu Milchproben gesunder Kühe aufweisen. Die Größe der Partikel im Bereich 7-20 µm entspricht dabei der Partikelgröße von somatischen Zellen. Im Verlauf einer abklingenden Mastitis geht diese Partikelanhäufung wieder zurück. Die detektierte Partikelanzahl ist dabei mit der mittels Fossomatic bestimmten somatischen Zellzahl vergleichbar. Das Potenzial der impedanzbasierten Partikelzählung zur schnellen Detektion von somatischen Zellen konnte bestätigt werden.

Schlüsselwörter: Partikelzählung, somatische Zellen, viertelindividuelles Melken

Einleitung

Mastitis ist die am weitesten verbreitete und bekannteste Eutererkrankung. Dabei wird durch verschiedene spezifische Erreger eine Euterentzündung verursacht. Als Folge ist nicht nur das Leiden der Kühe zu nennen, auch die von den betroffenen Kühen gewonnene Milch unterliegt in ihrer Zusammensetzung starken Veränderungen. Flockungen, Blutbeimengungen, artuntypisches Aroma, Keimgehalte in hohen Konzentrationen und starke Mengenänderungen der Milchhauptbestandteile und Mineralstoffe führen nicht nur zu einer ungenießbaren Milch, sondern auch zu einer starken Beeinträchtigung der Verarbeitung dieser Milch zu Milchprodukten und damit zu hohen wirtschaftlichen Verlusten. Bei einer durchschnittlichen Jahresmilchleistung von 6050 kg/Kuh, einem Milchauszahlungspreis von etwa 0,30 Euro und einer durchschnittlichen betrieblichen Herdengröße von 33,8 Kühen ist nach der DVG (2002) mit einem mastitisbedingten Verlust von bis zu 5000 € im Jahr zu rechnen. Es ist folglich von großer Bedeutung, die Milch erkrankter Euterviertel möglichst früh aufzufinden, um so eine hohe Qualität der Rohmilch zur Auslieferung zu gewährleisten.

Für eine zuverlässige und frühzeitige Detektion einer Erkrankung in konventionellen und den automatischen Melksystemen (AMS) ohne Melkpersonal, besteht ein erhöhter Bedarf an geeigneter Sensortechnik, die auf Grundlage von effizienten, online- und sensorfähigen Analysemethoden arbeitet. Neben den bereits etablierten, aber nicht zufrieden stellenden Methoden zur Messung der somatischen Zellzahl und der Leitfähigkeit der Milch, wurden bereits zahlreiche Methoden zum Einsatz der Mastitiserkennung entwickelt. Diese erfordern jedoch bisher eine aufwendige Aufbereitung wie z. B. die durchflusszytometrische Erfassung von Abwehrzellen oder Mastitiserregern (GUNASEKERA *et al.* 2003, HOLM & JESPERSEN 2003), die Anwendung bestimmter Chemikalien zur Färbung der DNA (VIGUIER *et al.* 2009) oder sind kostenaufwendig, wie z. B. das Nahinfrarot-sensorbasierte System zur Messung der Zellzahl/ml (BORSBOOM & DOMMERHOLT

2004). Um geeignete onlinefähige Methoden zu erarbeiten, müssen die bekannten Methoden verbessert bzw. neue Formen der Analytik zum onlinefähigen Einsatz entwickelt werden. Einen möglichen Ansatz bieten dabei besonders optische und impedanzbasierte Methoden.

Die Messung mit dem Coulter Counter wurde schon mehrfach positiv auf die Eignung zur Früherkennung der Mastitis untersucht und mit anderen Methoden wie z. B. der mikroskopische Zählung oder der Fossomatic verglichen (GINN *et al.* 1979, MILLER *et al.* 1986). Nach den Vorschriften ist die Probenaufbereitung für diese Messungen jedoch sehr zeit- und arbeitsintensiv. In dem IDF Standard 148 von 1991 (INTERNATIONAL DAIRY FEDERATION 1991) wird z. B. eine vollständige Vorschrift für die Aufbereitung von Milchproben zur Messung im Coulter Counter herausgegeben. Ein notwendiger Fixierungsschritt und die Zerstörung großer Fettkügelchen in der Milch macht dieses Verfahren bisher, wie auch die Verfahren der Durchflusszytometrie, nicht onlinefähig für eine Anwendung im automatischen Melksystem oder in der Qualitätssicherung. Aus einem Optimierungsansatz hinsichtlich der genannten IDF-Vorschrift sollten daher vereinfachte Aufbereitungsschritte für Milchproben abgeleitet werden, wodurch die Früherkennung einer Mastitis mit dem Coulter Counter ermöglicht werden könnte.

Material & Methoden:

Referenzanalytik

Die Bestimmung der somatischen Zellzahl pro ml wurde mit der Fossomatic 360 (Foss Electric, Dänemark) als Referenzanalytik durchgeführt. Die Milchproben wurden vor der Messung mit der Fossomatic 360 zunächst gut gemischt und im Wasserbad auf 40°C erwärmt (INTERNATIONAL DAIRY FEDERATION 1991).

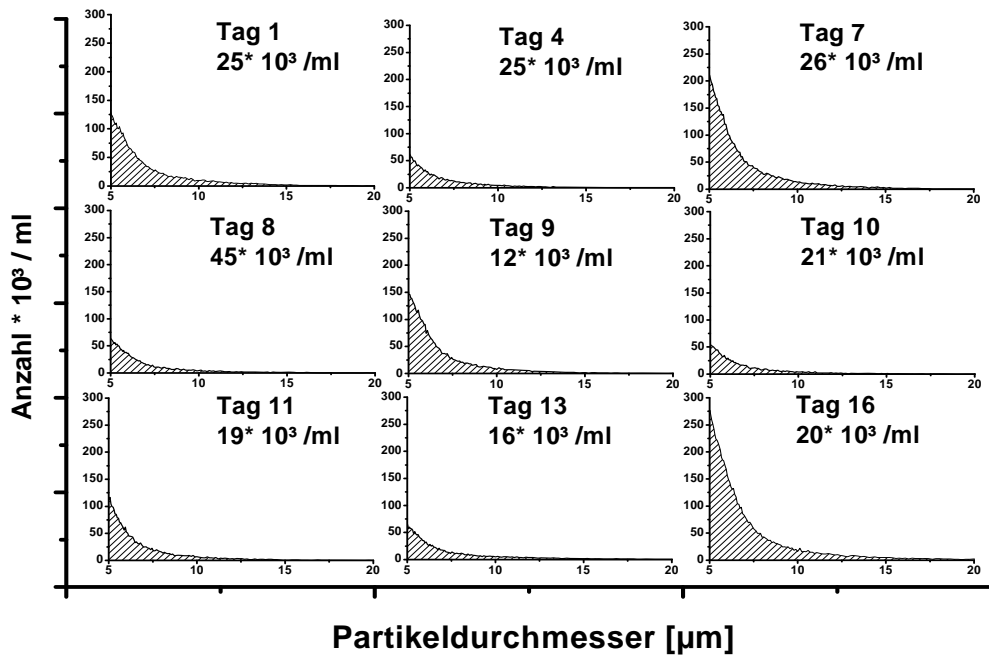
Partikelzählung

Die somatische Zellzahl der Milchproben wurde mit dem MultisizerTM 3 Coulter Counter® (Coulter Counter) der Firma Beckmann Coulter (Krefeld, Deutschland) bestimmt. 2 ml Vorgemelk wurden 10 min bei 14000 x g und Raumtemperatur zentrifugiert. Die oberste Schicht (Fett) wurde entfernt und das Pellet im verbleibenden Überstand resuspendiert. Ein Aliquot dieser Probe (0,2 ml) wurde in 19,8 ml Isoton gegeben und im Coulter Counter mit der 100 µm-Kapillare gemessen. Jede Messung der Partikelzahl erfolgte in Dreifachbestimmung.

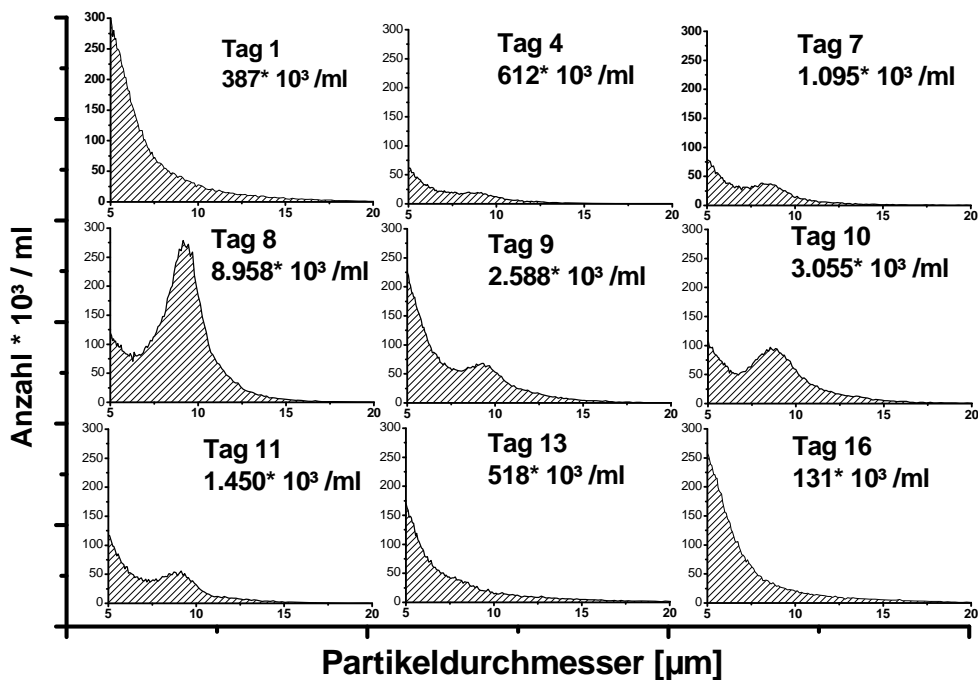
Ergebnisse & Diskussion

Die Untersuchung von Mastitisverläufen (subklinische Mastitiden) unterschiedlicher Kühe und deren Eutervierteln zeigten jeweils die Entstehung einer Partikelzahl im Durchmesserbereich von 7–12 µm während einer Mastitis. Ein Beispiel für den Verlauf eines

erkrankten Euterviertels ist in **Abbildung 1B** abgebildet. Als Vergleich dazu ist ein gesundes Euterviertel der gleichen Kuh über den gleichen Zeitraum dargestellt (**Abbildung 1A**). Es ist zu erkennen, dass bei einer Erhöhung der somatischen Zellzahl die Partikelanzahl im Größenbereich von 7–12 μm stark ansteigt und beim Abklingen der Erkrankung die Partikelanhäufung wieder abgebaut wird bzw. sich zurückbildet, bis die Partikelgrößenverteilung wieder ihren Ausgangszustand erreicht hat.



A



B

Abbildung 1: Darstellung der Partikelgrößenverteilung im Vorgemelk während eines Mastitisverlaufs über zwei Wochen. Einzeldarstellungen der Partikelgrößenverteilung eines gesunden Euterviertels (A) und eines erkrankten Euterviertels (B) während des Krankheitsverlaufs. Die mit der Fossomatic ermittelten Zellzahlen der Milchproben sind unter den jeweiligen Tagesangaben angegeben.

Da nach SANDGREN *et al.* (1991) und TÖPEL (1981) der der Partikelgrößenbereich von 7–20 µm dem Durchmesser einiger somatischen Zellen entspricht, liegt die Vermutung nahe, dass der „Peak“ durch die bei einer Immunreaktion vermehrt auftretenden Abwehrzellen wie z.B. der polymorph kernige neutrophile Granulozyten (PMN), entsteht. Darüber hinaus zeigt LANGEFELD (2001), dass im Anschluss an die Angriffswelle der PMN, die Erreger in einem weiteren Schritt von den Makrophagen phagozytiert werden. Nach SANDGREN *et al.* (1991) weisen die Makrophagen einen größeren Partikeldurchmesser auf als die PMN. Damit könnte die in den Ergebnissen aufgetretene Verschiebung der Partikelanhäufung erklärt werden. Es ist aber auch nicht auszuschließen, dass durch die Aufnahme der Bakterien durch PMN bei der Phagozytose, eine Vergrößerung der Partikel erreicht wird.

Der Vergleich zwischen der durch die Fossomatic und dem Coulter Counter ermittelten Zellzahl bestätigt die Daten von MILLER *et al.* (1986), dass die gemessenen Zellzahlen sowohl bei einem gesunden Euterviertel ($< 10^5$) als auch bei einem erkrankten Euterviertel ($> 10^5$) vergleichbar sind (**Abbildung 2**). Damit festigt sich die Annahme, dass mit der Partikelanhäufung während einer Mastitis die somatischen Zellen im Coulter Counter gemessen werden. Die in **Abbildung 2B** leicht erhöhten Zahlen/ml des Coulter Counters im Vergleich zur Fossomatic sind vermutlich darauf zurückzuführen, dass bei der Messung mit dem Coulter Counter, neben den somatischen Zellen, auch nicht-zelluläre Partikel wie Proteine oder Zellfragmente detektiert wurden (DJABRI *et al.* 2002). Der ermittelte Restfettgehalt von 0,09% ist sehr gering, so dass eine Überlagerung des Peaks durch restliche Fettkomponenten weitestgehend ausgeschlossen werden kann. Eine Begründung für eine niedrigere detektierte Partikelzahl mit dem Coulter Counter könnte die z. T. ungewünschte Abtrennung von somatischen Zellen mit hoher Dichte beim Zentrifugieren zur Fettabtrennung sein. Dies muss in weiteren Untersuchungen überprüft werden

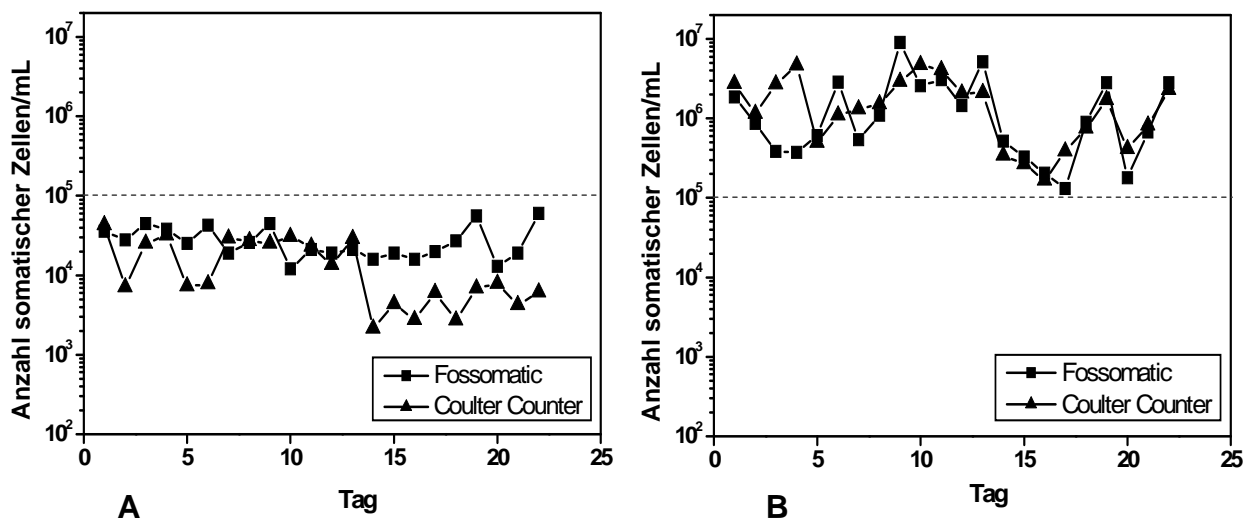


Abbildung 2: Vergleich der somatischen Zellzahl/ml eines gesunden (A) und eines erkrankten (B) Euterviertels, ermittelt mit der Fossomatic und dem Coulter Counter (7–20 µm).

Die Untersuchungen im Rahmen dieser Arbeit haben das Potenzial der Coulter Counter Messung zur Identifizierung erkrankter Kühe anhand von Vorgemelkproben gezeigt. Aufgrund des erarbeiteten und einfach anwendbaren Aufbereitungsschrittes mittels Zentrifugations-basierter Fettentfernung bietet diese Methode ein hohes Potenzial für den Einsatz als prozessbegleitende Analyseverfahren. Zur Steigerung der Methodenrobustheit für eine Früherkennung sollte speziell die Aufbereitung an weiteren Mastitisproben überprüft und verbessert werden. Weiterhin soll überprüft werden, inwieweit die erarbeiteten Methoden auch auf andere Fraktionen des Gemelks wie z. B. das Hauptgemelk oder das Endgemelk übertragbar sind, da die Leitfähigkeiten sowie die Zellzahlen der einzelnen Fraktionen sehr unterschiedlich sein können (HAMANN & GYODI 1999). Daraus kann unter Umständen sogar auch eine Erhöhung des Erkennungspotenzials der Methoden resultieren.

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Measuring teat dimensions using image analysis

Messung der Zitze Dimensionen anhand der Bildanalyse

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Abstract: *The interaction between teat and teatcup liner can strongly affect the milking characteristics and udder health. Therefore teat morphology is an important parameter in choosing the most appropriate liner. Nevertheless, teat morphology is rarely considered in choosing a teatcup liner. Gathering information on teat morphology on large scale with current techniques is time consuming, subjective and not always accurate. However, the ability to measure teat shape parameters in an easy way and on large scale has many applications. This study presents a new vision based measuring system that uses a camera to obtain a 2D image of the teat and image processing analyses to determine teat length and diameters. The technique is proven to be accurate (error less than 6%), repeatable and reproducible for both teat length and diameters.*

Keywords: *dairy cows, teat dimensions, teatcup liners, measuring technique, image analysis*

Zusammenfassung: Die Interaktion zwischen Zitze und Zitzengummi kann die Melkeigenschaften und die Eutergesundheit stark beeinflussen. Folglich ist die Zitzenmorphologie ein wichtiger Parameter bei der Auswahl des geeigneten Zitzengummis. Dennoch findet die Zitzenform zu wenig Beachtung bei der Auswahl des Zitzengummis. Informationen über die Zitzenmorphologie auf umfangreichen Skalen mit gegenwärtigen Techniken zu erfassen ist Zeit raubend, nicht immer genau und oftmals sehr subjektiv. Daher bietet die Möglichkeit der automatischen Erfassung in umfangreichen Skalen viele Anwendungsfelder. Diese Studie zeigt ein neues Messsystem welches 2D Bilder der Zitze und Bildanalyseverarbeitung nutzt um Zitzenlänge und –durchmesser zu bestimmen. Die Technik ist genau (Fehler kleiner 6%) im Punkt Wiederholbarkeit und Reproduzierbarkeit für die Parameter Zitzenlänge und -durchmesser.

Schlüsselwörter: Milchkuh, Zitzenmaße, Zitzengummi, Messtechnik, Bildanalyse

Introduction

The teat is a very important organ in the defence against mastitis. Nearly all intramammary infections (IMI's) occur as a result of pathogens gaining entry to the mammary gland through the teat canal (CHRISTAL *et al.* 1999). The milking machine is directly and indirectly involved in about 6% to 20% of the overall new IMI's. Direct effects consist of bacterial transport, impacts and cross-contaminations while indirect effects include the impairment of the teat condition, making the teat more susceptible (MEIN *et al.* 2004). It is obvious that these direct and indirect effects should be prevented as much as possible. The liner design is proven to play a very important role in the occurrence of these effects (GLEESON *et al.* 2004). Furthermore, previous studies have shown that liner design usually has a greater influence on milking characteristics than any other machine factor (BRANDSMAN 1968, MEIN *et al.* 2003). A good choice of liner is therefore important for good udder health as well as for good milking performance. Because of the interaction between teat and teatcup liner, teat morphology is an important parameter in choosing the most suitable liner for a herd. However, the selection of a teatcup liner for a herd is currently based on a 'trial and error' basis (DE KONING *et al.* 2003). Due to the large number of available liner types and given the large variation in teat dimensions between herds, between cows of the same herd and between teats of the same cow, choosing the most appropriate liner for a herd is not without difficulties. In practice, it is regularly observed that teatcup liners are not adjusted to the herd. Information on specific teat dimensions will be a first step towards better based teatcup liner choice.

State of the art: measuring methods

Visual scoring is up till now the general method to determine teat dimensions. Although subjective, it is a very fast and widespread technique that can be used on a large scale. In practice usually only teat length is scored and different scoring scales are used in different countries. Most countries use a linear scale from 1 to 9 or from 0 to 50. Nevertheless, teat length is one of the 18 standard traits used in the international classification system introduced by the World Holstein-Friesian Federation (WHFF) to provide uniform and standardised information regarding the transmitting abilities of bulls (WHFF 2005). In some countries additional traits are scored. For example, in Denmark teat diameter is scored as well (VAN DRIE 2007). For research purposes, teat size is sometimes scored as a combination of teat length and circumference (SAPP *et al.* 2004). To obtain more objective and accurate results, calipers and measuring tapes are used to determine teat length and diameters (HICKMAN 1964, BLAKE & MCDANIEL 1979, LIN *et al.* 1987, TILKI *et al.* 2005). Another frequently used tool for measuring teat length is a transparent open-ended tube with a graduated scale and a diameter of 30 or 45 mm. The tube is placed over the teat and the length is noted from the scale (HAMANN *et al.* 1993, HANSEN 2002, NEIJENHUIS 2004, GLEESON *et al.* 2005). Here, the teat base is the point where the diameter of the tube equals that of the teat.

For measuring changes in teat end thickness, HAMANN & MEIN (1988) described the use of the cutimeter, a device that is normally used to measure skin thickness of cattle to check their reactions for tuberculosis tests. The cutimeter consists of two parallel jaw plates, each with a surface area of 400 mm², connected to a spring and a calibrated scale. The cutimeter is placed around the teat and a pressure of 20 – 25 kPa is applied on the teat. Although the cutimeter technique has good accuracy and repeatability, the measurements may be influenced by the absolute diameter of the teat. A modified version of the cutimeter was developed: an electronic caliper device. A pressure sensor connected to one of the jaws measures the pressure between the teat and the jaws at incremental steps of 0.5 mm closure of the jaws. Since the recordings start when the pressure between the jaws and the teat is 0.125 kPa, the first reading is a measurement of the diameter of the teat apex (HAMANN *et al.* 1988). Another extensively employed method for measuring teat morphology and teat tissue changes is ultrasonography (GLEESON *et al.* 2004, NEIJENHUIS 2004, PAULRUD *et al.* 2005). To prevent deformation of the teat image, direct contact between the probe and the teat is avoided by placing the teat in a latex bag filled with warm water. The variables recorded from the ultrasonographic image with a software program are teat canal length, teat cistern width, teat wall thickness and teat diameter. With this method, teat dimensions are measured accurately but an experienced observer and substantial measuring time are needed.

It can be concluded that, although the existing methods all have advantages and disadvantages, until now no objective, accurate and fast method capable of gathering data on a large scale is available. However, such a method is a prerequisite for better selection of teatcup liners or more specific breeding to more uniform teat dimensions. Digital image processing technology offers new opportunities and has already been tested to measure udder morphology in dairy ewes (MARIE-ETANCELIN *et al.* 2002).

Vision based measuring technique

At the Institute for Agricultural and Fisheries Research (ILVO) in Flanders, Belgium, a vision based measuring system has been developed. Certain requisites must be met for a vision based approach to be successful. For accurate and standardised analysis, light conditions and position of the object to the camera need to be kept constant. Other important factors that must be taken into account are robustness, weight and ergonomic aspects.

The measuring device consists of an aluminium profile through which the teats are, each separately, inserted through a round opening of 50 mm diameter. To obtain 2D images of the teats, an AVT Guppy F-046B camera with a 25 mm lens is mounted on the other end of the profile. At the back of the profile a LED source is placed for illumination. It serves as background light to acquire high contrast contours of the teats, which is essential for accurate measurements (**Figure 1**). The camera and the LED-background are triggered simultaneously by a push button on the aluminium housing.

After a picture is taken, it is automatically transcribed to a tablet PC. The function of the tablet PC is tripple: it is used for controlling the settings of the camera, for automatic storing of the images and for visual control of the images by a second person. The latter is needed to make sure the images meet the requirements necessary for further image processing. For good image analysis the subject needs to be isolated from the surroundings. If this is not the case, a new image has to be made. The resolution of the images is 0.189 mm/pixel.

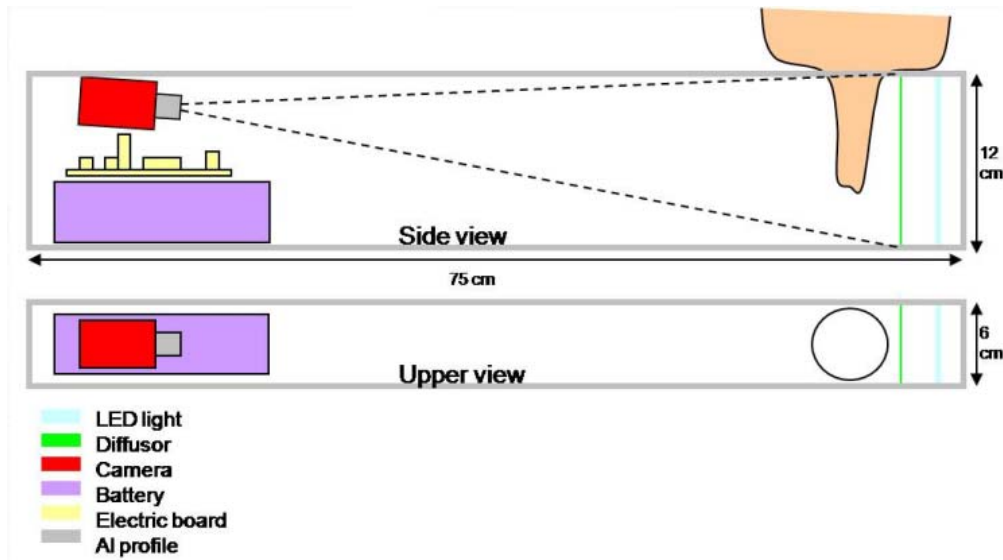


Figure 1: Vision based measuring device for measuring teat dimensions

The analysis is performed with an image processing algorithm in Halcon 8.0. The software calculates the length of the teat and a predefined number of diameters at relative lengths of the teat base (**Figure 2**). A correction factor is added to teat length and diameter measurements for errors that are made if the teat is under an angle in the transverse plane.

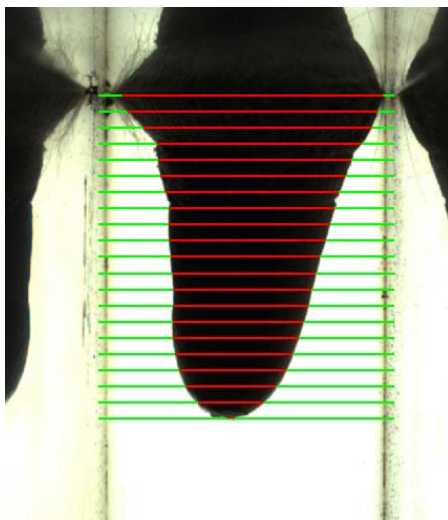


Figure 2: Image of a teat taken with the teat measuring device with indication of the different diameters calculated

Teats positioned straight through the opening, give almost no inaccuracies. For teats that make an angle of maximum 30° towards the camera the error on the teat length is less than 5%. For teat diameters the maximum error of the barrel under that angle is 6%. The measuring technique is proven to be repeatable and reproducible for teat length as well as teat diameter measurements. The majority of variation is present at the cow and quarter level rather than at the observation level, indicating variation between repeated measurements is small.

Future perspectives

The newly developed vision based measuring tool, measuring teats in a fast, objective and accurate way, will make it possible to identify and investigate factors influencing teat dimensions. In addition, since information of the whole teat is available, liner performance can be evaluated in relation to teat dimensions by assessing udder health and milking characteristics. The information generated using the tool will enable better selection of teatcup liners adapted to herd on the short term. Automatic milking systems should even be able to choose the liner best fitting for a certain teat. On a longer term the information will lead to more uniform teat dimensions within a herd through selective breeding, what will simplify the liner choice. Better liner selection will result in better teat condition, decreasing the incidence of intramammary infections and thereby improving the quality and the quantity of the milk yield.

Conclusion

Various methods have been described to measure teat dimensions. However, these methods have a poor objectivity, give only little information or are only practical in experimental conditions. The use of image analysis permits a faster, more objective and accurate measurement of teat shape parameters. A new objective, accurate, repeatable and reproducible 2D vision based measuring method is presented. Further experiments will be conducted to get more information on factors influencing teat dimensions and, by assessing udder health and milking characteristics, on the relationship between them and liner performance.

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Authors Index

Baert Jeroen, <i>Belgium</i>	106
Bilgen Hamdi, <i>Turkey</i>	31
Brunsch Reiner, <i>Germany</i>	31, 44, 63
De Koning C.J.A.M. (Kees), <i>The Netherlands</i>	81
De Vlieghe Sarne, <i>Belgium</i>	106
Degirmencioglu Adnan, <i>Turkey</i>	31
Erdogan Utku, <i>Turkey</i>	31
Forsbäck Linda, <i>Sweden</i>	72
Fröhling Antje, <i>Germany</i>	99
Genbrugge A., <i>Belgium</i>	106
Jakob Martina, <i>Germany</i>	30
Liebers Falk, <i>Germany</i>	30
Müller Anika B., <i>Germany</i>	63
Öz Hülya, <i>Turkey</i>	16, 31
Rasmussen Morten Dam, <i>Denmark</i>	54
Reinemann Douglas J., <i>USA</i>	7
Rose Meierhöfer Sandra, <i>Germany</i>	16, 31, 44, 63
Schlüter Oliver, <i>Germany</i>	99
Ströbel Ulrich, <i>Germany</i>	16, 31, 44
Svennersten Sjaunja Kerstin, <i>Sweden</i>	72
Van Weyenberg Stephanie, <i>Belgium</i>	106
Vangeyte Jurgen, <i>Belgium</i>	106
Zwertvaegher Ingrid, <i>Belgium</i>	106

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