Development of an Online Analysis and Control System for Individual Quarter Milking Systems

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In dedication to

my wife, Helene

our son, David Theodor

our parents

and our grandparents.

Who fights can lose.

Who doesn't fight has already lost.

Wer kämpft kann verlieren.

Wer nicht kämpft hat schon verloren.

Bertolt Brecht

Kurzfassung (deutsch)

In der Milchviehhaltung nimmt die Anzahl der eingesetzten Onlinesensoren zu. Somit können bedeutende biologische Veränderungen bei Kühen z. B. Sekretveränderungen frühzeitig erkannt werden. Hohe mechanische Belastungen am Zitzengewebe, die z. B. zu Ringbildungen führen, treten beim Melken jedoch immer noch häufig auf. Eine nicht optimal angepasste Melktechnik kann einer der Gründe dafür sein.

Hauptziel dieser Arbeit ist es, ein Vakuumregelungssystem für das zitzenendige Melkvakuum zu entwickeln, das in engen Zeitabständen reagiert. Das zitzenendige Melkvakuum soll durch die Regelung in der Saugphase bei großen Milchflüssen einen konstant niedrigen Vakuumabfall aufweisen. In der Entlastungsphase soll die Regelung dagegen einen konstant hohen Vakuumabfall erzeugen.

Bei Nassmessungen (ISO 6690, 2007) wurden verschiedene viertelindividuelle Melksysteme im Melklabor und in Praxisbetrieben in Bezug auf ihr zitzenendiges Melkvakuum untersucht. Nachfolgend wurden verschiedene Vakuummess- und Aktorsysteme zur Vakuumbeeinflussung untersucht. Die wichtigsten Ergebnisse der Untersuchungen bestehen darin, dass die Konzeption für ein Vakuumregelungssystem gefunden und ein Prototyp gebaut werden konnte. Weiter wurden die Anforderungen an ein optimales zitzenendiges Melkvakuum erarbeitet.

Das Konzept für das entwickelte Vakuumregelungssystem lässt erwarten, dass das zitzenendige Melkvakuum in der Saugphase auf 20 kPa bei einem Milchfluss von 0,25 l/min/Euterviertel reduziert werden kann. Bei hohen Milchflüssen von 1,5 l/min/Euterviertel und mehr wird das Vakuum in derselben Phase hingegen auf einen Mittelwert von 30 kPa eingestellt. Damit kann erstmals ein hohes Melkvakuum bei hohen und ein niedriges Melkvakuum bei niedrigen Milchflüssen erreicht werden. In Zukunft sollte das entwickelte Vakuumregelsystem zur Nutzung in allen viertelindividuellen Melksystemen angepasst werden.

Schlagwörter:
Vakuumregelungssystem, Vakuumschwankung, Vakuumabfall, Milchfluss, Zitzenende

Abstract (English)

The number of online-sensors in dairy farming is increasing. In this manner, important biologically changes in cows as for example changes in secretion can be detected at an early stage. But high mechanical strains on the teat tissue during milking still occur frequently and can for example lead to formation of teat rings. A suboptimal adjusted milking technology can be one of the reasons for the mentioned observations.

The objective of this dissertation was to develop a vacuum control system for the teat-end vacuum that can react in short time intervals. The teat-end vacuum produced by that control system should be with constant low vacuum reduction in suction phase at high milk flows. Moreover, in release phase the control system should provide constantly high vacuum reductions.

In wet-tests (ISO 6690, 2007) several individual quarter milking systems in laboratory and practical milking parlours were evaluated in terms of their associated teat-end vacuum conditions. Several vacuum measuring and actuator systems for controlling the vacuum were tested. The most important result of the studies was that the general concept for a teat-end vacuum control system was developed, and a prototype of that system was produced. Important requirements for an optimum teat-end vacuum were revealed during that work.

The concept for the planned vacuum control system suggests that it is possible to reduce the mean teat-end milking vacuum in the suction phase to 20 kPa at a flow rate of 0.25 l/min per udder quarter. At higher flow rates of 1.5 l/min and more per udder quarter, the teat-end vacuum is similar to the machine vacuum with a mean value of approximately 30 kPa. Therefore, for the first time, it is possible to supply a high teat-end vacuum at a high and a low teat-end vacuum at low milk flow rates. In the future, the developed vacuum control system should be adapted for installation in all types of individual quarter milking systems.

Keywords:
Vacuum control system, vacuum fluctuation, vacuum reduction, milk flow rate, teat end

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LIST OF PUBLICATIONS

This dissertation is based on the work contained in the following Publications, referred to Arabic letters in the text.

A Ströbel, U., Rose-Meierhöfer, S., Öz, H., Entorf, A. - C., Popp, L. & Brunsch, R. Analysis and evaluation of the teat-end vacuum conditions in different automatic milking systems. *Irish Journal of Agricultural and Food Research* (accepted manuscript, 2011.12.12).

B Öz, H., Rose-Meierhöfer, S., Ströbel, U. & Ammon, C. (2010) Comparison of the vacuum dynamics of conventional and quarter individual milking systems. *TBD - Journal of Agricultural Sciences* 16, 162-168.

C Ströbel, U., Rose-Meierhöfer, S. & Brunsch, R. (2011) Comparison of two vacuum recording methods in a quarter individual milking system. *Emirates Journal of Food and Agriculture* 23 (1), 27-36.

D Ströbel, U., Rose-Meierhöfer, S., Öz, H. & Brunsch, R. (2012) Development of a computer-based control system for the teat-end vacuum in individual quarter milking systems. *Computers and Electronics in Agriculture* (submitted manuscript, 2011.12.19).

E Ströbel, U., Rose-Meierhöfer, S., Brunsch, R., Zieger, E., Maier, J. & Hatzack, W., inventors, Leibniz Institute for Agricultural Engineering Potsdam-Bornim, applicant. Verfahren und Kit zum automatischen Melken von Tieren (Method and Kit for automatic milking of animals). *Official Identification*, No.: 10 2011 075 138.6 (submitted to the German Patent and Trade Mark Office, 2011.05.03; estimated time of publication, December 2012).

Publication A is already accepted but not yet published. Publications B and C already were accepted and published. Publication D was submitted and is under review, but has not yet been accepted. Publication E was submitted to the German Patent and Trade Mark Office and the estimated time of publication will be December 2012.

List of Abbreviations and Scale Units

The list of abbreviations and formulae is given for the pages 2 to 65 of this dissertation. The abbreviations and formulae of the publications A to E are given and explained within these documents.

Abbreviation	Nomenclature
AMS	Automatic milking system(s)
AMS A	Automatic milking system A
AMS B	Automatic milking system B
AMS C	Automatic milking system C
ATB	Leibniz Institute for Agricultural Engineering Potsdam-Bornim
BIO_{farm}	Biomilker® milking system located in a farm
BLE	Bundesanstalt für Landwirtschaft und Ernährung, Germany
b-phase	Suction phase of pulsation cycle
CON	Conventional milking system
CON_{farm}	Conventional milking system located in a farm
d-phase	Release phase of pulsation cycle
EP	European Patent
H_{AB}	Hypothesis for Publications A and B
H_C	Hypothesis for the Publication C
H_{DE}	Hypothesis for the Publications D and E
ICAR	International Committee for Animal Recording
IDF	International Dairy Federation
IQS	Individual quarter milking system(s)
IQ-milking	Individual quarter milking
ISO	International Standardization Organization
Kit	Arrangement, Anordnung
M	External sensor of MilkoTest 52 (vacuum measuring device)

Abbreviation	Nomenclature
M1	Sensor 1 of MilkoTest 52
M2	Sensor 2 of MilkoTest 52
MT52	MilkoTest 52 (vacuum measuring device)
MULTI	Multilactor® milking system
$MULTI_{farm}$	Multilactor® milking system located in a farm
$MULTI_{lab}$	Multilactor® milking system located in the milking laboratory
SGS	Single guided milking system(s)
S	Permanent inserted pressure sensor in a test casing
VCV	Vacuum control valve(s)
VCV A	Mechanically driven vacuum control valve
VCV B	Electronically driven vacuum control valve

Abbreviation	Scale unit	Nomenclature
Claw volume	cm^3	Claw volume in cubic centimeter
Distance	mm	Distance in millimeter
Flow rate	l/min per …	Flow rate in liter per minute per udder or per udder quarter
Measurement accuracy	%	Measurement accuracy in percent
Measuring deviation	% or kPa	Measuring deviation among two measuring systems in percent or kilo Pascal
Pulsation rate	cycles/min	Pulsation rate in cycles per minute
Sampling rate	Hz/ kHz	Sampling rate in Hertz or in kilo Hertz
Vacuum	kPa	Vacuum in kilo Pascal

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1 INTRODUCTION

The desire for technical devices that are adjustable with very high precision and that can react to changes in their environment automatically is almost as old as mankind. This desire has inspired engineers and inventors for thousands of years. CARL BENZ (1844-1929) expressed his sentiment with the sentence: "The love of invention never dies". The passion for invention remains fascinating in present times. Thus, the well-known computer pioneer STEVE JOBS (1955-2011) had similar feelings and stated: "The only way to achieve an extraordinary performance is to love what you do". A developed invention should perform each task through a high quality process and without any stop to the work, no matter what the circumstances are or how they change during the operation. This process should be continued until the machine is stopped by its operator. In reality, these standards can be only partly be attained. The passion to achieve perfection has also driven the inventors and researchers working on milking techniques and equipment. In the last few decades, these passions have led to extraordinary inventions for improving milking techniques. On the other hand, some set-backs occurred during this time. Because cows" udders are sensitive and milk is a perishable food, the development of milking technology has been very difficult in the past. Despite these problems, around the year 1860, the first mechanisation of the milking process was accomplished by inventing a first-hand milking apparatus with vacuum application, and with this, the first suction milking machine was developed by COLVIN (ORDOLFF, 2008). One of the next big successes was achieved by Dr. ALEXANDER SHIELDS in 1885 with the invention of a milking machine with an integrated pulsator. The next important step was accomplished by ALEXANDER GILLES in 1903 with the construction of the two-chamber teat cup (ROSE, 2006).

Other important inventions in the history of milking and vacuum technology are noted: In 1910, the first pipeline milking machine with a central vacuum supply was built; in 1929, the first electrical pulsator was developed; in 1965, it became possible to produce different vacuum applications in the milking cluster and in the milk pipeline; in 1970, the flow-based control of milking for milking machines with clusters was developed; in 1980, the separation of milk extraction and milk transportation became possible; in 1984, stimulation of the milking cluster using an increased pulsator frequency was possible; and since 1990, the use of farm-experienced milking robots has been possible (ORDOLFF, 2008). Further, since 2006, individual quarter milking has been possible in milking parlours (ROSE-MEIERHÖFER ET AL., 2010a). Moreover, the trend is that with more developed and improved sensor technology, the animal as an individual is increasingly the centre of consideration (UMSTÄTTER and KAUFMANN, 2001). Thus, single udder quarters can be treated individually and with more precision than before. However, even in the modern individual quarter milking systems (IQS), both automatic and parlour milking systems are still far from having realised the full potential of individual quarter milking. The reasons for this are the high costs, which would prevent the inclusion of enhanced sensor technology in such milking systems. Other reasons are to be found in the fact that the miniaturisation of electronic components and the research to gather relevant information requires much time. This is true especially if the new technology must be produced with high-quality sensor components. Despite this limitation, there is intensive research on the individual quarter technique for milking machines.

Thus, the primary objective of this work was to develop the knowledge to produce a control system to provide a milk-flow-based vacuum application for each individual udder quarter.

To reach that objective, it was necessary first to analyse the vacuum conditions in select state-of-the-art milking systems. Considering the vacuum data of the state-of-the-art milking systems, it was necessary to determine how the alternative vacuum control concept should be developed. Thus, five tasks were found necessary to split the work for this dissertation into parts. These tasks were as follows: 1.) Describe the vacuum behaviour of state-of-the-art automatic milking systems (AMS); 2.) Compare the vacuum conditions in the Multilactor® milking system with those of a classic milking system with milking clusters; 3.) Search for fitting sensors and measuring places in the milking system to realise a permanent, continuous measurement of the teat-end vacuum conditions; 4.) Develop the control algorithms for the system; and 5.) Develop a statement of recommendations for technical realisation of a control system.

2 STATE OF THE ART AND TECHNOLOGY

2.1 Vacuum behaviour

The teat-end vacuum in the teat cups of a milking system is always reasonably different from the machine vacuum, which can be adjusted for each milking system (SCHLAIß, 1994). Other reasons for the changes in the vacuum level are the movement of the liner and the volume changes of the rooms in the milk tube that occur through the removal of milk (WORSTORFF ET AL., 1982). Furthermore, the geometry of the two-chambered teat cup and the pulsation settings of the milking system play a major role in the movement of the liners and in the teat-end vacuum in a milking system. According to WEHOWSKY and TRÖGER (1994), the vacuum that is actually applied to the teats depends on the milk that streams out and on uncontrolled air intakes. Further, the vacuum depends on the factors that were noted by WORSTORFF ET AL. (1982). In the ISO 6690 (2007) guideline, the vacuum has been evaluated in terms of vacuum reductions and fluctuations, and there are defined calculation methods for both types of vacuum changes.

2.1.1 Vacuum fluctuations

Referring to NYHAN (1968), TOLLE ET AL. (1977) and TAN ET AL. (1993), vacuum fluctuations at the teat end could be cyclic, acyclic or irregular and mixed. Acyclic vacuum fluctuations are formed by a too-low performance of the vacuum pump or by pipes with a too-low diameter. Vacuum fluctuations are possible also by the double function of the vacuum for milking and milk transport (WORSTORFF, 1976). For acyclic vacuum fluctuations, the following causes are named by SPOHR ET AL. (1996): A too-weak vacuum pump, a leaky milking machine, air ingress that results from changing the milking cluster or by falling milking clusters, too-high towing resistance of the main air pipe or too-small diameters of milk line. Further, AMIRANTE ET AL. (2005) stated that it is evident that the observed acyclic vacuum fluctuations caused by the incorrect design of the milking plant could reach much higher values as fluctuations caused by the observed milk meters in their study. These acyclic fluctuations can be seriously harmful to the sanitary state of the udder, if they are not immediately compensated through an effective vacuum reserve. Acyclic vacuum fluctuations are an interruption of the stable vacuum sequence. A stable vacuum from the milk pipe to the claw and the teat end is a fundamental precondition for satisfying milking requirements. Therefore, a stable vacuum is the main goal of every milking machine (HOEFELMAYR and MAIER, 1980; NOSAL and BILGERY, 2002). Thus, the stability of the vacuum is extremely important for animal health and the effectiveness of milking (TAN and REINEMANN, 1994). With regard to udder diseases, the vacuum fluctuations occurring in milking systems have a high importance (MEIN, 1992).

Cyclic vacuum fluctuations also occur in modern milking plants with large pipeline diameters and efficient vacuum pumps. Cyclic vacuum fluctuations develop only close to the milking clusters. The wave of the cyclic vacuum fluctuations follows the pulse timing (WORSTORFF and FISCHER, 1999). The pumping action of the liner speeds the milk up by forward and backward oscillations thereby resulting in the possibility of a respray of milk and a respray of milk aerosols to the teat, which could result in the transmission of pathogens (RABOLD ET AL., 2003; HERMANN, 1990). SPOHR ET AL. (1996) names the following causes for cyclic vacuum fluctuations: the dimensions of the milking clusters are too small, the ventilation hole at the claw is too tight or blocked, the outflow of the milk from the milking cluster is blocked or the vacuum is too low. In a study by AMIRANTE ET AL. (2005), the vacuum fluctuations reached very high values, especially when the maximum milk release starts to end. During the previous phases, the fluctuations were reduced by half, and they showed a more cyclic or constant pattern, which is less dangerous to the udder. Many scientists differ in their beliefs regarding the relevance of the cyclic vacuum fluctuations. For example, SCHLAIß (1994) stated that through cyclic vacuum fluctuations themselves, no negative influences on the udder health are expected. On the other hand, the risk of an infection of the udder increases greatly at the end of milking when only a small milk flow comes out of the teat. According to FLÜCKINGER ET AL. (1979), the recommendations of scientists range from just avoiding the acyclic fluctuations to the avoidance of all existing types of vacuum fluctuations.

WORSTORFF ET AL. (1972) assessed the relevance of vacuum fluctuations as follows: He and his co-authors noted that the respray of milk from an infected quarter to the other potentially healthy teat ends increases the transmission of pathogenic microorganisms. WORSTORFF (1976) claimed that the cyclic vacuum fluctuations are characterised mainly by the intensity of the milk flow. ROSE (2006) observed that cyclic vacuum fluctuations in conventional milking methods with air intake made the development of a useful, individual quarter milking machine more difficult because the fluctuations increase with smaller, single-guided milking tubes. According to THIEL and MEIN (1979), vacuum fluctuations slowed the milking process. In an earlier study, THIEL ET AL. (1968) compared high and low cyclic fluctuations, and they could not find any effect of fluctuations on the milking performance. O"SHEA and O"CALLAGHAN (1980) found that the rate of new infections increases with unstable vacuum settings. In contrast, other research suggests that the generated vacuum fluctuations likely have a positive effect that contributes toward better udder health. Cyclic vacuum fluctuations arise in Biomilker®- or in SystemHappel®-milking clusters because in these systems the vacuum in the release phase is reduced. HAMANN ET AL. (2001) and SAGKOB ET AL. (2010) compared the effects of the aforementioned milking clusters (with a low d-phase vacuum) with a conventional milking cluster, and in particular, evaluated the effect of the milking cluster on teat condition. The authors of both studies concluded that the low teat-end vacuum in the release phase leads to a reduction of hyperkeratosis and usually to an overall better teat condition. It is possible not to have negative effects due to cyclic vacuum fluctuations are possible, as long as the maximum vacuum amplitudes of the cyclic fluctuations are relatively low. Additionally, the fact that a calf produces a moderate cyclic vacuum when sucking at the cow‟s teat is important.

It was suspected in the 1960s that vacuum fluctuations generally have a negative effect on the udder health of the cow. Consequently, building milking machines in a way that leads to the lowest possible vacuum fluctuations and reductions was attempted. The aim was to generate a teat-end milking vacuum that was very similar to the machine vacuum of the milking system. Today, scientists agree that cyclic vacuum fluctuations are acceptable if they occur within defined limits. Controlled cyclic vacuum fluctuations even can have a positive effect on the udder health. Overall, there is still no official guideline for determining the ideal cyclic vacuum condition at the teat end because of the differences in teat morphology of each cow and udder quarter. Based on the literature, some of the characteristics for the optimal teat-end milking vacuum can be deduced. A teat-end vacuum curve that can be considered optimal should show a vacuum level between 26 kPa and 39 kPa in the milking phase (b-phase) (RASMUSSEN and MADSEN, 2000) and a much lower and steady teat-end vacuum in the release phase (d). Within the b-phase, the vacuum should be constant during the time span of the entire b-phase, and it should show the lowest possible vacuum fluctuations. These rough requirements for the optimal vacuum curve are confirmed by many of the cited studies. For example, these findings were confirmed by HAMANN ET AL. (2001) and SAGKOB ET AL. (2010).

2.1.2 Vacuum reductions

The vacuum reduction is the difference of the mean vacuum values measured during a period of time in a milking system, which are calculated between a machine vacuum measuring point and a second measuring point in the system. For both measuring points, the mean value must be formed of at least five pulse cycles (ISO 6690, 2007). The vacuum reductions and fluctuations can be calculated for every phase in the pulsation cycle as well as for the whole cycle. The causes of the incidence of vacuum reductions and vacuum fluctuations are the same. In addition to the causes of vacuum fluctuations, pollution of the vacuum pipe is a reason for vacuum reductions. RASMUSSEN and MADSEN (2000) described in detail that milking with a low vacuum (which they specify to be 26 to 30 kPa and which is calculated as the average of a-, b-, c- and d-phase) in contrast to a high vacuum (which they specify to be 33 to 39 kPa and is a calculated analogue) extends the averaged milking time and increases the frequency of climbing liners. For a high vacuum, in contrast, it could be shown that the average milking time only moderately shortened (REINEMANN ET AL., 2001), but the amount of open teat ends after milking is increased. Further, high vacuum also increased the time needed by the teat ends to close again. In addition, a high vacuum increases the amount of hyperkeratosis at the teat end, as in previous mentioned studies (MEIN ET AL., 2003).

The vacuum reduction data gathered to date points to the following conclusion: If claw-, milk- and vacuum tubes and other installations such as milk meters have the correct dimensions, no serious vacuum reductions can occur. In addition, the vacuum reductions significantly depend on the milk flow at every different teat of a cow. The ISO 5707 (2007) guideline requires that the pulse vacuum during the b-phases should not be more than approximately 4.0 kPa under the machine vacuum. In contrast, the vacuum in the d-phase should not be greater than 4.0 kPa above the level of the atmosphere. According to ISO 5707 (2007) and 3918 (2007), there is a difference of pressure at the change between the phases, which is 4.0 kPa lower than the machine vacuum and 4.0 kPa greater the atmospheric pressure. According to LINCKE (1999), high vacuum reductions can lead to adhesion problems with the teat cups. Additionally, decreases in milk flows can occur with high vacuum reductions. WORSTORFF (2001) suggested tube diameters of 16.0 mm for the long milk tubes because such tubes led to desired low vacuum reductions. In praxis, the vacuum reduction of 5.0 to 8.0 kPa is often higher than desired because tubes with 14.0 mm or more are rarely in use. Considering the previously noted requirements for the optimal teat-end vacuum curve, it must be noted that oversized tube diameters cause an extremely low vacuum reduction in the d-phase, which could have even negative effects on udder health. This effect must be considered in choosing milk tubes with different inner diameters.

2.2 Milking technology and udder health

The effect of milking technology on udder health is highly related to the vacuum behaviour in the milking system. Thus, HAMANN and DÜCK (1984) do not consider the respray important to the development of udder diseases because of its low speed. In the returning air, which results from the opening liners, milk can be included in form of droplets (THOMPSON and PEARSON, 1983) or aerosols (WHITTLESTONE ET AL., 1972), and by that, depending on the setting of the pulsator, in modern milking clusters, danger to udder health can also result. HAMANN (1982) explained the higher risk of infections at the end of the milking process with the missing flow of milk around the teats. Further, the impact of teat tip and teat canal for udder health should not be underestimated. HAMANN (1987a) stated that the teat canal is the primary physical and chemical barrier to invasion of mastitis pathogens into the udder. Moreover, the changes in the teat-end condition are associated with mechanical forces exerted by the vacuum and the moving liner during machine milking. As a result, hyperkeratosis commonly occurs at the transition between the teat end and the teat canal. Moreover, HAMANN (1987b) concluded that mastitis can be caused through sub-optimal adjustment of the milking technique such as failure in pulsation and through sub-optimal teat-end vacuum. Sub-optimal teat-end vacuum can lead to hyperkeratosis. This is true for all type of milking systems. WALSER declared as early as 1966 that correctly working milking equipment is a prerequisite for healthy, complete and rapid milk withdrawal and that udder health is essential for the cost efficiency of milk production.

HÄUSSERMANN and HARTUNG (2010) compared several milking systems with different system and vacuum settings, and one of the results was that the teat-end vacuum is affected by the level of milk flow, the milking system, the systems inserted components and the settings of the milking technique as pulse ratio and rate. However, this finding indicates that the machine vacuum is not a good parameter to use in evaluating the quality of the milking process. Moreover, the composition of the settings is relevant to teat and udder condition. In principle, the milking machine should not create excessive strain on the teat tissue during the milking process (GEIDEL, 2002). The milking process has positive and negative effects on udder health. During the milking process, bacteria are washed out before they have a negative effect on the udder. On the other hand, strong forces have a great effect on the udder during milking.

Examples are the internal hardening of the teat-ends, hyperkeratosis, bacteria transfer and delayed milk-flow (WORSTORFF and FISCHER, 2000). The longer the teat is connected to intensive or high vacuum, the higher the probability is of restricted blood and lymph circulation in the teat. Thus, the teat-tissue is then too greatly physiologically strained (FAHR and VON LENGERKEN, 2003). Further, the cow‵s individual physiological conditions and individual behaviour differs greatly, as BRUNSCH and SCHOLZ (2003) determined when they tested individual cow water consumption in a suckling cow cattle herd. Moreover, KAUFMANN ET AL. (1996) and UMSTÄTTER (2002) also found much individuality in cattle herds when they measured a wide range of heart frequency values in individual dairy cows.

In summary, it can be stated that there is no milking system available that can prevent mastitis-promoting effects completely (HAMANN, 2001). This statement remains true today, in 2012. Thus, the development of a control system for a precise adjustment of the teat-end vacuum for each udder individually per quarter is a very important objective for improving milking equipment in the future.

2.3 Individual quarter milking

All individual quarter and automatic milking systems with single, guided milk tubes have some decisive advantages compared to conventional milking systems (DAVIS ET AL., 2000; REINEMANN ET AL., 2002; ROSE ET AL., 2004). Some important advantages are, for example, that separating quarters could eliminate new infections of mastitis. Quarter control of pulsation and/or vacuum is possible in individual quarter milking systems (IQS), and they will improve the sensitivity of automated mastitis detection (REINEMANN, 2010). Separation of milk streams also allows the diversion of quarter milk, which can be useful in minimising milk losses from infected cows. The separation of milk streams also can prevent economic losses for farmers if the technical realisation in the future is cost efficient enough (REINEMANN, 2010).

The examinations of different milk levels in quarters by UMSTÄTTER and KAUFMANN (2001) have shown that most commonly, the maximal differences in milking time within one udder range from one to three minutes. Additionally, the unevenly divided amount of milk between the front and the back udder half supports an individual treatment of the single quarters (UMSTÄTTER, 2002). Individual quarter milking is a milking process in which each single udder quarter is observed and treated individually, and it is more precise than conventional milking systems. A further advantage of the individual quarter milking is that the milking data, such as milk flow and the milk constituents, as well as other milk-related data can be obtained separately for each udder quarter.

Most individual quarter milking systems (IQS) on farms are automatic milking systems (AMS) (HALACHMI, 2009). The number of world-wide installed IQS shows a rapidly increasing trend (HALACHMI, 2009; HARMS, 2009). The first frequent use of single guided milk tubes was in AMS because that technology requires that teat cups be automatically attached. The additional advantages of the single guided milk tubes became more evident during the world-wide testing of AMS. According to SCHÖN ET AL. (2000), there are primarily two different types of construction characteristics visible in AMS that are related to the milking and attaching unit of these milking systems. Approximately half of the marketed AMS work with a modular milking unit. The four teat cups can be attached simultaneously to each teat. For the rest of the systems, each teat cup is attached one after the other by a robotic arm. However, independent from the milking unit, all systems work in almost all cases with more than 2.000 mm long single guided milk tubes because the individual observation of the four quarter milkings is extremely important for each manufacturing company. Thus, at the moment, automatic milking is the most important part of individual quarter milking. Overall, the development of the AMS is one of the most important agricultural inventions of the 20th century (MARIS AND ROE, 2004).

The Multilactor® milking system was launched onto the market, has been commercially available for more than two years (STRÖBEL ET AL., 2009) and is the first IQS for milking parlours. Multilactor® was developed by the company Siliconform GmbH & Co. KG (Türkheim, Germany). The Multilactor® operated differently from a conventional milking cluster. The teat cups can be attached from a milking magazine, and they are attached manually and in pairs to the udder. The detachment of the teat cups occurs automatically but not on the individual quarter level (ROSE and BRUNSCH, 2007). As a further advantage of that system, using individual quarter milking in conventional milking parlours is expected to reduce somatic cell count, which is an important indicator of udder health (ROSE ET AL., 2006b). Thus, individual quarter milking has been possible in AMS for many years, and now with the development of the Multilactor® milking system, it is also possible to milk individually quarter-wise in almost all types of conventional milking parlours, excluding in swing over and side by side milking parlours.

Other IQS have been on the market for more than a year, for example, the IQ-milking cluster produced by the GEA group (Bönen, Germany) or the AMR™ robotic carrousel of DeLaval group (Glinde, Germany). Long, single-guided milk tubes in each IQ-milking unit are an advantage for introducing additional technical equipment to perform a more gentle milking process on the quarter level. Examples of technically sophisticated equipment are cell count-, hormone concentration- or vacuum measurement, online at the quarter level, which will be introduced on the market at an increasing frequency (STRÖBEL ET AL., 2011b). Additional support for the effectiveness of the individual quarter-wise evaluation of milking data can be found in the study of QUERENGÄSSER ET AL. (2002). These veterinarians concluded that teat-endoscopy and the measurement of quarter milk flow and milk yield with Lactocorders® are useful tools for examining teats with milk disorders.

In summary, it can be stated that only in systems with single guided milk tubes can the milking parameters be recorded on the individual quarter level, and thereby a much better control of udder health and milk quality is possible (ROSE and BRUNSCH, 2007). Therefore, it makes sense to use the individual quarter milking system (IQS) in conventional milking parlours as well. Further, the amount of IQS sold has increased in recent years, and the number has increased in milking parlours as well as in automatic milking systems (AMS). Thus, there is great potential for individual quarter milking to be used on farms and investigated in the future.

2.4 Vacuum control systems

A large number of patents and product ideas for milking machines that allow the control of the teat-end adjustments of the milking machine are already available or developed. Some of the published information influencing the development of the work in this dissertation are given as examples: In the European Patent EP 1 186 229 B1 (VAN DEN BERG and BEIJE, 2007), an animal individual and computer-controlled device was described. The system is able to control the milking phase and the release phase and the vacuum level of the system pulsator. The vacuum measurement occurs in areas very close to the teat. The disadvantage of this concept is that the teat-end milking vacuum is adjusted only indirectly by a change in the pulsation settings. With the help of the control system developed for the mentioned patent, it is not possible to produce a very precise frequently acting control system for the teat-end milking vacuum. Further, the European Patent EP 2 033 511 A2 (PETTERSON, 2009) also describes measurement of the vacuum near the teat end and the control of that vacuum. During the vacuum measurement in this invention, the head vacuum is measured. With the head vacuum, the milkability of a milking system can be analysed. In this machine, the sensor signals measured in the head of the liner can be used to interrupt the periodic movement of the liner with an actuator. The actuator is installed next to the teat cup. Thus, the collapsed state of the liner can be maintained for up to 10 seconds. This patented machine has this effect especially at the end of the milking process and in the milk-out phase of the milking process. The objective of the patent is to shorten the milking duration. However, this invention did not result in complete control of the teat-end milking vacuum. Such a complete control could result in the entire milking process becoming much more gentle and would reduce the mechanical load and the stress on the teat tissue.

Other developments with control systems used in the milking technology are a milk-flow-controlled milking system, which determine the end of the milking process and the removal of the milking unit. That system could prevent overmilking. These types of systems were developed in the 1970s by the companies Elfa-Elsterwerda and Miele. The systems also helped to simplify the physical work of milkers during the milking processes (ORDOLFF, 2008). The Duovac-300 milking machine, developed by Alfa-Laval in 1976, also worked with a flow controlled vacuum at the beginning and end of the milking process. That technology could guarantee efficient milk removal (ORDOLFF, 2008). On the other hand, both mentioned systems did not work during the entire milking process, as the control system of the present dissertation will do. Thus, these systems could improve milk removal but not greatly decrease the high mechanical load on the teat ends, caused by the high vacuum during the whole milking process of a cow. Another milking system, developed in the 1990s, controlled the pulsation during the whole milking process with a frequently altering pulsation rate and ratio that depends on the measured milk flow data. During the development and testing of that pulsator, ORDOLFF (1991) found very low strippings compared to earlier measurements in uncontrolled milking systems. However, it could not be ensured that the liner collapses were filled out completely in that milking system, which had a pulsation ratio of 85% suction phase at the highest possible milk flow rates (SCHLAIß, 1994). Additionally, with that milking system, the variables controlled are only the easily adjustable pulsation ratio and rate. An exact control of the teat-end milking vacuum is also not reached with the mentioned system. Therefore, exact control of the teat-end milking vacuum was explored in the present study.

Hence, all of the described developed control systems and all of the additionally investigated methods and apparatuses for controlling milking systems have clearly different objectives compared to the objectives determined for the present study. Additionally, many of the patented control systems for the milking technology are only useful to research institutions and not under farm conditions because the manufacturing of the mentioned systems is much too expensive for use under farm conditions.

3 OBJECTIVES OF THE DISSERTATION

The primary objective of the present dissertation was to develop the intellectual and scientific basis for a control system for the teat-end vacuum in individual quarter milking systems (IQS). In the end, the system should produce a vacuum application per udder quarter, which is very close to the already mentioned optimal teat-end vacuum curve.

Specific objectives of the dissertation were stated as follows:

- Analysis and evaluation of the teat-end vacuum conditions via the Wet-test-method in different automatic milking systems (AMS) as a widely used type of IQS.
- Comparison of the teat-end vacuum conditions in an IQS for milking parlours with the conditions in a conventional milking cluster for milking parlours.
- Development of a vacuum sensing system for a continuous evaluation of the teat-end vacuum condition in the Multilactor® milking system, applicable to all types of IQS and the development of a practicable, precise and sophisticated actuator system for direct, computer-based, online reaction to the sensing technology.
- Development of the control algorithms for the developed vacuum control system and the statement of recommendations for the technical realisation of the mentioned control system.

4 MATERIAL AND METHODS

4.1 Wet-test-method and locations for measurements

Vacuum measurements using the Wet-test-method described in ISO 6690 (2007) were conducted in each of the five given publications that are part of this cumulative dissertation. The locations of the measurements in the automatic milking systems (AMS) for Publication A were conducted by companies or farms in Denmark and Germany. Another place where the measurements were taken was at a farm in Remptendorf, Germany, where a quarter individual Multilactor® and conventional milking system were installed and tested in Publication B. All of the other measurements for the Publications C, D and E were conducted in the laboratory milking parlour at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB) in Potsdam.

The details of the connections of the vacuum with the sensors and the different measuring devices are given separately in each publication of the present dissertation. Moreover, the technical details and the measuring deviations of the measuring devices used are also described in each of the attached Publications A - E. The frequently set technical adjustment of the milking and measuring systems used is also described in the following subchapters of the present dissertation. Publications A – E, as given in the table of contents, are the appendix of that work, and all of them are included with abstract and full biographic data along with the text of that dissertation.

4.1.1 Laboratory milking parlour

The laboratory milking parlour at the ATB in Potsdam was used to conduct all the measurements that were necessary to develop the intellectual and scientific basis for the teat-end, individual quarter vacuum control system. The ATB milking parlour is equipped with milking equipment from different manufacturers. For the development of the control system, only the milking location that is equipped with a Multilactor® milking system was used (Figure 1). The year of construction was 2010. The state of the technical development of the used Multilactor® was the version, which was already equipped with the software and pulsation system and with the Pulsatronic terminal of the Impulsa AG, Elsterwerda, Germany. This software version used was PMA SV 5.90 Oase © 2011 IMPULSA.

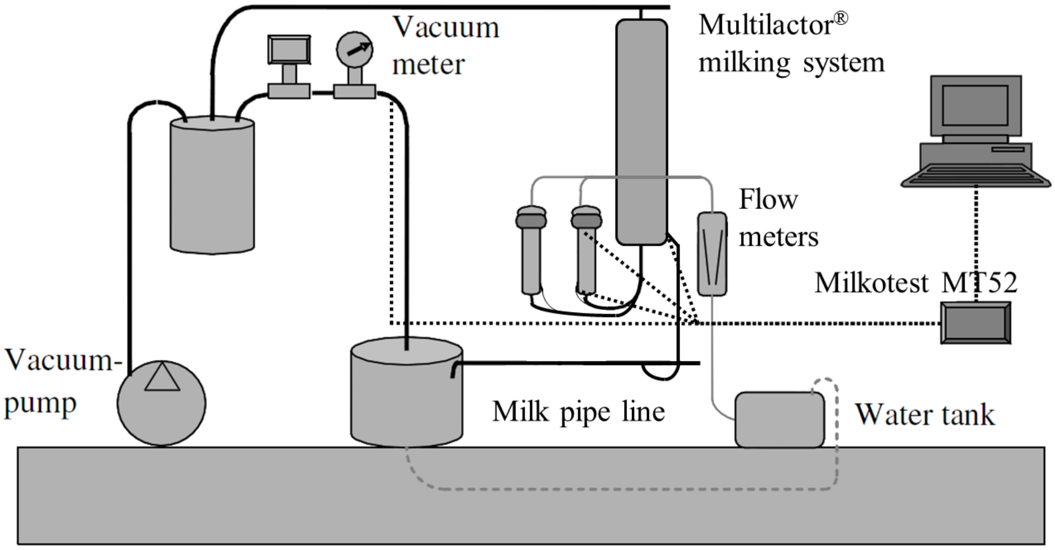


Figure 1: A schematic drawing of the Multilactor® milking location in the laboratory milking parlour at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), with the equipment for the Wet-test-method (modified according to ROSE, 2006).

The machine vacuum in the parlour is adjustable between approximately 20 and 60 kPa. The parlour produces a steady vacuum, and it is equipped with a vacuum pump produced by the GEA Company (Bönen, Germany).

4.1.2 Simulation of the milking process

During the experiments, ISO artificial teats were used (ISO 6690, 2007). Water or milk at room temperature was used to simulate the effects of the milk flow; the flow ranged between 0.8 and 8.0 l/min per udder. As a flow simulator, four flow meters (Parker Hannifin Corporation, Cleveland, USA) installed on a board were used. Each flow meter allowed the measurement or the adjustment of the flow rate, which ranged between 0.0 and 2.0 l/min per udder quarter, with a measurement accuracy of ± 2%. The vacuum sensors were connected with T-pieces or with 16-gauge injection needles (BD Nokor Admix Kanüle 16G) to the vacuum lines and tubes. The opening of each needle was set in the downstream direction. The T-pieces can be used instead of the injection needles to connect the pressure sensor to the tube inside. Frequently used flow rates were 0.0; 1.0; 2.0; 3.0; 4.0; 5.0 and 6.0 l/min per udder. Moreover, a commonly chosen number of repeated measured pulsation cycles was 40.

4.2 Vacuum recording systems

4.2.1 Bovi Press

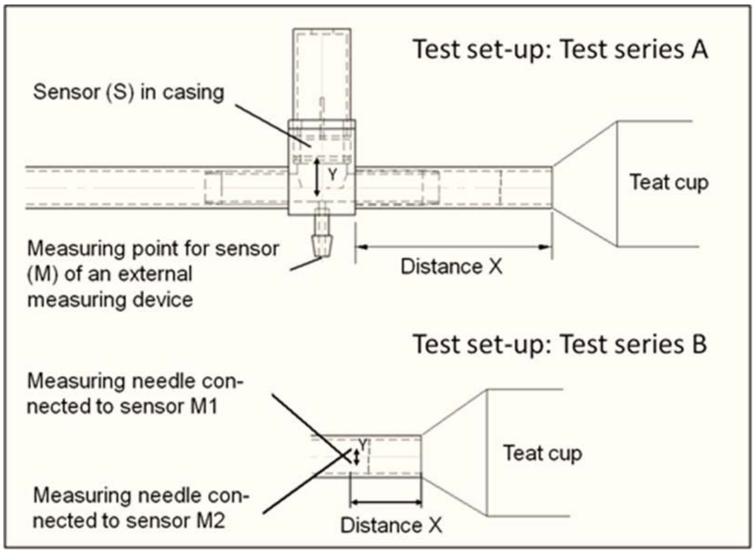
The vacuum was measured in wet-tests (ISO 6690, 2007) using a Bovi Press measuring system (A & R Trading GmbH Echem, Germany) in Publications A and B, which accommodated samples greater than 300 Hz, with an accuracy of ± 0.1 kPa, as was the case for the two above-mentioned studies. A measurement accuracy of ± 0.6 kPa is required, as defined in ISO 6690 (2007). The vacuum was recorded for seven pulsation cycles for each measurement at the ISO-teat-end (ISO 6690, 2007) in the pulsation chamber and in the machine vacuum line, simultaneously. Only three sensors per udder quarter, at the above-mentioned locations, were evaluated when the measurements were conducted by that device.

4.2.2 MilkoTest MT52

In the wet-tests (ISO 6690, 2007) in Publications C, D and E, the vacuum was measured using a MilkoTest MT52 measuring system (System Happel® GmbH, Friesenried, Germany) sample with 500 Hz and with an accuracy of ± 0.1 kPa, while a measurement accuracy of ± 0.6 kPa is required, as mentioned above (ISO 6690, 2007). The MT52 has four vacuum sensors. Three or four of the four sensors were used to measure and save the vacuum data simultaneously. The vacuum at the teat-end in the artificial teat, in the pulse chamber and in the main vacuum line, was measured with the MT52. Vacuum sensor 1 of MT52 was connected to the machine vacuum line. Sensor 2 was connected to the pulse chamber through a T-piece. The connection of sensor 2 was performed at a distance of 30.0 mm under the end of the teat cups‟ pulse pipe. The blockage of T-pieces occurs rarely compared to blockages in measuring needles. Therefore, the T-pieces are predestined for laboratory measurements (ROSE, 2006). The connection of sensor 3 was realised by a direct, 30.0 mm long tube connected to the end of the artificial teat. The inner diameter of the tube was 2 mm. This choice of the style used to connect the sensors was described in Publications D and E. In Publication C, two of the four sensors of the MT52 were connected in a different way to an in-house-developed test casing for pressure sensors. The details are given in Figure 2. In another experiment described in Publication C, the two sensors (3 and 4) of the MT 52 were both connected with 16-gauge injection needles to one milk tube to compare the deviation of the measurement of the two measuring points. According to ROSE (2006), both 16-gauge injection needles as well as T-pieces are most suitable for such measurements. Additionally, in the experiments in Publication C, the machine and pulsation vacuum was measured by sensors 1 and 2 of the MT52 measuring device. Sensors 3 and 4 of the MT52 were used for sampling the deviation among the two sensors or in comparison to the sensor in test casings.

4.2.3 Sensor systems and test casings

The vacuum sensor system, developed at the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB), was used only in Publication C and was constructed as prototype one for a permanent teat-end vacuum measuring system for individual quarter milking systems (IQS). The sensor system consists of three parts: Each of the four sensors for each milk tube was inserted to a casing and was connected to an analogue-digital converter. This converter was connected with an interface to a computer. For data recording, the software LabView was available on the computer (National Instruments Germany GmbH, München, Germany). Each of the permanently integrated sensors in the casing is a high quality, calibrated piezoresistive pressure sensor (KELLER DRUCKMESSTECHNIK GMBH, 2008). According to the manufacturer‟s instructions (KELLER DRUCKMESSTECHNIK GMBH, 2008), the measurement accuracy of the mentioned sensors is 0.5%. The maximum measurement frequency is 2.0 kHz. In test series A of Publication C, the measuring deviation between the vacuum control device (MT52) and the permanently inserted pressure sensor of the developed sensor system was measured (Figure 2). To evaluate the test casing with the introduced pressure sensor (test series A) compared to a conventional and often-used measurement method for collecting the milk tube vacuum data (test series B), an experimental design was built as follows: At test series A, the measuring deviation between the vacuum control device (M) and the permanently inserted pressure sensor (S) has been measured (Figure 2). At test series B, the measuring deviation between two sensors (M1, M2) of one external measuring device has been evaluated to compare both types of test set-ups. The two sensors (M1, M2) have been connected to the milk tube with measuring needles (Publication C). The pair of sensors was set into the long milk tube of a Multilactor® milking system at three different positions. In detail, each of the two sensor pairs (test series A and B) was inserted with a distance to the teat end of 100 mm, 140 mm and 2,750 mm.



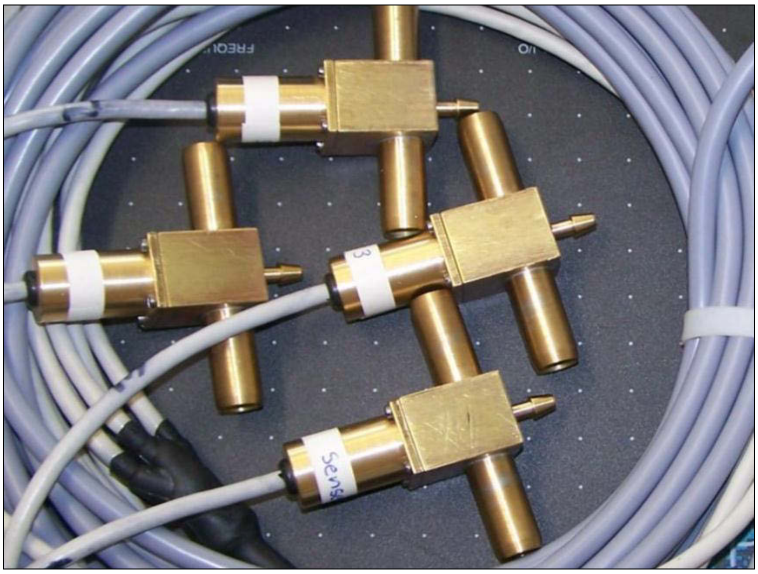


Figure 2: A schematic drawing of the test set-up: Sensor system with test casings (Test series A) constructed at the ATB (both figures) and sensor system with two measurement needles (Test series B) (above figure; Publication C).

4.3 Milking systems

To provide an overview of all milking systems used and tested during the present dissertation, the most important technical details are given in Table 1. The most important differences among the systems are described in the following subchapters.

Table 1: Technical details of all the tested milking systems, used in that dissertation.

Type of milking system	AMS A	AMS B	AMS C	CON_{farm}	BIO_{farm}	$MULTI_{farm}$	$MULTI_{lab}$
Year of production	2008	2008	2006	2009	~2006	2009	2010
Location	Wiebels-dorf Germany	Berlin Germany	Kolding Denmark	Rempten-dorf Ger-many	Ach-selschwang Germany	Rempten-dorf Ger-many	Potsdam Germany
Worked with, in Publication	A	A	A	B	B	B	C, D, E
Machine vacuum (kPa)	47	44	44	40	35	38	35
Pulsation ratio	63/35	65/35	60/40	60/40	60/40	60/40; 65/35	60/40; 65/35
Type of pulsation	Alterna-tive	Alternativ, individual quarter regulation	Alternativ	Alternativ	Alternativ	Sequential	Sequen-tial
Construction of milking unit	Individual quarter	Module	Individual quarter	Cluster	Cluster	Individual quarter	Individual quarter
Claw volume, if with cluster (ml)	--	--	--	300	300	--	--
Milk tube length from teat cup to the “claw” (mm)	2000	4600	2500	~170	~170	~3095	~3095
Inner diameter of the milk tube at the teat cup (mm)	12	12	11	12	12	10	10

4.3.1 Automatic milking systems

There are different length ratios and inner diameters of milk tubes in the three automatic milking system (AMS) types, which were evaluated in Publication A to obtain information about problems with vacuum behaviour in individual quarter milking systems. Each of the three tested AMS types is produced by a different manufacturer; thus, each of them is a different brand. The most important technical data for each AMS are given in Table 1. The pulsation rate for all three AMS was 60 cycles/min. AMS B was equipped with an individual quarter control system for the pulsation settings. The other two AMS types were equipped with alternative pulsation. Further, AMS B was equipped with a milking unit, which is constructed as a module. The other two AMS were constructed with individual quarter tube guidance. The length of the milk tubes is also given in Table 1. The inner diameter of the mentioned milk tubes was 12 mm for AMS A and B and 11 mm for C. The teat cups of the three AMS types were all constructed with a permanent air-inlet at the end of each teat cup that allows air ingress into the milk tube. Furthermore, all three AMS were equipped with a frequency-controlled vacuum pump.

4.3.2 Conventional milking systems and Multilactor® on a farm

Two types of conventional milking system and a Multilactor® system ($MULTI_{farm}$) were compared to each other in terms of the teat-end vacuum behaviour in these systems in Publication B. All three milking systems were located in German dairy farms that cooperate with the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB) (Publication B). Further, all three milking systems were introduced in three similar tandem milking parlours on two different farms. CON_{farm} and $MULTI_{farm}$ were installed on the same farm in Remptendorf, Germany. The Biomilker® milking system was located in Achselschwang, Germany, on another cooperating farm. All three systems have a milkline in low line installation, and each is equipped with milk meters. The CON_{farm} milking system was equipped with a "Westfalia Classic 300" milking cluster, which was manufactured by GEA (Bönen, Germany). The cluster was used as a reference cluster in Publication B. A second Biomilker® milking cluster (BIO_{farm}), also manufactured by GEA (Bönen, Germany), was used to compare the vacuum conditions. The Biomilker® system allows periodic air-ingress under the teat. Alternative pulsation at a rate of 60 cycles per minute and a ratio given in Table 1 was applied at all milking parlours and clusters at all experiments. The machine vacuum and more technical data from CON_{farm}, BIO_{farm} and $MULTI_{farm}$ are also given in Table 1.

4.3.3 Multilactor® milking system in the laboratory and on a farm

The Multilactor® milking system (MULTI) is a newly developed milking system that allows individual quarter milking in the milking parlour. Some advantages of individual quarter milking for milking technology were already given in the State of the art and technology chapter. The most important technical innovations in MULTI are the following: Cleaning for teat cups that occurs between the milking of two following cows, individual quarter tube guidance and disinfection inside and outside of each teat cup using an automatic washing unit, sequential pulsation and four vacuum cut-off valves, which react promptly to unwanted teat cup fall-offs (ROSE-MEIERHÖFER ET AL., 2010a). Siliconform GmbH & Co. KG (Türkheim, Germany) has developed and manufactured MULTI.

Further, MULTI is equipped with the Biomilker® technology (Siliconform GmbH & Co. KG, Türkheim, Germany). That technology has not been used in an individual quarter milking system (IQS) before MULTI"s invention (Publication B). The Biomilker® technology was developed for conventional milking clusters and was adapted to the individual quarter milking system Multilactor®. Each of the four Biomilker® valves provides a periodic air-ingress in the release phase (d-phase) of the pulsation cycle (HOEFELMAYR and MAIER, 1980). The system was equipped with sequential pulsation. In contrast to alternative or monotonous pulsation, the sequential pulsation works with four pulsators. The pulsation cycle of teat cup two starts with a time delay of 25% (relative to the pulsation duration) after teat cup one. Teat cup three starts with a 25% delay after teat cup two and so on. Further, MULTI is equipped with a pneumatic arm, named Actuator®.

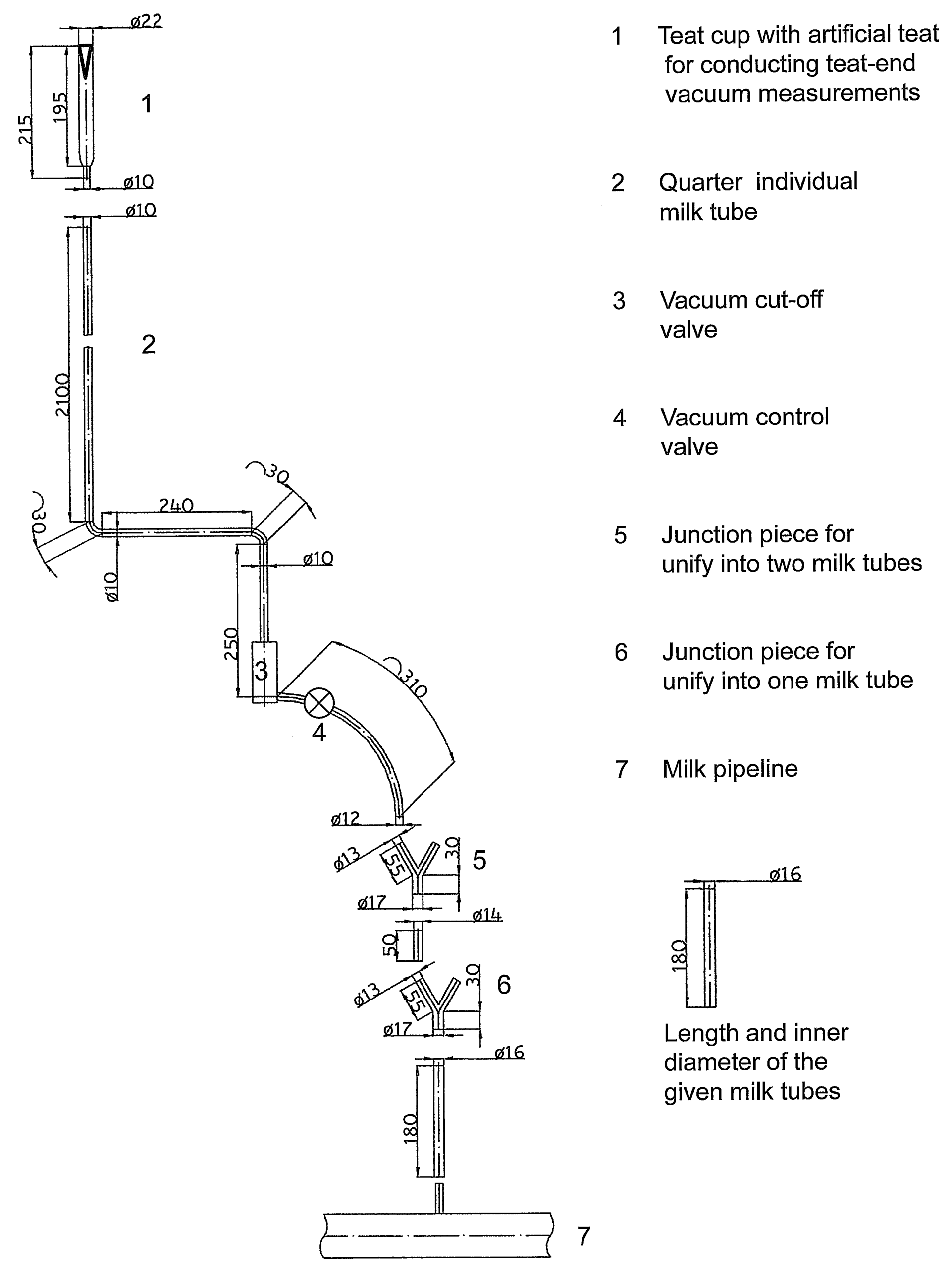


Figure 3: Diagram of the Multilactor® milking system with tube length data and inner tube diameters of its duct system (STRÖBEL ET AL., 2011a).

This arm moves the four milk tubes regularly, whereby the muscular system of the udder is meant to be stimulated and relaxed. The length of the milk tubes from the teat cup to the claw was 3,095 mm, and the inner diameter of the tubes was 10 mm. The additional data from the tube guidance system in the MULTI can be found in Figure 3 below. The technical data of the basic MULTI type and the specifications of that system from different studies are given in Table 1.

The Multilactor® milking system was used in different variations in the investigations of this dissertation. An older type of MULTI (with terminal and software from Kraft & Butzke GmbH, Leipzig, Germany) called $MULTI_{farm}$ was used in farm experiments performed in a dairy farm in Remptendorf, Germany (Table 1). The results gathered with that milking system were reported in Publication B. All the other experiments, described in Publications C, D and E, were conducted in the Multilactor® milking system, which is located in the laboratory milking parlour of the Leibniz Institute for Agricultural Engineering Potsdam Bornim (ATB) and that system is called $MULTI_{lab}$. The pipe and tube length and the inner diameters of the MULTI duct system have been (with minimal variation) the same in each type of MULTI used. Further, a vacuum control valve was used only in Publications D and E, where the effect of that valve on the vacuum conditions at the teat end was tested. A figure with that valve‟s technical details is given in Publications D and E (Figure 2 in D). In Figure 3, the artificial teat, which was used in all tests with MULTI and the vacuum control valve are included in the drawing. The point at which the mentioned devices are introduced to the MULTI is shown in Figure 3. The pulsation rate for all experiments with MULTI was 60 cycles per minute. Moreover, the varying technical data for the different experiments are given in Table 1.

4.4 Statistical analysis

The determination of the pulsation phases in all attached Publications A – E, was conducted using a customised SAS macro according to the formulae presented in ISO 5707 and 6690 (2007). For all publications, statistical evaluations were conducted with the statistics software SAS 9.2 TS Level 2 MO (SAS Institute, Cary, USA). In Publications A, B and C, the evaluation of the vacuum data was made using parametric tests based on a linear model. The collected data of the tested milking and measuring systems were compared with each other. A linear model was formulated with the MIXED procedure. For calculation of the mean values, the MEANS procedure was used. In some cases, graphs were produced with the statistics software JMP, Version 8.0 or with Microsoft Excel. In Publications D and E, additionally, regression functions have been adapted to the measured vacuum data, using the statistics software JMP 8.0 (SAS Institute, Cary, USA).

5 RESULTS AND DISCUSSION

5.1 Vacuum behaviour in individual quarter milking systems

The hypothesis (H_{AB}) of the first part of this dissertation was that constructive differences among the tested milking systems have a significant effect on the teat-end vacuum behaviour in the tested milking systems.

5.1.1 Results during the vacuum behaviour measurements

In Publications A and B, experiments for evaluating the vacuum behaviour in six commercially available milking systems have been conducted. Three of the systems were automatic milking systems (AMS). The other three systems were two conventional milking clusters with permanent (CON_{farm}) and periodic (BIO_{farm}) air-inlets and the already-described milking system Multilactor® ($MULTI_{farm}$) for individual quarter milking in milking parlours. The highlights of the results for each of the six milking systems are given in Table 2.

Table 2: Vacuum reductions at the teat-end in the six tested milking systems at different flow rates in the b-and d-phases of the pulsation cycle (taken from Publications A and B).

Milking system	Mean vacuum reduction in kPa at a flow rate in l/min per udder at b- and d-phase of the pulsation cycle					
	1.0 (b)	2.0 (b)	4.0 (b)	1.0 (d)	2.0 (d)	4.0 (d)
AMS A	2.5	3.1	4.5	3.7	5.3	8.6
AMS B	2.3	2.6	3.3	4.0	5.0	7.1
AMS C	--	3.8	5.7	--	2.4	6.4
$MULTI_{farm}$	1.6	3.0	5.9	9.1	13.3	21.8
CON_{farm}	2.0	2.8	4.3	2.2	3.1	5.0
BIO_{farm}	1.4	1.9	2.9	5.4	8.7	15.2

An evaluation of the six milking systems shows that the Biomilker® cluster (BIO_{farm}) has the lowest vacuum reductions, with 1.9 kPa and 2.9 kPa at flow rates of 2.0 and 4.0 l/min per udder in the b-phase (Table 2). Among the AMS, the lowest vacuum reductions with 2.6 kPa and 3.3 kPa at flow rates of 2.0 and 4.0 l/min per udder in the b-phase (Table 2) were found for AMS B. In AMS C and in $MULTI_{farm}$, moderately higher values for vacuum reductions were found compared to the other four milking systems of 5.7 kPa and of 5.9 kPa, at a flow rate of 4.0 l/min per udder in the b-phase. Further, by considering only the flow rate of 2.0 l/min per udder or less in the b-phase, the lowest mean vacuum reductions were found in BIO_{farm} and $MULTI_{farm}$, which were lower than 1.6 kPa (Table 2). In the d-phase, both milking systems with periodic air-inlets, namely, BIO_{farm} and $MULTI_{farm}$, showed a much higher vacuum reduction than the CON_{farm} and the AMS. For example, at a flow rate of 4.0 l/min in the d-phase, the reductions of the CON_{farm} and the AMS were between 5.0 and 8.6 kPa; in comparison, the BIO_{farm} and $MULT_{farm}$ reductions were between 15.2 and 21.8 kPa (Table 2).

Additionally, in Publication A, for the wet-tests (ISO 6690, 2007), the results on the effect of the three different AMS for the flow rate and for the interactions of the two effects on vacuum reductions and fluctuations were investigated. The F-test showed that both the flow rate and the interaction between the flow rate and milking system have significant effects on vacuum reductions and fluctuations ($Pr < 0.0001$). This is true for the vacuum conditions in the b- and in the d-phases of the pulsation cycle. A significant effect of the milking system without flow rate interactions was found only for the vacuum reduction in the d-phase. The significant effect of the flow rate shows that increasing flow rate causes increasing vacuum reductions and fluctuations in the AMS (Publication A). In Publication B, significant differences between the milking systems $MULTI_{farm}$, CON_{farm} and BIO_{farm} for the vacuum reductions in the b- and d-phases ($P \leq 0.05$ for all values) were found. Moreover, a significant effect of the flow rate on the vacuum reductions in both phases was found by that study. Therefore, the effect of the flow rate was found in all six tested milking systems: in AMS A, B, C and in the BIO_{farm}, CON_{farm} and the $MULTI_{farm}$ milking systems.

5.1.2 Discussion of the vacuum behaviour measurements

The data reported in Publications A and B and given in Table 2 will be compared and discussed with the findings of other authors. For example, O'CALLAGHAN AND BERRY (2008) investigated a self-developed individual quarter milking system (IQS) in a parlour with a high milk line, although in that study the machine vacuum was 50 kPa for the self-developed IQS. In comparison, it was 47 kPa for the AMS A, 44 kPa for the AMS B and C, 40 kPa for CON_{farm}, 38 kPa for $MULTI_{farm}$ and 35 kPa for BIO_{farm} in the present studies. Thus, the mean vacuum reductions of IQS in that study can be compared with the mean reductions of the AMS,

CON_{farm}, BIO_{farm} and $MULTI_{farm}$ in the two studies undertaken at a flow rate of 4 l/min. The milking systems in the present two studies have, compared to the single teat cup unit of O"CALLAGHAN AND BERRY (2008), substantially smaller vacuum reductions in the b-phase and also, for some flow rates, smaller reductions in the d-phase. In the b-phase, the IQS showed reductions of 17.0 kPa at a flow rate of 4.0 l/min. In comparison, the mean vacuum reduction of the three AMS was 4.5 kPa. The mean reduction in the b-phase of BIO_{farm} and $MULTI_{farm}$ was, in comparison, 4.4 kPa and 4.3 kPa for CON_{farm}. Thus, the values from the study by O"CALLAGHAN AND BERRY (2008) were more than three times higher than all the values measured in the present study. Further, IQS showed, at a flow rate of 4.0 l/min in the d-phase, a vacuum reduction of 25.0 kPa was found, compared to a mean vacuum reduction of 7.2 kPa with the three tested AMS. In BIO_{farm} and $MULTI_{farm}$, the d-phase data with a mean of 18.5 kPa were similar to the IQS. In comparison, the CON_{farm} in that study showed, with 5.0 kPa, slightly lower values than the AMS. Additionally, ROSE-MEIERHÖFER ET AL. (2010b) found in milking-time tests a vacuum reduction of 10.0 and 10.1 kPa in the b-phase for CON and MULTI milking systems at a flow rate of 4.0 l/min, which applied to a conventional system with a claw volume of 300 cm^3 at a machine vacuum of 42 kPa. The machine vacuum of the MULTI was 39.5 kPa in that study. In comparison, in the present studies, the reductions in the b-phase were 4.4 kPa for the mean of the BIO_{farm} and $MULTI_{farm}$, 4.3 kPa for the CON_{farm} milking system and 4.5 kPa as the mean of the three AMS. Thus, the vacuum reductions in the b-phase measured in the CON and MULTI milking systems in the milking time tests of the former study show higher vacuum reductions of 5 – 6 kPa compared to the AMS, CON_{farm}, BIO_{farm} and $MULTI_{farm}$ systems in the present studies, as investigated by the Wet-test-method (ISO 6690, 2007). Here, it may be possible that the method of measurement and the machine vacuum of the milking systems could play a decisive role in understanding the differences among the very similar milking systems.

The data collected during both studies from Publications A and B verify the hypothesis (H_{AB}). In Publication A, the effect of the milking system on vacuum behaviour was significant only in some cases, but the interaction between the milk flow and the milking system was significant in all cases for vacuum fluctuations and reductions in the b- and d-phases, and a steady change in the flow rate over each cow"s complete milking process is imperative. Therefore, the effect of a changing flow rate is always interacting with the effect of the milking system used on farms. Thus, the parameter „milking system" represents the different tube system constructions of the six tested milking systems. The systems BIO_{farm}, CON_{farm} and $MULTI_{farm}$ in

Publication B showed a direct effect of the milking systems on the vacuum reductions, and the combined effect of the interaction between the flow rate and the system was not included in the statistical model in that study. Definitively, all the results from Publication B support for verification of H_{AB}. However, it is not only these results that verify H_{AB} but also those of BJERRING and RASMUSSEN (2002), who observed that the vacuum fluctuations at the teat-end are larger in AMS than in conventional milking systems. These authors noted that the blocking of the air intake still increases the vacuum fluctuations and that higher air intake leads to a higher content of free fatty acids in the milk but to lower vacuum fluctuations. These authors found that differently constructed milking systems had different effects on the vacuum fluctuations. Furthermore, the same authors found larger fluctuations in the AMS than in conventional systems. This observation is supported by the data in Table 2. For all flow rates and tested pulsation phases, with one exception, the vacuum reduction in the CON_{farm} was lower than in each of the three tested AMS. Thus, the construction has an effect on the vacuum behaviour. Moreover, large vacuum reductions are always connected to high vacuum fluctuations in milking systems. However, in addition to the confirmation of H_{AB}, another detail was revealed during the measurements. From the results, the claim could be made that high vacuum reduction should be attainable in the release phase, independent of the milk flow rates of the milking system.

Additional support for the verification of the hypothesis was noted by O'CALLAGHAN (2004) when he evaluated the effects of a milking unit on vacuum variation during simulated milking. He found that increasing the inner diameter of the long milk tube resulted in a significant increase in teat-end vacuum in the suction phase. His results are based on an experiment with several milking clusters. Further, ROSE ET AL. (2006a) found that, also in individual quarter milking systems (IQS), the inner diameter of the milk tubes has an influence on the teat-end vacuum. Additionally, RASMUSSEN ET AL. (2006) revealed that the AMS model and the water flow were the most important factors influencing vacuum fluctuations, which further confirms the present results. One counter-argument could be that of STRÖBEL ET AL. (2011b), who found, in a comparison of three different milk tube positioning settings tested with an IQS, that the change in tube position does not disturb a gentle milking process and desirable vacuum conditions at the teat end. However, in this comparison, the milk-tube lengths of all three settings were equal. Thus, the difference was one of tube position and was not related to the construction of the milking system used. Comparing the milking systems from both publications, as in Table 2, it can be stated that the vacuum reductions in the d-phase are the highest in the BIO_{farm} and $MULTI_{farm}$ for the flow rates shown. This is a result of the similar air-inlet technology of both systems and supports H_{AB} as well.

5.1.3 Conclusions from the vacuum behaviour measurements

The trueness of H_{AB} leads to the conclusion that there is potential to change the vacuum conditions in a desirable way if an electronic actuator is introduced into the milking systems. The actuator must be able to change the milk tube diameter. The effect is similar to a change in the construction of the milking system but can be adapted electronically as a high speed application. A further argument for the development of a vacuum control system is that there is often a negative effect on the teat-end vacuum conditions in individual quarter milking systems (IQS) with long and single guided milk tubes. Another argument for developing a control system is that the production of stable vacuum conditions, for example, by a control system, especially at the teat-connected part of the milking cluster, could prevent the damaging impact of vacuum fluctuations on udder health, according to VOGELAUER (1989). Further, in the same study, it was determined that stable vacuum conditions could prevent epithelial damages at the teat cistern and teat base, as well as an increased backflow of milk in the milking clusters. Consistent with these findings, TANCIN ET AL. (2007) showed a relationship between milk flow and pre-stimulation. They found that milking without pre-stimulation negatively influences the milk flow, not only at the beginning but also at the end of milking. The alveolar milk ejection induced by the release of oxytocin in response to machine milking during the entire milking procedure is an essential factor for rapid and complete milk removal in dairy cows. Additionally, milk removal can be disturbed under different conditions, at the central or peripheral level (TANCIN and BRUCKMAIER, 2001). For example, stress caused by pain from too high a vacuum at the teat-end, which could be avoided by a control system, can disturb the milk removal and thus hinder a successful milking process. The greatest foreseeable disadvantage of the control system will be the production costs and, in research, the risk of finding no solution to the control algorithm. However, the successful development of the milk-flow-based vacuum control system could yield great advantages for IQS and especially for AMS.

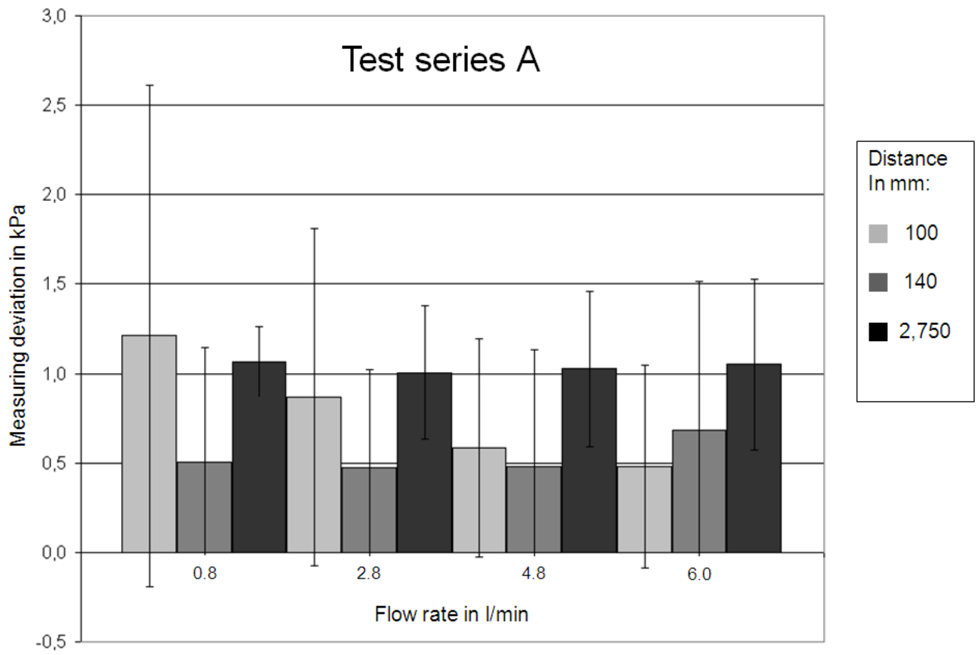
Thus, to summarise the findings from the two studies, it can be stated that H_{AB} is true and that the optimal vacuum adjustment at the teat-end in milking machines is essential for a successful milking process with low vacuum reductions and fluctuations in the b-phase and with a short decline phase of the milk flow curve at the end of the milking processes. Consequently, the control of the vacuum reductions in the b-phase remains necessary, and fluctuations in the d-phase are mainly a result of high vacuum reductions in this phase. The control of the whole teat-end vacuum conditions should be conducted with a flow-based vacuum control system. Further, it could be shown from Publication A that the control system will be of great importance for automatic and individual quarter milking systems.

5.2 Development of sensor technology

The hypothesis (H_C) of the second part of this dissertation was that a vacuum measurement with test casings, close to the teat-ends, allows a vacuum measurement that is precise enough to measure the teat-end vacuum for control of the teat-end vacuum behaviour of the milking system.

5.2.1 Results from the development of the sensor technology

In Publication C, a technical solution for the permanent installation of pressure sensors close to the teats was created for use in the Multilactor® milking system or in other individual quarter milking systems. To evaluate the developed test casing with the introduced pressure sensor (test series A) compared to a conventional and often-used measuring method for collecting the milk tube vacuum data (test series B), an experimental design was built as described in chapter 4.2.3.



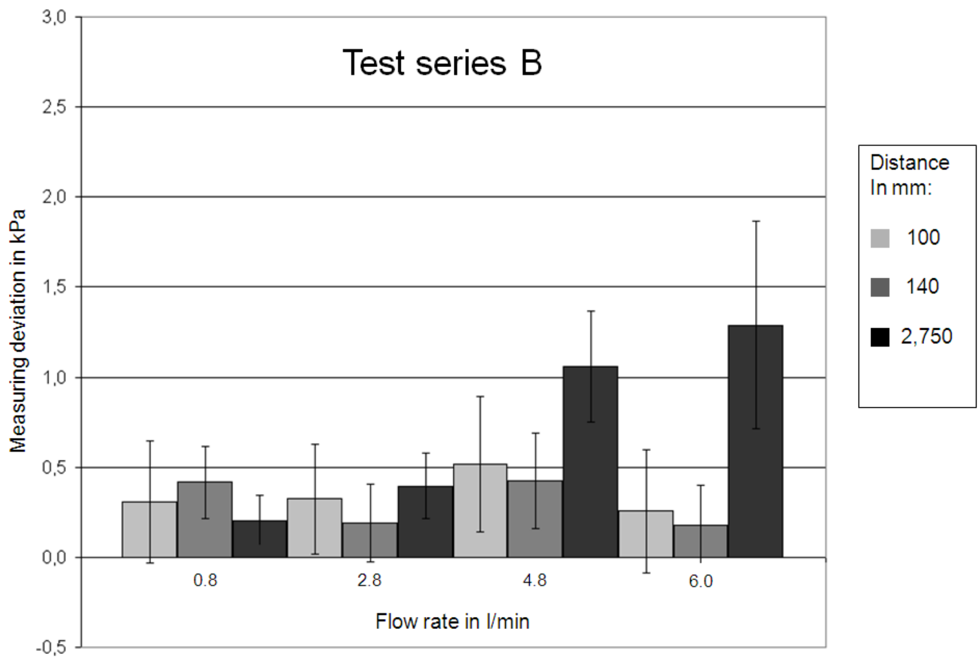


Figure 4: Measuring deviation on the test set-up of test series A and B at different flow rates and at different distances to the teat cup (Publication C).

The present study shows that, generally, measurement within a casing-inserted pressure sensor (test series A) is possible, and such installation of pressure sensors into the milk tube can occur with the constructed casing in a cost-efficient way (Publication B).

Thus, it has been found that the mean of the measuring deviation, at test series A at each flow rate, was less than 1.25 kPa and, at test series B, was less than 1.30 kPa (Publication C), which is approximately 3.7% of the machine vacuum when the vacuum is 35 kPa, as it was during the tests (Figure 4). By comparing the mean of all flow rates and all distances in test series B, a lower measuring deviation has been found compared to test series A. The standard deviations at all flow rates were higher in test series A than in B (Publication C). Furthermore, it was shown in test series B at a distance of 2,750 mm that there are higher measuring deviations with higher flow rates. In test series A, the lowest deviation has been found at a distance of 140 mm on average, for all flow rates. In test series B, the difference between the deviations of all the tested distances is not high, with the exception of the distance of 2,750 mm. There has been a great difference in the deviation and in the standard deviations in test series B. Over all tests, the values of the repetitions that were conducted are consistent from both test series (Publication C). By comparing the test series, the measurement with the conventional and often-used measurement method (test series B) showed in almost all cases a lower measuring deviation, compared to test series A with the developed sensor casing. However, in sum, the measuring deviations with a maximum of 1.3 kPa were low for both test series.

The proof of the principal functionality was examined statistically in Publication C. In Table 3, the calculation results for the measuring deviations are tabulated. The type 3 test for fixed effects showed that the influence of test series and the influence of distance have a significant effect on the measuring deviation. The flow rate has no significant effect.

Table 3: Type 3 test for the fixed effects of the measuring deviations in two test series (A and B) for vacuum measurements, determined by a linear model (taken from Publication C).

Effect	Den DF	F-Value	Pr > F	Significance
Test series	41	12.48	0.0010	s.*
Flow rate	41	0.45	0.7214	n. s.^{n}
Distance	41	10.0	0.0003	s.*

* Significant at the 0.025 alpha level; n Not significant at the 0.025 alpha level;

Both test series were not perfect and are different from the ideal case, which would show a 0.0 kPa deviation. Test series A leads to an estimated effect of 0.74 kPa on the deviation, and test series B leads to an effect of 0.42 kPa compared to the ideal case. Thus, the mean values of both test series show an estimated standard error of 0.0064 kPa. By comparing test series A and B in general, it can be stated that in test series B, there are significantly lower deviations. Thus, the conclusion from these results was that the casing with the sensor should be optimised (Publication C). The optimisation was conducted by the Impulsa AG (Elsterwerda, Germany) together with studies from the Leibniz Institute for Agricultural Engineering Potsdam Bornim (ATB).

Because of the good results that were achieved in measuring the deviation in the total values (maximum 1.30 kPa) compared to the reference method and because of the requirement for a frequent production of the test casings, these casings were modified to be used in the final prototype of the vacuum control system. The sensors were installed permanently at the Multilactor® milking system in improved and modified sensor casings made of synthetic material

(Figure 5). The new and easier-to-calibrate sensors allow a measurement at the Multilactor® milking system casings. That second prototype of the test casing was constructed as a permanent vacuum-measuring system for milk tubes with an inner diameter of 10.0 mm, which as especially useful in all types of individual quarter milking systems. The technology of that measuring system is similar to the above-mentioned prototype one of the sensor casing in Figure 2 (test series A). The four sensors of the measuring system were also manufactured by Keller Druckmesstechnik GmbH (Jestetten, Germany) (KELLER DRUCKMESSTECHNIK GMBH, 2008) and have the same capability characteristics as the sensors in the above-mentioned prototype one measuring system with test casings. The most important difference between the two prototypes is that the casing prototype two is much less expensive to produce, and damaged sensor can be replaced more easily. Further, the casing is more resistant to hard shocks caused by the cow. Moreover, the calibration and the corresponding software interface is much more user friendly compared to the prototype one sensor casing system. The sensor system is now fully integrated into the Impulsa AG herd management system. In future more measurement data from that sensor system will be collected. Assuming that these data will show a positive result, the sensor system can also be introduced to a milking system at a distance of 2,750 mm to the teat end. Therefore, a calculated relationship will allow a rough estimation of the teat-end vacuum values by measuring the vacuum at the quarter-individual milk tube in a distance of approximately 2,750 mm to the teat end.

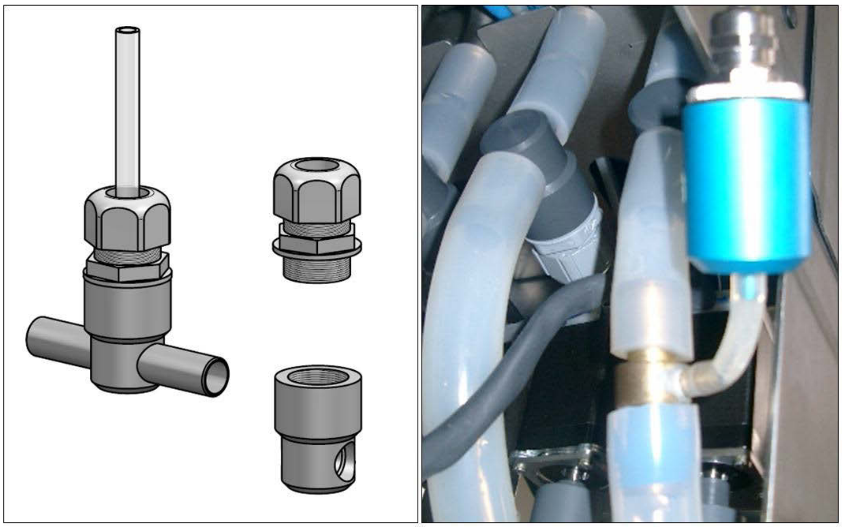


Figure 5: Prototype two of vacuum sensors in test casings, as a drawn and inserted into the Multilactor® milking system (Sources: IMPULSA AG, 2010).

5.2.2 Discussion of the development of sensor technology

The presented results of the total and per cent measuring deviation, found in the prototype one vacuum measurement system with test casings (test series A) will be considered in relationship to the vacuum differences and measuring deviations that have been collected in previous studies. For example, ROSE ET AL. (2006a) determined that in some conventional milking clusters, the vacuum reduction can increase to 14 kPa at a machine vacuum of 42 kPa. If there is a measuring deviation of approximately 1.0 kPa between the tested sensor and the reference, the result is sufficient for the development of a permanent, online, teat-end vacuum control system. Even with this measuring deviation, a large share of the vacuum reduction can be prevented with the vacuum control system, and therefore the mean vacuum level with a vacuum control system can be adjusted to a much lower level, especially at low flow rates, compared to the mean vacuum values that have been identified by ROSE ET AL. (2006a). Both arguments support the verification of hypothesis H_C, that a vacuum measurement with test casings that are close to the teat-ends allows a vacuum measurement that is precise enough to yield the input signals for a vacuum control system. On the other hand, the higher measuring deviation of the test casing in test series A compared to the reference method in test series B suggests that the recorded vacuum measurement is not precise enough and should be improved. Thus, H_C would not be supported. However, it must also be stated that the teat-end vacuum data that are measured should not serve to calculate the exact milk flow, as performed by ICAR- (International Committee for Animal Recording) certified milk meters. To the contrary, the data should serve only to estimate the milk flow in an approximate way. Furthermore, the absolute value of the measured mean vacuum level in kPa, measured with the help of the casings, also gives important information that is precise enough to determine if the vacuum is too high for the udder of a cow. Further, the measured mean vacuum level gives information on whether the teat-end vacuum level is acceptable in the relevant phase of the milk flow curve during the milking process. For that purpose, a maximum deviation of 1.3 kPa is acceptable. Therefore, the measurement with the casing of test series A is sufficiently precise.

Even the ICAR field test for the approval of milk meters allows a measurement deviation of equal to or less than 3% (relative to the total milk yield of a cow) between a cow‟s milk yield measured by a milk meter and that measured by a reference method using a milk can on an approved balance. That 3% rule is stated in the ICAR guidelines (ICAR, 2011). The results for the test-series A sensor in the casing, in comparison, showed that for all measurements with a distance of 140 mm, a maximum measuring deviation of only approximately 2% (relative to the machine vacuum of 35 kPa, adjusted in the test set-up). These facts further support the verification of hypothesis H_C that the developed measuring system is sufficiently precise because the reported measuring deviation is lower than the deviation required by ICAR. Moreover, currently available milking systems offer no possibility for continuous measuring and control of the vacuum from the teat cup. Thus, the developed vacuum control system for the teat-end vacuum has theoretically the potential to minimise the cost of the milking process (Publication C). Therefore, to introduce a permanent vacuum measurement system to milking machines, the measuring accuracy found in test series A is high enough for the first attempt to develop such a technology. Another argument for the relevance of the developed sensor casing is that the vacuum data measured by the reference system always have a small measuring mistake, even if it is measured at the same measuring point. The employed MilkoTest MT52 measuring device (System Happel GmbH, Friesenried, Germany) has an accuracy of ± 0.1 kPa, given in its manual, while a measuring accuracy of ± 0.6 kPa is required by ISO 6690 (2007). However, the manual also reveals that the measuring accuracy easily can change to ± 1.0 kPa, for example, if the sensors of the device are confronted with extreme hot or cold (not certified) temperatures. A final argument for a more positive evaluation of the deviations in test series A, compared to B, is that during the tests, the measurements were begun simultaneously in series B and with a time delay in series A. The time delay could be corrected in a self-developed Microsoft Excel data sheet, but the time delay could not be completely avoided during the preparation of the results. The Microsoft Excel data sheet is based on a mathematic algorithm, which shifts the compared two vacuum curves against each other, by minimising the deviations between the two vacuum curves. The differences in the starting procedure resulted because both compared sensors in test series B were connected to the device MT52. Thus, the measurements began automatically and simultaneously. In contrast, in series A, the starting procedure must be fulfilled manually at two measuring devices, at the tested device and at the reference device, which was the above-mentioned MilkoTest MT52.

Other arguments for the as-soon-as-possible use of the sensors in casings are the following: For the vacuum reductions, the purpose of the complete control system is to reach values such as those RASMUSSEN AND MADSEN (2000) reported for milking at low vacuum. Additionally, the control system should be realised in a way that the teat-end vacuum is much lower at low milk flow rates and in the release phase compared to the suction phase because machine–on time will only slightly increase during milking at low vacuum, if the low vacuum is only produced for the noted time-intervals in the release phase. There are also arguments for the acceptance of the developed measuring system with test casings (test series A) because it is the basis for enabling the vacuum control system. The highest measuring deviation at test series A at different flow rates is 1.30 kPa. Research on a vacuum control system should be pursued with the casing developed for that study because there are different ways to improve the measuring results, for example, with a mathematical error reduction model (Publication C). Consistent with that, KAUFMANN and UHR (2002) stated that knowledge regarding the measurement of animal reactions with sensor-based methods is, in some disciplines of animal production, still not sufficiently used. For example, in some cattle producing farms, it is still usual that some of the data are collected by human observation. Thus, the development of more online-sensors such as those used in test series A, will improve the efficiency and precision of the milk production. Additionally, there are some arguments for the use of the prototype two test casings rather than those of prototype one: Thus, in prototype two, the sensors are protected from undesired teat cup fall-offs and do not disturb the farmer during the changing of the teat cup liners. A final general argument for the use of the measuring system, even when it has not reached the best possible accuracy, is that the sensor in the casing can be introduced into the milk tube completely and that it is robust and will not be damaged from the rough environment around the teat cup.

5.2.3 Conclusions from the development of sensor technology

Most of the discussed results support the validity of H_C, leading to the conclusion that the developed measuring system with sensors in casings is ready for use for observing the teat-end vacuum under farm conditions. These systems also can be used as an important part of a planned vacuum control system. In the series of measurements to detect the accuracy of the used sensors in casings, it was shown that an installation with a sensor casing was possible because the mean values of measuring deviations had a maximum of 3.5 % relative to the machine vacuum. Therefore, the basis for developing a vacuum control system with four sensor casings as signal transmitters was developed in Publication C. Moreover, TANCIN ET AL. (2006) found that vacuum modifications and cow preparation for milking could play an important role for the milkability of cows. In detail, the vacuum settings along with the cow preparations greatly influence the milkability of the cows in the decline phase of the measured milk flow curves at the quarter level. The duration of the decline phase seems to be an important variable in the physiological response of dairy cows to milking machines. Thus, a teat-end vacuum system could also influence the duration of the decline phase of the milk flow curve in a positive way by adjusting, higher or lower, the teat-end vacuum, depending on the udder morphology of the cow‟s udder. In conclusion, the sensor technology should be introduced much more frequently in animal and dairy productions to achieve greater efficiency, and most of the above-shown arguments support the validity of hypothesis H_C and the fact that the completely developed test casings with sensors produce accurate and relatively precise vacuum values.

To summarise the findings from Publication C and of the qualitative evaluation of the sensor casing of prototype two, it can be stated that only small but significant differences in the measuring deviation between both mentioned test series exist. However, in all, the total measuring deviations have been found to be such low values that the usability of the measuring system is evidenced with the help of Publication C. From two other studies (ROSE ET AL., 2006a; ICAR, 2011), it is supported that H_C is correct and that the optimal vacuum adjustment at the teat-end in milking machines it is essential for a successful milking process with low vacuum reduction and fluctuations in the b-phase. The control of all of the teat-end vacuum conditions should be performed with the help of the developed vacuum measuring system. Further, Publications A and B showed that the control system will be of high importance for automatic and individual quarter milking systems.

5.3 Development of actuators and control technology

The hypothesis (H_{DE}) of the third part of this dissertation was that a change in the cross sectional areas in the four single-guided milk tubes influences the vacuum conditions at the teat-end of each quarter and results in more possibilities for the control of the teat-end vacuum. The valves for changing the cross sectional areas in the milk tubes were introduced at the casing of the Multilactor® milking system during that experiment.

5.3.1 Results from the development of the control technology

In Publications D and E, the technology developed for controlling the teat-end vacuum was evaluated. Two different prototypes of vacuum control valves (VCV) in the laboratory seemed to point to success for reducing the vacuum in the milk tube. Both were examined more closely. In Publications D and E, the Wet-test-method (ISO 6690, 2007) in combination with two different prototypes of the vacuum control valve was used (Table 4), all of which were installed after or instead of the shut-off valve in the Multilactor® milking system. The exact placement is shown in Figure 3 (chapter 4.3.3). Therefore, finding the exact cross sectional areas in the different described vacuum-control-valve prototypes (VCV) was critical to establishing the desired vacuum reduction result at the teat end. A technical drawing of the employed VCV is given in Publications D and E. The throttling effect of the VCV for the evaluated vacuum behaviour in the Multilactor® with and without vacuum control unit and the measured results are presented in Figure 6. The condition "without vacuum control system" in that context shows that the control system was switched off during these measurements. Thus, the VCV was generally in the position "tube cross section area is completely open" (opening diameter = 10 mm), when the condition "without control system" was measured.

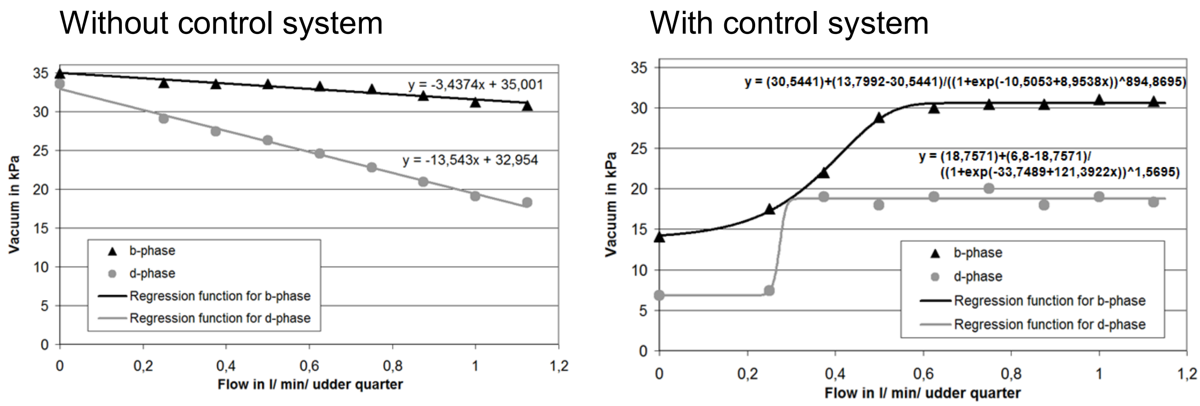


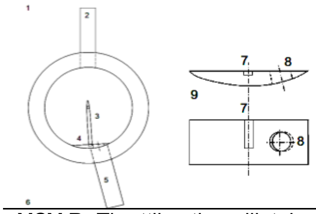
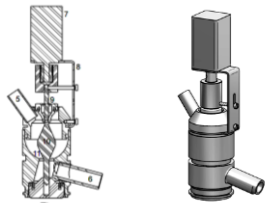
Figure 6: Comparison of the vacuum behaviour in the Multilactor® milking system for different milk flow levels, measured with and without the vacuum control system (STRÖBEL ET AL., 2011a).

The comparison of both diagrams in Figure 6 shows that there is clearly a reduction in the teat-end vacuum caused by the online analysis and control system that results from having low- or medium-level milk flows. The vacuum at low flow rates, especially for flow rates under 0.6 l/min per quarter, is much lower for the suction (b) and for the release (d) phase. For example, for a flow rate of 0.4 l/min per quarter, a mean vacuum of only approximately 22 kPa was found in the suction phase “with control system”, when in the case “without control system”, a mean vacuum of approximately 34 kPa was found. In the release phase, the mean vacuum “with control” was at a level of approximately 19 kPa, and approximately 27 kPa was found “without control”. At flow rates under 0.4 l/min per quarter, the differences between the controlled and uncontrolled case was even greater, which makes sense because a high vacuum is not necessary to transport the milk at low milk flow rates. The low vacuum in these parts of milking obviates high stress on the teat tissue of the cow. To the contrary, in the uncontrolled case at the low flow rates, a mean vacuum in the suction phase that is nearly as high as the machine vacuum of the milking system was found. Moreover, for the flow rates higher than 0.6 l/min per quarter in the suction phase, a high vacuum also in the case “with control”, similar to the machine vacuum, was found to be required, allowing for a fast milk supply for the cow and a time-efficient milking process, in the controlled case. Furthermore, a very effective vacuum reduction at the teat-end was reached in the case of low milk flows. Therefore, at present, the developed vacuum control system in a Multilactor® milking system is, for the first time, a milking system that controls the vacuum analogue to the milk flow, instead of the other way around.

In Publications D and E, three vacuum control models were developed. The three developed control models have been the basis of the software production for the online vacuum control system. All three models are presented in greater detail in Publication D. Therefore, the model functions for the adjustable mean vacuum data were calculated. All the model functions have been adapted to the given vacuum data, with the help of the statistic software JMP 8.0 (SAS Institute, Cary, USA). For calculating the regression functions, the procedures “analysis” and “modelling” or “model adaptation” have been used for models 1 and 3 in the publication. The linear regression models for model 2 and for the model “without control” have also been adapted using Microsoft Excel in both publications. For model 1, a polynomial function has been identified, and for variant 3, a logistic 5p-function has been used and adapted using an iteration process. The generalised logistic function is widely used as a flexible sigmoid function for growth modelling. This function extends the possibilities of the well-known logistic curves (RICHARDS, 1959). The details of the model functions and of the adjusted coefficient of determination used to compare the quality of the “function adaption” are presented in Publication D. In this dissertation, only the best of the three control models is given in comparison to the condition “without control” (Figure 6).

Another result of the development efforts was comparison of the advantages and disadvantages of the different constructions for the different control valves, which were shown in Table 4. Additionally, for both VCV, it was possible to develop a control model, which was needed to provide important information that was used in creating the software for the complete control system. In Table 4, VCV B was found to be the more suitable valve, and it could be considered to be a further development of VDV A. After selecting the better VCV, the completion of the online-analysis and control system for the teat-end vacuum could start. The evaluation of both of the employed VCV prototypes is given in Table 4. Thus, the decision to further improve VCV B was made with the help of the evaluation in Table 4.

Table 4: Schematic representation and evaluation of both of the tested vacuum control valves (VCV), according to BLE (2010).

Schematic representation and description	Advantages	Disadvantages	Evaluation
VCV A: Throttling the milk tube with installation of sliding cores that have different borehole diameters. 	- During laboratory testing, it is suited for searching for the optimal borehole sizes for controlling the teat-end vacuum. - Allows only a finite number of different borehole sizes. Source: Siliconform GmbH & Co. KG. and STRÖBEL ET AL. (2011a)	- Using the VCV is not possible in combination with an electric motor. - A change of the sliding cores with borehole requires much time. - The borehole sizes cannot be changed finitely.	The VCV A is most suitable for laboratory tests but not very well suited for dynamic controlling purposes.
VCV B: Throttling the milk tube with horizontal motion of a valve tappet.  Source: Impulsa AG and STRÖBEL ET AL. (2011a)	- It is possible to adjust the opening area in the valve very exact - It is possible to readjust each tappet position repeatedly in a short period of time. - Allows an infinite number of different adjustable opening areas (sizes). - The VCV is adapted to fluidic and flushing requirements. - The VCV can fulfil an additional function in the Multilactor®. - The VCV can easily be operated electronically by a computer.	- Before the VCV are available in series production, the production costs are higher for VCV B as for VCV A.	During the development of VCV B, the experience in development with VCV A has been used. Thus, VCV B is well suited for controlling the vacuum.

Moreover, the control unit with the above-mentioned sensors in an again-optimised test casing (prototype two) and the four valves of the prototype VCV B were built and installed in the latest type of the Multilactor® milking system. Figure 7 shows the latest version of VCV B when it is introduced to the Multilactor®.

Figure 7: Essential parts of the vacuum control system with the sensors, with the vacuum control unit and with the four actuators (the four vacuum control valves) are shown in the figure (STRÖBEL ET AL., 2011a).

As a final result, the complete vacuum control system was produced as a combined hardware and software solution by Impulsa AG (Elsterwerda, Germany) ordered by the ATB. This was not a direct but rather an indirect result of this dissertation because without the model data and experiments, the complete technical realisation of the control system would not have been possible. To show a complete picture of the efforts, it is important to understand that the theoretical work resulted in a completely new prototype of a Multilactor® unit in the laboratory of the ATB. As a starting point, the calculations from the previous model calculations and results were used. The final control system was programmed so that it is possible to change the essential basic settings in the software, allowing for full adjustment of the control parameters to the specific device and the conditions in the milking parlour. The noted possibilities for changing the settings could be defined as calibration of the vacuum control system. The block diagram for the finished vacuum control system is presented in Figure 8. With that block diagram, all functions of the currently realised vacuum control system are explained.

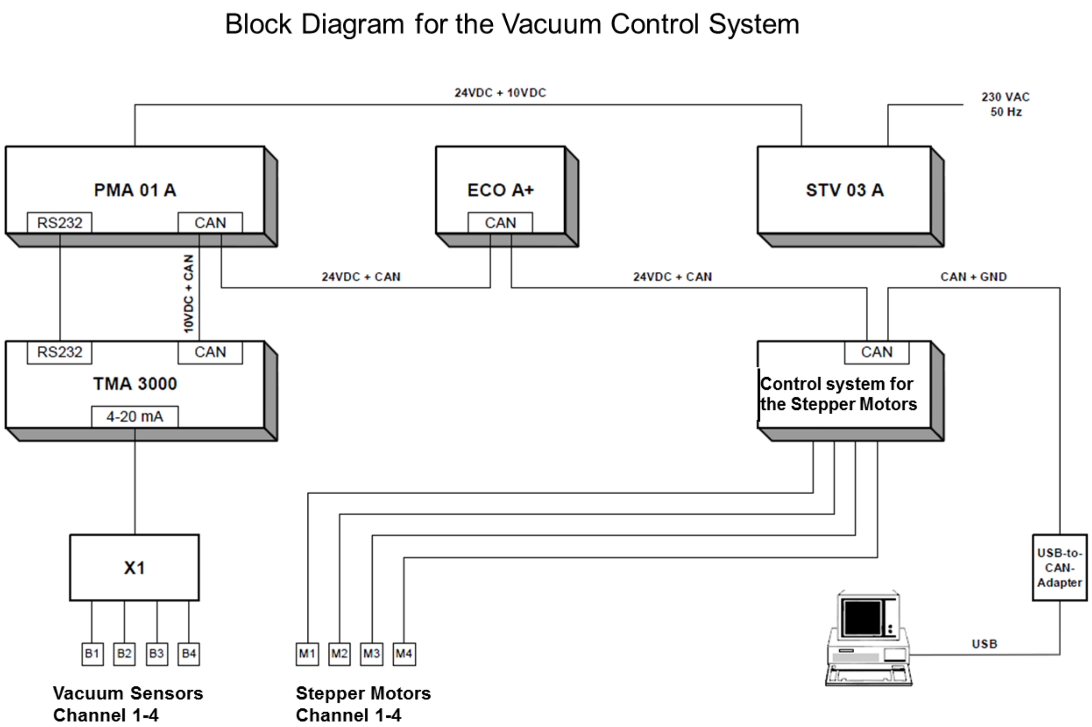


Figure 8: Block diagram for the vacuum control system. This system is fully integrated into the herd management system of the Impulsa AG (Source: IMPULSA AG, 2011).

5.3.2 Discussion of the development of control technology

A comparison and discussion of the data gathered by simulating the effect of the vacuum control system with the data from previously evaluated milking systems shows the advantages and disadvantages of the control system that was developed during the work for this dissertation. Additionally, the validation or rejection of the hypothesis (H_{DE}) will be decided here. In an earlier study, ROSE-MEIERHÖFER ET AL. (2010b) found a vacuum reduction in the suction phase (b) of 10.4 kPa at a flow rate of 1.13 l/min per udder quarter in milking-time tests, for a conventional cluster. The claw volume was 300 ccm. Further, the machine vacuum was adjusted to 42 kPa. The reduction of 10.4 kPa was compared to the results measured in the $MULTI_{lab}$ with control system, where a vacuum reduction of only 4.0 kPa was found, measured both in the b-phase and at the same flow rate. Thus, it could be shown that the control system can prevent vacuum reductions in the b-phase and that is has an influence on the teat-end vacuum. Therefore, H_{DE} is supported by the presented data. For the b-phase, it is true that a high vacuum reduction, which occurs especially at high milk flow rates, leads to teat cups falling off and to a delay in the milking duration of cows (WORSTORFF, 1976; REINEMANN ET AL., 2001; HAMANN, 1987b). Furthermore, in the official ISO test (ISO 6690, 2007) for milking systems, the vacuum reductions must be below a defined level. Thus, the control system is progressive and can help prevent vacuum applications of milking systems that do not meet the requirements of ISO 6690 (2007). Furthermore, another argument for the useful application of the developed control system is that low flow rates do not require a high vacuum for the transportation of the milk to the receiver (Publication D). Thus, a high vacuum at lower flow rates (under 0.5 l/min per quarter) is not necessary for the transportation of the milk and may result in damage to the teat tissue. The ability of the system to produce low teat-end vacuum at low flow rates and high vacuum at high flow rates also supports H_{DE} and the statement that the control system has much greater potential to control the teat-end milking vacuum. Thus, when the control system is introduced to a milking system, over-milking can occur only with a strongly reduced teat-end vacuum. Moreover, currently available switch-off functions for avoiding over-milking can remove the milking cluster only, when the slowest quarter is properly milked out and not earlier (Publication D).

In 2008, O'CALLAGHAN and BERRY investigated a single guided milking system (SGS), which was developed at their institution. The system was installed in a parlour with high line installations. In this prior study, the machine vacuum was 50 kPa for SGS (O'CALLAGHAN and BERRY, 2008). $MULTI_{lab}$ with control system works with a vacuum of 35 kPa. The vacuum situation is compared at a flow rate of 1.0 l/min per quarter. A comparison of the 2008 data of O"CALLAGHAN and BERRY with data produced by the simulated vacuum control system, developed in this dissertation, was undertaken and shows the following results: In the b-phase, the measured mean vacuum reduction in per cent of the machine vacuum were 34.0% for SGS and 11.4% for $MULTI_{lab}$ with the control system. In the d-phase, the reduction was 50% for SGS and 45.7% for $MULTI_{lab}$ with control, indicating that in the b-phase, $MULTI_{lab}$ with control has a much lower vacuum reduction (Publication D). Thus, $MULTI_{lab}$ has a lower vacuum consumption and is, in this view, more effective at the same milking vacuum. Additionally, the energy consumption to obtain the same level of teat-end vacuum in b-phase is lower. Thus, SGS required a high machine vacuum because of the very high reduction in the b-phase. The result of a high machine vacuum in state of the art milking systems is always a too-high vacuum in the d-phase. The vacuum in the b- and d-phase is always affected by the machine vacuum in the system. The absolute value of the mean vacuum in the d-phase was 25 kPa for SGS and 16 kPa for $MULTI_{lab}$ with control. Thus, even when the per cent reduction in the d-phase is very similar for both systems, the mean vacuum in the d-phase in SGS was much too high, compared with the requirements of the mentioned optimal vacuum curve, collected from a literature review.

Many of the currently available milking systems have no major vacuum reduction in the d-phase, as a major vacuum reduction is produced with the vacuum control system. Furthermore, ROSSING ET AL. (1985) found in an investigation among high-yielding cows, that yields over 12 kg per milking had a negative effect on the total milk production. ROSSING and HOGEWERF (1997) concluded from this that it is increasingly desirable for high-yielding dairy cows to be milked more than twice a day. Thus, the machine-on time in total has increased with high-yielding cows. A gentle milking process is therefore essential for such cows. These cows should be protected from unnecessary strain caused by too high a vacuum, as suggested by IDF (1994). To summarize, a comparison of the results from Publication B with the vacuum conditions produced by MULTI with a control system has also been conducted. This study showed vacuum reductions at a flow rate of 0.25 l/min per quarter in the d-phase of 2.2 kPa for CON_{farm} and of 5.4 kPa for the Biomilker® in the laboratory (Table 2). In the $MULTI_{lab}$ with the control system (Figure 6), the reduction in the d-phase at the same flow rate is 28.0 kPa. Thus, the strain on the teats at low flow rates is much less when the control system is used. Especially for low milk flow rates, this result is also true compared to teat-preserving milking technologies, such as the Biomilker® and SystemHappel® technologies (System Happel® GmbH, Friesenried, Germany). At higher flow rates, similar vacuum reduction effects have been found in the mentioned teat preserving milking systems. Additionally, the data from Publication B, compared with the data of $MULTI_{lab}$ with the control system, support H_{DE}. The teat-end vacuum in $MULTI_{lab}$ with control is influenced by the position and cross sectional area in the vacuum control valve, and $MULTI_{lab}$ with control offers greater possibilities for a proper adjustment of the teat-end vacuum behaviour of that milking system.

5.3.3 Conclusions from the development of the control technology

The results and discussion in the third part of this dissertation leads to the following conclusions for the entire study: All the results from the third section of this dissertation show that the hypothesis (H_{DE}) could be confirmed by all the data gathered in Publications D and E. The vacuum can be adjusted very precisely by the tested vacuum control valve, by a change in the cross-sectional area as the opening area in that valve. Furthermore, the data from the literature show that a permanently acting vacuum control system is urgently needed because there are still many studies that report poor teat conditions caused by milking technique. Another fact from the results in chapter 5.3.1 is that the developed vacuum control system is already far along in the technical realisation process (Figure 7 and 8). The conclusion from this is that the technical realisation of the system should be continued and completed without delay and that the introduction to farms should begin as soon as possible. Thus, many of the presented arguments confirm the fact that the developed vacuum control system is at the moment the best alternative for controlling the teat-end vacuum that could soon be used on farms (Publication D).

6 CONCLUSIONS

The present dissertation shows that in future, research is needed to further improve the already innovative individual quarter milking technique with vacuum control system. A more precise vacuum application as developed in this dissertation should be introduced to more milking systems on the market. To find a technical solution for that objective, it will be necessary to separate the milking vacuum and the adhesive vacuum in milking machines completely. In detail, the conclusions from this dissertation are the following:

- Within the investigated AMS, the AMS B showed, in general, the vacuum conditions that are most close to the stated optimal teat-end vacuum curve. A still suboptimal vacuum condition for all AMS is the still-too-high vacuum in the d-phase at low flow rates.
- $MULTI_{farm}$ and BIO_{farm}, investigated in the Publication B have a positive effect as follows: The reduction of the mean vacuum level in the d-phase, as the flow rate increases, provides an effective massage to the teat, but that effect should also be available at lower flow rates.
- The produced vacuum conditions in $MULTI_{lab}$ “with” a control system are closer to the stated optimal vacuum curve, compared to the vacuum conditions in the other investigated milking systems such as AMS A, B and C in Publication A and as $MULTI_{farm}$, CON_{farm} and BIO_{farm} in Publication B.
- The developed vacuum-sensing system can be used for detecting teat cups, which are kicked off by the cows.
- The developed vacuum-sensing system can also be used to control the pulsation pattern in almost every milking system.
- The sensor system with test casings (prototype one) still works properly but should be improved before integration into the vacuum control system can occur. The improvement was partly performed during the dissertation, and a prototype two sensing system was developed, equipped with a better calibration system for the vacuum sensors. However, the prototype two sensing system should be evaluated once again to be sure that it also works properly.
- The $MULTI_{lab}$ “with control” produces better milk-flow-related data for the teat-end vacuum than the $MULTI_{lab}$ “without vacuum control”. Further, the system “with

control" meets much better the requirements of the concept of the optimal teat-end vacuum curve.

- With the developed vacuum control system, milking machines are able to produce a constant or increasing mean teat-end vacuum in the b- and d-phases of the pulsation cycle at varying flow rates.
- Further, it can be assumed that the identified relationships for a vacuum as a function of opening area in the valve and flow rate are also correct for all identically constructed Multilactor® milking systems ($MULTI_{lab}$) and for all vacuum control valves, which are constructed similar to the used valves.
- The control system should be evaluated in farm experiments to determine if there is a positive effect on the udder health, teat condition and milkability, as assumed during the development process. In the near future, the system should be launched to the market.

7 SUMMARY

Major progress was made in modern dairy farming in recent years. Animal health, housing conditions and cow performance have been increased. More Online- Sensors have been developed and used in farms. Some of them can detect udder infections very early and others can distinguish between usable and faulty milk. But in addition to the progresses, there are some avoidable strains to the teat tissue of cows, characterised by callous ring formation at the teat ends, hyperkeratosis and tissue hardenings that remain big problems by today and can cause tremendous economic losses. In many cases strained teat tissue promotes udder infections. Moreover there are various reasons for strain on the teat tissue. But still today, the teat tissue is strained too much and that can be caused by disproportionately high vacuum conditions at the teat end. The disproportionately high vacuum is frequently produced by not optimal adjusted milking systems.

On the basis of this inventory, it was the main objective of this dissertation to develop a vacuum control system for the teat-end milking vacuum that can react in short time intervals. The teat-end milking vacuum in a milking system should be adjusted by the control system in a way that there are constant low mean vacuum reductions in the suction phase. In contrast in the release phase the control system should provide flow related vacuum reductions.

In wet-tests performed according to (ISO 6690, 2007), several individual quarter milking systems in the laboratory and practical milking parlours were evaluated in terms of their associated teat-end vacuum conditions. Then, several vacuum measuring and actuator systems for controlling the teat-end vacuum were tested in a laboratory milking parlour. The most important result of the studies was that the general concept for a teat-end vacuum control system was developed and a prototype of that system could be produced. Moreover, some important requirements for an optimum teat-end vacuum were revealed during that work. The developed concept for the planed vacuum control system suggests that it is possible to reduce the mean teat-end milking vacuum in the suction phase to 20 kPa at a flow rate of 0.25 l/min per udder quarter. At higher flow rates of 1.5 l/min and more per udder quarter, the teat-end vacuum is similar to the machine vacuum with a mean value of approximately 30 kPa. Therefore, for the first time, it is possible to supply a high teat-end vacuum at a high and a low teat-end vacuum at low milk flow rates in a milking system. The essential results of this dissertation were published in 4 reviewed journal papers and in a submitted patent specification.

In the future, the developed vacuum control system should be adapted for technical introduction to all types of popular individual quarter milking systems. Thus, it can be widely used under farm conditions, and the system can help in treating the teat tissue of the cows with care. Further, the effects of the system on teat condition and milkability should be evaluated in a farm test. In the long term, a technology should be developed to adjust the adhesive force and the vacuum required for the milking process, independently of each other. With such a development, the teat-end vacuum could be adjustable in a much wider range in comparison to the present situation.

8 ZUSAMMENFASSUNG

In der Milchviehhaltung wurden in den letzten Jahren viele Fortschritte erzielt. Die Haltungsbedingungen wurden verbessert und die Leistung der Tiere konnte gesteigert werden. Beim Melken werden immer mehr Online- Sensoren eingesetzt, die z. B. Eutererkrankungen frühzeitig erkennen oder die schadhafte Milch absondern. Neben den vorhandenen Fortschritten sind vermeidbare Belastungen des Zitzengewebes bei Kühen, wie z. B. Ringbildungen, Hyperkeratosen und Verhärtungen auch heute noch ein großes Problem das bedeutenden wirtschaftlichen Schaden verursacht. Eutererkrankungen werden häufig durch geschädigtes Zitzengewebe begünstigt. Für Schädigungen des Zitzengewebes gibt es vielerlei Gründe. Aber auch heute noch entstehen diese Schädigungen durch übermäßig starke Vakuumbelastung an der Zitzenspitze und damit durch nicht optimal angepasste Melktechnik.

Aufgrund dieser Bestandsaufnahme war es das Hauptziel dieser Arbeit, ein Vakuumregelungssystem für das zitzenendige Melkvakuum zu entwickeln das in engen Zeitabständen reagiert. Das zitzenendige Melkvakuum soll durch die Regelung einen konstant niedrigen Vakuumabfall in der Saugphase aufweisen. In der Entlastungsphase des Pulszyklus soll die Regelung dagegen einen hohen milchflussunabhängigen Vakuumabfall erzeugen.

Bei Nassmessungen nach (ISO 6690, 2007) wurden mehrere viertelindividuelle Melksysteme im Melklabor und in Praxisbetrieben in Bezug auf ihr zitzenendiges Melkvakuum untersucht. Nachfolgend wurden mehrere Vakuummess- und Aktorsysteme zur Vakuumbeeinflussung im Melklabor untersucht. Die wichtigsten Ergebnisse der Untersuchungen bestehen darin, dass die grundlegende Konzeption für ein Vakuumregelungssystem gefunden und ein Prototyp gebaut werden konnte. Weiter wurden bedeutende Anforderungen an ein optimales zitzenendiges Melkvakuum erarbeitet. Das Konzept für das entwickelte Vakuumregelungssystem lässt erwarten, dass das mittlere zitzenendige Vakuum in der Saugphase auf 20 kPa, bei einem Milchfluss von 0,25 l/min/Euterviertel reduziert werden kann. Bei hohen Milchflüssen von 1,5 l/min/Euterviertel und mehr wird das Vakuum in derselben Phase hingegen auf einen Mittelwert von 30 kPa eingestellt. Damit kann erstmals ein hohes Melkvakuum bei großen und ein niedriges Melkvakuum bei kleinen Milchflüssen erreicht werden. Die wesentlichen Ergebnisse der Arbeit wurden in 4 referierten Journalbeiträgen und einer eingereichten Patentschrift veröffentlicht.

In Zukunft sollte das entwickelte Vakuumregelsystem für alle häufig vorkommenden viertelindividuellen Melksysteme angepasst werden, damit es breiten Eingang in die Praxis findet und zur Schonung des Zitzengewebes beitragen kann. Das entwickelte Regelungssystem soll in allen viertelindividuellen Melksystemen zum Einsatz kommen. Dafür wurde es entwickelt. Außerdem sollte die Wirkung des Systems in einem Praxisversuch untersucht werden. Langfristig muss weitergeforscht werden, damit das Haft- und Melkvakuum am Melkbecher getrennt voneinander eingestellt werden kann. Damit kann das zitzenendige Melkvakuum noch umfangreicher als bisher gestaltet werden.

9 LIST OF REFERENCES

The list of references is given for the pages 2 to 65 of this dissertation. The references of the publications A to E are given within these documents always at the end of each document.

Amirante, P., Bianchi, B., Montel, G. L. (2005): Dynamic tests during cow milking with different types of milk meters. Veterinaria Italiana 41 (1): 68-78.

Bjerring, M., Rasmussen, M. D. (2002): Vacuum fluctuations in the liner during automatic milking. Proceedings, First North American Conference on robotic milking, Toronto, Canada, pages: 64-66.

BLE (Bundesanstalt für Landwirtschaft und Ernährung) (2010): Zwischenbericht zum Projekt OASE, Berichtszeitraum 01.01.2010 bis 31.12.2010, Projektförderkennzeichen 511-06.01-28-1-33.004-07, erhältlich bei der BLE, Bonn.

Brunsch, R., Scholz, V. (2003): Individuelle Wasserversorgung von Rindern an einer Photo-voltaik-Weidezentrale. Landtechnik 58 (6): 396-397.

van den Berg, K., Beije, M., inventors, Maasland N. V., assignee. (2007): A method of automatically milking animals. European patent, No.: 1 186 229 B1. Submission date: 2007.03.07.

Davis, M. A., Maltz, E., Reinemann, D. J. (2000): Consideration of teat morphology and milking characteristics for robot milking conditions. In: Robotic Milking, Proceedings of the International Symposium held in Lelystad, The Netherlands, 17.-19. August 2000, pp. 56-59.

Fahr, R., v. Lengerken, G. (2003): Milcherzeugung. Grundlagen, Prozesse, Qualitäts-sicherung, Frankfurt/M.: DLG-Verlag.

Flückinger, E., Hodel, O., de Martini, F. (1979): Vergleichende Untersuchungen über Druck- und Strömungsverhältnisse in Zitzenbechern verschiedener Melksysteme, Milchpraxis, 17 (2): 66-69.

Geidel, S. (2002): Mensch, Kuh und Technik im Takt. Sonderheft Rind, Neue Landwirtschaft 13 (11): 32-34.

Halachmi, I. (2009): Simulating the hierarchical order and cow queue length in an automatic milking system. Biosystems Engineering 102 (4): 453-460.

Hamann, J. (1982): Zum Transfer von Mastitiserregern in Abhängigkeit vom Melksystem. Milchwissenschaft 37 (5): 285 – 286.

Hamann, J., Dück, M. (1984): Modifikationen von Melksystemen und Mastitisprävention. Milchwissenschaft 39 (1): 12-15.

Hamann, J. (1987a): Machine Milking and Mastitis Section 3: Effect of Machine Milking on Teat-end Condition – A Literature Review. Bull. Int. Dairy Fed. 215: 33-53.

Hamann, J. (1987b): The role of machine factors in the aetiology and pathogenesis of mastitis. Hohenheimer Arbeiten. Research on Milk Production, Stuttgart, Germany, pages 22-56.

Hamann, J. (2001): Zum Einfluss von Haltungssystemen auf Eutergesundheit und Milchqualität. Rinderproduktion 43: 25-54.

Hamann, J., Bronzo, V., Moroni, P., Casula, A., Zecconi, A. (2001): Conventional and positive pressure pulsation effects on bovine teats and on immunological components of different milk fractions. Milchwissenschaft 56: 423-427.

Harms, J. (2009): Automatisches Melken – Stand der Technik und Entwicklungstendenzen. ART-Schriftenreihe 9: 105-113. Eigenverlag, Reckenholz-Tänikon ART.

Häussermann, A., Hartung, E. (2010): A Field Study on Teat-End Vacuum in Different Milking Systems and its Effect on Teat Condition. Proceedings, Precision Dairy Management. The First North American Conference on Robotic Milking, 02.-05.03.2010, Toronto, Canada, pages 226-227.

Hermann, A. (1990): Entwicklung eines digitalen Messsystems zur simultanen Erfassung der Pulsierung der Zitzengummibewegung und des Drucks auf die Zitze im Melkzeug. Dissertation Universität Hohenheim, Stuttgart, Germany.

Hoefelmayr, T., Maier, J. (1980): Vom klassischen Zweiraumbecher zum Bio-Milker. Sonderdruck.

ICAR (International Committee for Animal Recording) (2011): International Agreement of recording practices, Section 11 - ICAR Rules, Standards and recommendations for testing, approval and checking of milk recording devices. Guidelines approved by the General Assembly held in Riga. Latvia on June 2010: pp. 295

IDF (International Dairy Federation) (1994): Teat tissue reactions to machine milking and new infection risk. Bulletin of the International Dairy Federation 297. IDF-FIL General Secretariat, Brussels, Belgium.

Impulsa AG (2010): Datenblatt zum Vakuumerfassungs- und Vakuumsteuerungssystem für das Projekt OASE. Datenblatt, Elsterwerda, Germany.

Impulsa AG (2011): Datenblatt zum Blockschaltbild der Vakuumregelung für das Projekt OASE. Datenblatt, Elsterwerda, Germany.

ISO 6690 (2007): Milking machine installations - mechanical tests. International Organization for Standardization.

ISO 5707 (2007): Milking machine installations - constructions and performance. International Organization for Standardization.

ISO 3918 (2007): Milking machine installations – Vocabulary. International Organization for Standardization.

Maris, U., Roe, K. (2004): Milk in the news. In: Meijering, A., Hogeveen, H., de Koning, C. J. A. M., Automatic Milking - a better understanding. Wageningen Academic Publishers, Wageningen, Netherlands, pages 27-36.

Kaufmann, C., Kündig, H., Binder, H., Thun, R. (1996): Messung von Stressparametern bei Nutztieren mittels aktiver Telemetrie, Schweizer Archiv für Tierheilkunde 138 (5): 234-240.

Kaufmann, O., Uhr, K. (2002): Rechnergestützte Tierüberwachung in der Mutterkuhhaltung. Landtechnik. 58 (1): 46-47.

Keller Druckmesstechnik GmbH (2008): Angebot für piezoresistive Drucktransmitter PR-8LY (Offer for piezoresistive pressure transmitter PR-8LY). Datenblatt (Data sheet), Potsdam, Germany.

Lincke, K. (1999): Euter sind keine Maschinen. DLZ, Jg. 50, H. 12, S. 66-69.

Mein, G. A. (1992): Chapter 4: Action of the cluster during milking. Machine Milking and Lactation, 97 – 140. Chapter 7: Basic mechanics and testing of milking systems. Machine Milking and Lactation, 235 – 272. Eds.: A. J. Bramley, F. H. Dodd, G. A. Mein und J. A. Bramley, Insight Books, Berkshire, Great Britain.

Mein, G. A., Williams, D. M., Reinemann, D. J. (2003): Effects of milking on teat-end hyperkeratosis: 1. mechanical forces applied by the teatcup liner and responses of the teat. Proceedings, 42nd annual meeting of the national mastitis council, 26.-29.01.2003, Fort Worth, USA.

Nosal, D., Bilgery, E. (2002): Lärm und Vibrationen als Stressfaktoren beim Melken. Agrarforschung, Band 9 (1): 4-7.

Nyhan, J. F. (1968): The effect of vacuum fluctations in milking machines. Symposium on Machine Milking, Shinfield, Reading, England. pp 70ff.

O"Callaghan E. J. (2004): Effects of the design of a milking unit in vacuum variations during simulated milking. Irish Journal of Agricultural and Food Research 43: 237-245.

O"Callaghan, E. J., Berry, D. (2008): A note on the design and testing of single teat cups for automatic milking systems. Irish Journal of Agricultural and Food Research 47: 205-209.

Ordolff, D. (1991): Melkzeuge und deren Eigenschaften aus der Sicht der Praxis. Milchpraxis 29 (2): 216-220.

Ordolff, D. (2008): The History of the Milking Machines: From Bucket Milking to Milking Robots. Yearbook Agric. Engineering (Jahrbuch Agrartechnik) 20: 260-267.

O"Shea, J., O"Callaghan, E. (1980): Effect of vacuum fluctuations and liner slip on new infection rates. Proceedings, International Workshop on Machine Milking and Mastitis, Moorepark, Ireland, pages 6 -18.

Petterson, T., inventor, DeLaval Holding AB, assignee. (2009): Method and arrangement for controlling the milking by a milking machine. European patent, No.: 2 033 511 A2. Submission date: 2009.03.11.

Querengässer, J., Geishauser, T., Querengässer, K., Bruckmaier, R., Fehlings, K. (2002): Untersuchungen zu Milchfluss und Milchmenge aus Zitzen mit Milchabflussstörungen. Praktischer Tierarzt 83 (11): 1008-1016.

Rabold, K., Aksen, T., Horb, R., Marschatz, H. H. (2003): Eutergesundheit und Qualitätsmilch-Service. DeLaval.

Rasmussen, M. D., Madsen, N. P. (2000): Effects of Milkline Vacuum, Pulsator Airline Vacuum, and Cluster Weight on Milk Yield, Teat Condition, and Udder Health. Journal of Dairy Science 83 (1): 77-84.

Rasmussen, M. D., Wiking, L., Bjerring, M. and Larsen, H. C. (2006): Influence of air intake on the concentration of free fatty acids and vacuum fluctuations during automatic milking. Journal of Dairy Science 89: 4596-4605.

Reinemann, D. J., Davis, M. A., Costa, D., Rodriguez, A. C. (2001): Effects of Milking Vacuum on Milking Performance and Teat Condition. Proceedings, AABP- National Mastitis Council. International Symposium on Mastitis and Milk Quality, 13-15.09.2001, Vancouver, Canada.

Reinemann, D. J., Davis, M. A., Maltz, E. (2002): The significance of individual teat morphology and physiology on milking performance: Possibilities offered by automatic milking. The first North American Conference on Robotic Milking, 20.-22.03.2002, IV-97-IV-99, Toronto, Canada.

Reinemann, D. J. (2010): Review of some of the potential benefits of quarter-milking. Proceedings, International Workshop the future of the quarter individual milking, 14-15.09.2010, Potsdam, Germany, pages 7-15.

Richards, F. J. (1959): A flexible growth function for empirical use. Journal of Experimental Botany 10: 290-300.

Rose, S., Brunsch, R., Huschke, W., Klimetschek, H.-J. (2004): Kraftübertragung vom Melkzeug auf die Zitze. Bornimer Agrartechnische Berichte 36/2004, High-Tech-Innovationen für Verfahrensketten der Agrarproduktion, Statusseminar, 29.- 30. September 2003, IHK Potsdam.

Rose, S. (2006): Untersuchung mechanischer Belastungen am Euter bei verschiedenen Melksystemen (Evaluation of mechanic forces on the udder with different milking systems). Dissertation, Berlin, Germany. Forschungsbericht Agrartechnik des Arbeitskreises Forschung und Lehre der Max-Eyth-Gesellschaft Agrartechnik im VDI (VDI-MEG) Nr. 436. Eigenverlag, Berlin.

Rose, S., Brunsch, R., Huschke, W. (2006a): Single tube guiding in conventional milking parlours. Proceedings, XVI CIGR World Congress Agricultural Engineering for a better world, 03-07.09.2006, Bonn, Germany, pages 455-456.

Rose, S., Brunsch, R., Schröter, K., Huschke, W., Klimetschek, H. (2006b). Adaptability of milking clusters to different udder formations in different milking systems. Agrartechnische Forschung 12: 53-58.

Rose, S., Brunsch, R. (2007): Viertelindividuelles Melken in konventionellen Melksystemen. Landtechnik 62 (3): 170-171.

Rose-Meierhöfer, S., Ströbel, U., Müller, A. B., Brunsch, R. (2010a). Vorteile ohne Sammelstück (Advantages without claw). Neue Landwirtschaft 21 (10): 64-66.

Rose-Meierhöfer, S., Hoffmann, G., Öz, H., Ströbel, U. and Ammon, C. (2010b): Milking-time tests in conventional and quarter-individual milking systems. Landbauforschung - vTI Agriculture and Forestry Research 60 (1): 11-15.

Rossing, W., Hogewerf, P. H. (1997): State of the art of automatic milking systems. Computers and Electronics in Agriculture 17: 1-17.

Rossing, W., Ipema, A. H., Veltman, P. F. (1985): The feasibility of milking in a feeding box. IMAG-DLO, Institute of Agricultural Engineering, Wageningen, Netherlands. Research Reports 85 (2): 39 pp.

Sagkob, S., Rudovsky, H-J., Pache, S., Herrmann, H-J. and Bernhardt, H. (2010): Auswirkungen verschiedener Melkzeuge auf Zitzenkondition und Milchabgabeparameter (Effects of different milking clusters on teat condition and milkability parameters). Landtechnik 65 (1): 27-30.

Schlaiß, G. (1994): Einfluss von modifizierter Zitzengummibewegung auf Milchabgabeparameter und zyklische Vakuumschwankungen. Dissertation Universität Hohenheim, Stuttgart, Germany. Forschungsbericht Agrartechnik des Arbeitskreises Forschung und Lehre der Max-Eyth-Gesellschaft Agrartechnik im VDI (VDI-MEG) Nr. 255.

Schön, H., Wendel, G., Pirkelmann, H., Artmann, R., van Hoven, F., Stumpenhausen, J., van Leeuwen, M., Hagting, J., Osthues, U., Bruckmaier, R. M., Meyer, H. D. (2000): Automatische Melksysteme. Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V., KTBL-Schrift Nr. 395.

Spohr, M., Wolf, K., Hesslinger, A. (1996): Beurteilung der Melktechnik durch den praktischen Tierarzt 7/1996: 635-638.

Ströbel, U., Rose-Meierhöfer, S., Ammon, C., Brunsch, R. (2009): Quarter individual milking with Multilactor® in milking parlours. Landtechnik 64 (2): 106-108.

Ströbel, U., Rose-Meierhöfer, S., Brunsch, R., Zieger, E., Maier, J., Hatzack, W., inventors, Leibniz Inst. for Agr. Engineering Potsdam-Bornim, applicant (2011a): Verfahren und Kit zum automatischen Melken von Tieren (Method and Kit for automatic milking of animals). Official Identification, No.: 10 2011 075 138.6. Submission date: 2011.05.03.

Ströbel, U., Rose-Meierhöfer, S., Samer, M., Brunsch, R (2011b): Effect of the milk tube position on the teat-end vacuum condition in the Multilactor® milking system. In: Lokhorst, C.; Berckmans, D. (eds.): European Conference on Precision Livestock Farming ECPLF, 11.07.-14.07., Prague (Czech Republic), Proceedings, pp. 528-535.

Tan, J., Janni, K. A., Appleman, R. D. (1993): Analysis of vacuum systems. Journal of Dairy Science 76: 2204-2212.

Tan, J., Reinemann, D. J. (1994): Frequency characteristics of vacuum fluctuations in milking systems. American Society of agricultural engineering, St. Joseph, USA, ASAE Paper No. 94-3569.

Tancin, V., Bruckmaier, R. M. (2001): Factors affecting milk ejection and removal during milking and suckling of dairy cows. Vet. Med. - Czech 46: 108-118.

Tancin, V., Ipema, B., Hogewerf, P., Macuhova, J. (2006): Sources of Variation in Milk Flow Characteristics at Udder and Quarter Levels. Journal of Dairy Science 89: 978-988.

Tancin, V., Uhrincat, M., Macuhova, J., Bruckmaier, R. M. (2007): Sources of Variation in Milk Flow Characteristics at Udder and Quarter Levels. Czech Journal of Animal Science 52 (5): 117-121.

Thiel, C. C. (1968): Forces acting on the teat. Proceedings, Symposium on Machine Milking, National Institute for Research in Dairying (NIRD) Shinfield, Reading, Great Britain.

Thiel, C. C., Mein, G.A. (1979): Action of the cluster during milking. Eds.: Thiel, C.C. and Dodd, F.H., Machine Milking. National Institute for Research in Dairying (NIRD) Shinfield, Reading, Great Britain, pages 116-155.

Thompson, P. D., Pearson, R. E. (1983): Milk droplet impacts during induced vacuum fluctuations: Influence of claw and other characteristics. Journal of Dairy Science 66: 562 – 572.

Tolle, A, Heeschen, W., Hamann, J. (1977): Grundlagen einer systematischen Bekämpfung der subklinischen Mastitis des Rindes. Kieler Milchwirtschaftliche Forschungsberichte 29. Nr.1.

Umstätter, C., Kaufmann, O. (2001): The importance of process control in relation to udder quarters in milk production. Proc. 5th Conference "Construction, Engineering and Environment in Livestock Farming", Stuttgart, Germany, 6.-7.03.2001, pp. 230-235.

Umstätter, C. (2002): Tier-Technik-Beziehung bei der automatischen Milchgewinnung. Dissertation, Humboldt-Universität zu Berlin.

Vogelauer, R. (1989): Praxisgerechte Melkmaschinenprüfung nach ÖNORM. In: Internationale Mastitistagung, St. Georgen Längsee, Kärnten, Österreich, 29. Mai bis 2. Juni 1989, Tagungsbericht, Teil 1 Vorträge, S. 123-128.

Walser, K. (1966): Untersuchungen über die Beeinflussung der Eutergesundheit durch die Melkmaschine. Zbl. Vet. Med. (A), Jg. 13, S. 149-230.

Wehowsky, G., Tröger, F. (1994): Milchgewinnung. In: Wendt, K., Bostedt, H., Milke, H. & Fuchs, H. W. (Hrsg.): Euter- und Gesäugekrankheiten. Gustav Fischer Verlag, Stuttgart.

Whittlesstone, W. G., Twomey, A., Crawley, W. E. (1972): The milking machines as vector for mastitis infections: I. The inter unit transmission of microorganisms. Milchwissenschaft 27 (10): 618 – 620.

Worstorff, H., v. Baer, H., Reichmuth, J., Zeidler, H., Tolle, A. (1972): Die Melkanlage als Vektor der Mastitis-Infektion: II: Zur Übertragung pathogener Mikroorganismen innerhalb von Tieren. Milchwissenschaft 27 (10): 620-626.

Worstorff, H. (1976): Einfluss von Vakuumschwankungen in Melkanlagen auf Pulsierung und Eutergesundheit (Effect of vacuum fluctuations in milking plants on pulsation and udder health). Landtechnik 12: 528-530.

Worstorff, H., Heinl, B., Auernhammer, H., Stanzel, H., Prediger, A. (1982): Optimierungsarbeiten mit konstanter bzw. kontrollierter Vakuumapplikation zur Milchabgabe bei Kühen. Milchwissenschaft 37 (4): 216 – 219.

Worstorff, H., Fischer, R. (1999). Ursachen und Lösungen für Mängel bei Anlage- und Melkvakuum. Milchpraxis 37 (2): 85 – 89.

Worstorff, H., Fischer, R. (2000): Die Bewegung des Zitzengummis besser verstehen. Milchpraxis 38 (2): 82-87.

Worstorff, H. (2001): Melktechnik auf dem Weg zur Vollautomatisierung - Chancen und Risiken. Milchpraxis 39: 134-139.

APPENDIX A

A

Analysis and evaluation of the teat-end vacuum conditions in different automatic milking systems (Publication A)

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Ströbel, U., Rose-Meierhöfer, S., Öz, H., Entorf, A. - C., Popp, L. & Brunsch, R.

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Analysis and evaluation of the teat-end vacuum condition in different automatic milking systems

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The number of automatic milking systems (AMSs) installed worldwide shows an increasing trend. In comparison to the preliminary models, new versions employ more sophisticated sensor technology than ever before. The originally developed AMSs were characterised by larger vacuum fluctuations and vacuum reductions than conventional milking systems. The objective of this study was to find out whether this situation still holds or if an improvement has occurred. The vacuum behaviour at the teat end of an artificial teat during simulated milking was measured in a study that involved different AMS types (AMS A, B and C). Each system was tested over a range of flow rates (0.8 to 8.0 L/min). The wet-test method was used and teat-end vacuum behaviour was recorded. At a flow rate of 4.8 L/min, the lowest vacuum fluctuation (6.4 kPa in b-phase) was recorded for AMS A, while the lowest vacuum reduction (3.5 kPa in the b-phase) was obtained for AMS B. AMS C yielded higher values for vacuum reduction and vacuum fluctuation. Consequently, it was concluded that AMS A and B, in terms of construction and operational setting (vacuum level), are more appropriate than AMS C. Nevertheless, high values for vacuum reduction or fluctuation have a negative effect on the teat tissue. Hence, one of the future challenges in milk science is to develop a control system that is able to allow fine adjustments to the vacuum curve at the teat end.

Keywords: Fluctuation; phase; quarter individual; reduction; wet-test-method

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APPENDIX B

B

Comparison of the vacuum dynamics of conventional and quarter individual milking systems (Publication B)

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TARIM BİLİMLERİ DERGİSİ — JOURNAL OF AGRICULTURAL SCIENCES 16 (2010) 162-168

Comparison of the Vacuum Dynamics of Conventional and Quarter Individual Milking Systems

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ABSTRACT

The effect of machine milking on udder health has been recognized for the past 100 years. Among different milking systems, a new quarter individual milking system called the Multilactor® (MULTI) has been developed to eliminate some detrimental effects of conventional milking systems (CON) and conventional systems with periodic air ingress (BIO) on udder health. The objective of this study was to determine the effects of milk flow on average liner vacuum during the b and d phases of pulsation in all systems by using a wet-test method defined in ISO 6690 (2007). Measurements were conducted in three different milking parlours where CON, BIO and MULTI were installed separately. It was found that, at an average flow rate of 4.8 l min^{-1}, the average vacuum in the liner during the b-phase was 35.0 kPa in CON, 32.6 kPa in BIO and 31.1 kPa in the MULTI system, compliant with the desired average vacuum in the liner of 32-42 kPa mentioned in ISO 5707 (2007). The average liner vacuum values during the d-phase differs from one system to another and these values were calculated to be 34.2 kPa, 12.3 kPa and 14.8 kPa for CON, MULTI and BIO, respectively. The reason why CON differs as compared to MULTI and BIO can be attributed to the fact that both, MULTI and BIO use the BioMilker system that allows periodic air ingress under the teat.

Keywords: Liner vacuum; Pulsation; b and d-phase; Vacuum reduction

Geleneksel ve Pençesiz Sağım Sistemlerinin Vakum Dinamiklerinin Karşılaştırılması

ESER BİLGİSİ

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Geliş tarihi: 10 Şubat 2010, Düzeltmelerin gelişi: 11 Eylül 2010, Kabul: 27 Ekim 2010

ÖZET

Geçen 100 yıl boyunca sağım makinasının meme sağlığı üzerine etkileri farkedilmiştir. Farklı sağım sistemleri arasında, geleneksel sağım sistemlerinin (CON) ve periyodik hava girişi olan geleneksel sağım sistemlerinin (BIO), meme sağlığı üzerindeki zararlı etkilerini ortadan kaldırmak amacıyla Multilactor (MULTI) adı verilen yeni bir pençesiz sağım sistemi geliştirilmiştir. Yapılan bu çalışmanın amacı, ISO 6690 (2007)'da tanımlanmış yaş deneme yöntemini kullanarak, üç sağım sisteminde nabız hareketinin b ve d fazlarında ortalama meme lastiği vakum basıncı değerine, süt debisinin etkisini belirlemektir. Ölçümler CON, BIO ve MULTI sağım sistemlerinin ayrı ayrı kurulu olduğu farklı sağımhanelerde gerçekleştirilmiştir. 4.8 l min^{-1} sağım debisinde, b fazı sırasındaki ortalama meme

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APPENDIX C

C

Comparison of two vacuum recording methods in a quarter individual milking system (Publication C)

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Comparison of two vacuum recording methods in a quarter individual milking system

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Abstract: The purpose of this study is to develop an approach for introducing a pressure sensor into the milk-tube of a milking system. The purpose for installing a permanent sensor (Test series A) was to measure the vacuum in the milk-tube as precise as it is possible in a certified external vacuum measuring system (Test series B). After calculation of the vacuum deviation at each simultaneously measured data pair, an evaluation was possible. Thus, the most important result of this study was the significant difference in the measuring deviation between test series A and B. At a flow rate of 0.8 l/min and at a distance of 100 mm between teat end and measuring point the deviation for test series A was 0.74 kPa and for test series B was 0.42 kPa. However, the measuring deviation is higher and consequently the quality of measuring is slightly lower in test series A. For this reason, the construction work for developing a vacuum control system with permanently installed pressure sensors and online measurements of vacuum was carried out. But the constructed casing should be improved to reach a lower measuring deviation. Whether this system is applicable for vacuum controlling after an improvement step or not, depends on the measuring deviation estimated by comparing vacuum at the teat end and under the teat cup. First results show a mean measuring deviation between both measuring points of about 1.0 kPa. Online vacuum controlling at the teat end can improve udder health and milk quality.

Keywords: Vacuum, milking system, quarter individual, control

المقارنة بين طريقتين تسجيل فراغ في نظام الحلب الفردية الربع

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الملخص: إن الغرض من هذه الدراسة هو وضع نهج لإدخال جهاز استشعار الضغط في أنبوب الحليب بنظام الحلب. وكان الغرض من أجل تثبيت جهاز استشعار دائم (اختبار سلسلة أ) لقياس الفراغ في أنبوب الحليب كما هو ممكن في نظام فراغ خارجي معتمد قياس (اختبار المجموعة ب). بعد حساب الانحراف للفراغ في كل زوج قياس البيانات في وقت واحد، كان تقييم ممكن. وهكذا ، فإن أهم نتيجة لهذه الدراسة الفرق كبير في الانحراف بين اختبار قياس سلسلة أ وب في معدل تدفق 0.8 لتر / دقيقة وعلى مسافة 100 مم بين نهاية الحلمة ونقطة قياس الانحراف عن اختبار وسلسلة 0،74 لاختبار سلسلة ب كان 0،42 كيلو باسكال. ومع ذلك، فإن قياس الانحراف هو أعلى، وبالتالي قياس نوعية أقل قليلا في سلسلة اختبار أ ولهذا السبب ، تم تنفيذ أعمال البناء لتطوير نظام التحكم في الفراغ مع مجسات ضغط مثبتة بشكل دائم والقياسات على الانترنت من خارج الفراغ. ولكن ينبغي أن تحسن غلاف شيدت من أجل التوصل إلى الانحراف أقل قياس. إذا كان هذا النظام ينطبق على السيطرة على فراغ بعد خطوة تحسن أم لا، يعتمد على قياس الانحراف يقدر بمقارنة فراغ في نهاية حلمة وتحت كأس حلمة. النتائج الاولية تظهر الانحراف يعني قياس بين كل نقطة قياس من حوالي 1.0 كيلو باسكال. يمكن السيطرة على الفراغ في نهاية حلمة الضرع وذلك بتحسين الصحة ونوعية الحليب.

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APPENDIX D

Development of a computer-based control system for the teat-end vacuum in individual quarter milking systems (Publication D)

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Ströbel, U., Rose-Meierhöfer, S., Öz, H. & Brunsch, R.

D

Computers and Electronics in Agriculture 2011

Development of a computer-based control system for the teat-end vacuum in individual quarter milking systems

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The milking technique used in dairy farms has an important impact on both the health of the dairy cows and the economic condition of the milk production. Progress in sensor technique and electronics has led to a decrease in the costs of such equipment. Additionally, good udder condition, lower frequency of udder disease and an extended service life of dairy cows will secure the competitiveness of modern dairy farms. Therefore, the objective of this study was to develop a teat-end vacuum control system with individual quarter control reaction. Based a review of the literature, this system is assumed to protect the teat tissue. The results of this study indicated that the developed system in this study was able to control the vacuum in a three-second cycle, depending on the milk flow rate. This system brings the reduction of the teat-end vacuum in the milking phase (b) to a level of 20 kPa at a flow rate of 0.25 l min^{-1} for one quarter possible. At flow rates higher than 1.50 l min^{-1} for one quarter, the teat-end vacuum can be controlled to a level of 30 kPa, because in this case it is desirable to have a higher vacuum for exhausting the milk. With this system it is possible for the first time to supply the teat-end with low vacuum at low flow rates and with higher vacuum at increasing flow rates. This system operates on the individual udder quarter and automatically controls the milking vacuum at reasonable costs. In currently available milking machines, increasing flow rates always cause vacuum reductions.

Keywords: Vacuum control system; fluctuation; reduction; milk flow rate; teat-end;

Bibliographic Data of Publication D:

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APPENDIX E

Verfahren und Kit zum automatischen Melken von Tieren (Method and Kit for automatic milking of animals) (Publication E)

Submitted to the Deutsches Patent- und Markenamt (German Patent and Trademark Office), Official Identification, No.: 10 2011 075 138.6., Submission date: 2011.05.03.

Ströbel, U., Rose-Meierhöfer, S., Brunsch, R., Zieger, E., Maier, J. & Hatzack, W., inventors, Leibniz Institute for Agricultural Engineering Potsdam-Bornim, applicant.

E

Zusammenfassung

Die vorliegende Erfindung betrifft ein Verfahren zum Melken von Tieren, umfassend einen Schritt i), bei dem man den Wert des zitzenendigen Vakuums in einer Melkvorrichtung, unter den beim Melken herrschenden Betriebsbedingungen von Vakuum und Pulszyklus, bei verschiedenen Melkströmen ermittelt, wobei man mittels eines Vakuumregelventils das im Milchschlauch herrschende Vakuum verändert, und einen Schritt ii), bei dem man während des Melkens das zitzenendige Vakuum mittels des Vakuumregelventils auf einen Sollwert einstellt. Weiterhin betrifft die Erfindung ein Kit zur Durchführung des Teilschritts i) des erfindungsgemäßen Verfahrens.

Zur Zusammenfassung gehört Fig. 1.

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Titel: Title:	Verfahren und Kit zum automatischen Melken von Tieren (Method and Kit for automatic milking of animals)
Erfinder: Inventor(s):	Ströbel, U.; Rose-Meierhöfer, S.; Brunsch, R.; Zieger, R.; Maier, J.; Hatzack, W.
Anmelder: Applicant:	Leibniz-Institut für Agrartechnik Potsdam-Bornim e. V. (Leibniz Institute for Agricultural Engineering Potsdam-Bornim)
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APPENDIX F

Translated summary of Publication E

The submitted patent in this work is available only in German. Therefore, the summary of the submitted patent is given in the appendix, translated into English. The summary was translated by Ulrich Ströbel:

The present submitted patent relates to a method for milking animals. The invention comprises a step i), in which the value of the teat-end vacuum in a milking apparatus and preconditions of milking applications of pulsation and vacuum at different milk flows can be measured. Furthermore, it is possible to change the vacuum in the milk tube by a vacuum control valve (VCV). Further, the present submitted patent relates to a second step ii), in which the teat-end vacuum can be controlled to a target value during the whole milking process by a vacuum control valve (VCV). Moreover, the invention relates to a „Kit" for the processing of step i) within the invented process (Publication E).

APPENDIX G

Contribution of the authors to the included publications

All the publications are written primarily by the first author. The contributions of the co-authors are as follows:

Publication A

Sandra Rose-Meierhöfer and Reiner Brunsch applied for and received the funding for the study. Sandra Rose and Ann-Christin Entorf helped conduct the measurements at the farms and institutions with the automatic milking systems. Further, all authors and especially Sandra Rose-Meierhöfer and Hülya Öz interpreted and discussed the findings, and they helped very much in improving the English language and with the statistical analyses. Ulrich Ströbel wrote the first drafts of the manuscript, worked on all of the processing steps of the publication and contributed 45% of this publication.

Publication B

Sandra Rose-Meierhöfer and Hülya Öz initiated the study and the funding for the study. Hülya Öz, Sandra Rose-Meierhöfer, Christian Ammon and Ulrich Ströbel conducted the measurements at a dairy farm in Remptendorf, Germany. Further, Hülya Öz produced the first draft of the manuscript and devoted much work to further improvement of the manuscript. Additionally, all authors and especially Christian Ammon and Hülya Öz interpreted and discussed the findings. Ulrich Ströbel conducted the first data acquisition and produced the first figures for the publication that were later improved by all authors. Thus, Ulrich Ströbel contributed 15% of the work to that publication.

Publication C

Sandra Rose-Meierhöfer and Reiner Brunsch initiated the funding for the study. Ulrich Ströbel conducted the measurements at the ATB laboratory milking parlour, together with an internship student. Further, all authors and especially Sandra Rose-Meierhöfer interpreted and discussed the findings, and they helped to greatly improve the English language and with the statistical analyses. Ulrich Ströbel wrote the first draft of the manuscript, worked in all of the processing steps of the publication and contributed 75% to this publication.

Publication D

Sandra Rose-Meierhöfer and Reiner Brunsch initiated the funding for the study. Ulrich Ströbel conducted the measurements at the ATB laboratory milking parlour for this study. Further, all authors and especially Hülya Öz and Sandra Rose-Meierhöfer interpreted and discussed the findings, and they helped to greatly improve the English language and with the statistical analyses. Ulrich Ströbel organised the necessary vacuum control valves for conducting the measurements during a research project, consulted with manufacturers to produce and improve the prototype of the control valve, wrote the basic drafts of the manuscript, worked during all processing steps of the publication and contributed 75% of the work towards the submitted publication.

Publication E

This submitted patent publication is closely related to Publication D. Sandra Rose-Meierhöfer and Reiner Brunsch initiated the funding that made the submitted publication possible. Before conducting the first measurements, Ulrich Ströbel was consulted, particularly by Jakob Meier and by Egbert Zieger, in relation to improving the vacuum control valve that was used in all tests for the study. Ulrich Ströbel conducted the measurements at the ATB laboratory milking parlour for this study. Further, all authors interpreted and discussed the findings. All authors, but especially Sandra Rose-Meierhöfer, helped to improve the language of and the discussion in the submitted patent. Ulrich Ströbel, Jakob Meier and Egbert Zieger organised the necessary vacuum control valves for conducting the measurements. Ulrich Ströbel wrote all the drafts of the manuscript, worked in all of the processing steps of the study and contributed 25% of the work involved in the submitted publication.

APPENDIX H

Erklärung

Hiermit erkläre ich an Eides statt, die vorliegende Dissertation selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt zu haben.

Berlin, den 22. März 2012 Ulrich Ströbel

APPENDIX I

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