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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

الريتش ستروبل * ، ساندرا روس – ميرهوفر و رينر برنش

معهـد ليبنيـز للهندسـة الزراعيـة ، بوتسـودام – بـورنيم ، مـاكس – ات- عليـي 100، 14469 بوتسـودام ، المانيـا

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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Introduction

Many milking systems are equipped with sensor technique for data recording. However, currently available milking systems offer no possibility for continuous measuring and control of the vacuum from the teat cup. Thus, a vacuum control system for the teat end vacuum will help to minimize the cost of the milking process. One of the most serious global problems is the agricultural land decreasing which advances day by day. The land will be used for real estate, industrialization, and roads for the betterment of human beings life's (Nasim et al., 2010). The land decreasing in combination with a rising world population leads to a steady rise in food prices. In 2008, the real international food prices reached their highest level since the end of 1970's and for the first time since 1981 the real food price index, published by the Food and Agriculture Organization (FAO), surpassed the 150 mark, the result of a sharp increase in 2006-07, and has been followed by an even steeper increment in 2008 (Muhammad et al., 2010). The increasing world population needs more cheap dairy products which can be achieved by encouraging the agricultural engineers to enhance the efficiency of dairy farming. One decisive step to solve the problem of increasing dairy product prices is to improve the technology as early as possible to get higher yields at lower production costs. Solid and controlled vacuum conditions in all milking systems help to secure the udder health and consequently to avoid the costs for veterinarians and milk losses. The creation of solid vacuum conditions in the milking system however, is one of the most important preconditions for guaranteeing satisfactory milking characteristics in the milking system (Hoefelmayr and Maier, 1979).

Negative impacts for udder health are being attributed to over-milking and to unlimited vacuum effects on the teat tissue (IDF, 1994). Thiel and Mein (1979) showed that an increase of machine vacuum leads to higher milk flow levels and amounts of re-milk. Thus, the adjustment of the teat-end vacuum is essential for the whole milking process. Some researchers hold that high vacuum at the teat end especially in the release phase of the pulse cycle leads to damage of the teat tissue. The alternation between suction and release phase during the milking process are the basic principle for the teat cup with two chambers. Rasmussen and Madsen (2000) reported that milking at low vacuum of 26 to 30 kPa in the teat end compared to high vacuum of 33 to 39 kPa increased machine-on time and frequency of liner slip. Indeed the stated vacuum levels are regarded as mean vacuum level of a whole pulse cycle. Milking at high vacuum, in contrast has been shown to decrease machine-on time slightly (Reinemann et al., 2001), increase the number of teat ends open after milking and the amount of time for teat ends to close after milking and increase teat-end hyperkeratosis (Mein et al., 2003).

Hyperkeratosis can lead to mastitis in the long-run. Hamann (1987) concluded that mastitis can be caused through sub-optimal adjustment of the milking technique like failure in pulsation and through sub-optimal teat-end vacuum. This is true for all kind of milking systems. Hamann et al. (2001) showed that a positive pressure system significantly caused smaller teat-end diameters and lower thickness values as compared to the conventional system. This corresponds well with Reinemann et al. (2001). The higher the vacuum under the teat is, the more the teat cup liner folds together in the release phase and the tissue gets squeezed too much (Hoefelmayr and Maier, 1979). According to Hömberg (2008) the teat-end vacuum in release phase should be under 20 kPa, which is very low but leads, as he found out, to a lower strain on the udder tissue.

Öz et al. (2010) showed fluctuations in suction phase between 4.0 and 5.0 kPa for a conventional milking cluster with 160 cm^3 claw volume and flow rates between 0.8 l/min and 6.0 l/min. As Worstorff (1976) found out, the main reason for the cyclical fluctuations is the cow-individual milk flow intensity, for example the flow rate per time interval. In 2002, Bjerring and Rassmussen found that the vacuum fluctuations at the teat end are larger in automatic milking systems than in conventional milking systems. That implies that it is a necessity to design the vacuum control system in a way that it can be introduced to both quarter-individual milking systems for milking parlour and to all kind of automatic milking systems. Additionally, Rose-Meierhöfer et al. (2010) found a vacuum reduction of 14 kPa in milking-time tests (farm experiments) at 8.0 l/min flow rate for a conventional milking system with milking cluster (claw volume of 300 cm^3) at a machine vacuum of 42 kPa. Thus the purpose for the striven vacuum control system is to produce vacuum fluctuations which are lower than 5.0 kPa for a flow rate of 6.0 l/min, as shown by Öz et al. (2010) for modern conventional milking systems. For vacuum reductions the purpose is to reach much lower reductions than Rose-Meierhöfer et al. (2010) found in a conventional milking system with milking cluster. A first analysis of own measurement results show that here is a high potential for improvement. Probably it is even possible to produce low vacuum reductions at high flow rates and high reductions at low flow rates, which would be much better for teat tissue than the current state of the art and which would be a minor revolution in milking technique. The quarter individual vacuum data of the teat-end milking vacuum, collected with the test set-up of this study can be used for controlling the vacuum at this point during the entire milking process. However, the development of a vacuum control system is a decisive scientific issue. With this new technique it will be possible to guarantee and to document, that the vacuum conditions at the teat are all the time within the limits according to ISO/ DIN 6690 (2007). If nevertheless a system error happens the control system will immediately correct the error or stop the milking system and alerts the farmer.

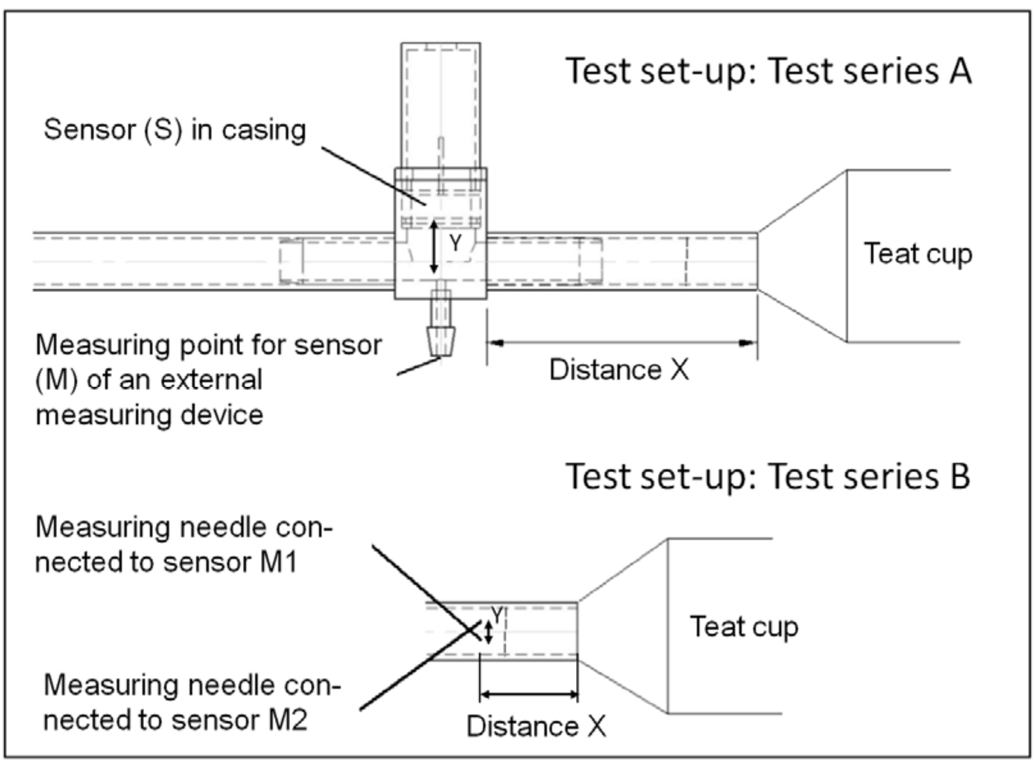
The streak canal of the teat is very sensitive and permits entry of bacteria which can move into the udder and cause inflammations. With a reduction of mechanic pressure at the teat, to the lowest level as possible, the teat can be healthy and resistant against bacterial infection, referring to Hamann (1987) and to the other authors quoted before. Thus, the amount of hyperkeratosis which makes it easier for bacteria to infect the teat can be decreased with the help of a teat-end vacuum control system. Such a control system could be optimized in the long run in a way that individually for each animal, under consideration of cattle breed, udder condition, cow’s health condition and stage of lactation, for each cow the optimal vacuum application will be calculated and afterwards generated. Many data for a good adjustment of the milking system are given in ISO/ DIN 6690 (2007) and protect farmer and cow. But these guidelines don’t react to the individual daily situation of the animal. A control system can do this. The vacuum application at the teat end, which is optimal for the economic situation of the farm, has not been developed and the optimal vacuum application for each teat and cow can only be measured, if first a precise teat-end vacuum measurement in or near the teat cup will be developed and if second the evaluating of the animal data by computer can be done automatically.

All the following measurements have been performed at a quarter individual milking system called Multilactor® (Company Siliconform, Türkheim, Germany). So far, this system is the only quarter individual milking system, which can be used in milking parlours. It disposes of periodical air-inlet and should work by low level vacuum of 35 kPa. The single tube guidance of the milking system Multilactor® has several advantages. Thus, it is easy to measure milk quality data on quarter level, because the separation of the quarter milk take place for a longer distance in the milk tube. Moreover, this kind of single tube guidance is able and more flexible for milking cows with unusually big udders or teat positions. Therefore, with a modification of the four teat cups the Multilactor®, in comparison to conventional milking systems with milking cluster and with short milk tubes, would easier be able to milk other farm animals more gentle like horses, sheep and camels which have more variation in udder anatomy. The camel can thrive under extreme hostile conditions of temperature, drought and lack of pasture and still produce milk of high nutritional quality (Yagil and Etzion, 1980). Moreover, the milk production potential of Pakistani camel is well recognized in the world (Iqbal et al., 2001). Therefore the camel in combination with a perfect adapted milking system could help to produce more milk on less productive soils and on low production costs for an increasing world population. That would be a great benefit for the populations in many transition countries.

Thus, the aim of this study was to develop a technical solution by inserting a pressure sensor into the milk tube of the milking system Multilactor®. The inserted pressure sensor has to be able to memorize the milking vacuum during the whole milking time. Furthermore, the question should be answered if an inserted pressure sensor (Test series A) has a measuring deviation in comparison to a conventional teat-end vacuum control device (Test series B) and if they are relevant for creating the vacuum control system.

Materials and Methods

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



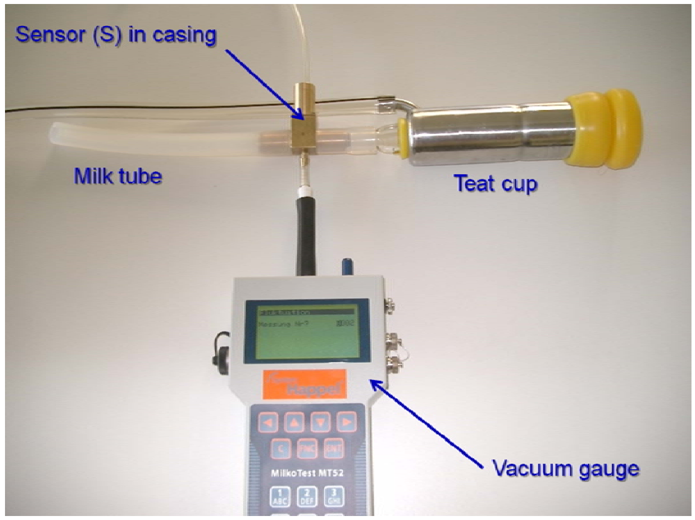


Figure 1. Overview of the test set-up: Sensor casing at the end of the teat cup (Test series A) and two measuring needles (Test series B).

Figure 2. Overview of the whole test set-up: Flow simulation at the milking system Multilactor® in the laboratory.

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

During test series B both sensors have been connected with measuring needles to the milk-tube, as schematically shown in Figure 1. The ends of the measuring needles with air-inlet at the needle points have been pierced into the milk-tube below the teat end in three variations, with the same value as in test series A. The values for the distance X are given in Table 1. The needles have been located with a distance (Y) of 6 mm to each other. Further, in Table 1, the set-up data of both test series are presented. Test series B helps to determine the admissible deviation between measurements from the two sensors.

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

Test series	Sensor 1	Sensor 2	X in mm*	Y in mm**
A	S	M	100; 140; 2,750;	12
B	M1	M2	100; 140; 2,750;	6

* Distance X between the measuring point and the end of the teat cup

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

The pressure sensors M, M1 and M2 are sensors at the vacuum control device MilkoTest MT52 (Company SystemHappel, Friesenried, Germany). According to manufacturer's instruction the measuring accuracy of the sensor (S) from Keller GmbH (2008) is 0.5%. The maximum measuring frequency is 2.0 kHz. At the vacuum control device MilkoTest MT52 the measuring accuracy of the sensors (M) has been 0.5%. The maximum measuring frequency is 1.0 kHz. The measurements took place at a measuring frequency of 500 Hz. The sensor (S) in the casing has been connected to an analog-digital converter, which has been connected by an interface to a computer. For data recording the software LabView has been available on the computer (National Instruments, USA). All the vacuum measurements have been carried out according to the wet-test method ISO/ DIN 6690, (2007). Here the milking process is simulated with the help of a flow meter for liquids and with artificial ISO-teats (ISO/ DIN 6690, 2007). Flow rates have been 0.8, 2.8, 4.8 and 6.0 l/min. All the measurements have been performed at a quarter individual milking system Multilactor® which has been described already at the introduction. All the measurements have been carried out at the same udder quarter. At each test series at least two repetitions have been carried out. As test liquid water has been used.

For determination of the suitability of the sensor inserted in the casing, the mean measuring deviation between both measuring systems has been calculated for each test. The calculations of the results have been carried out by calculating the difference between each pair of values in kPa, at minimum 7000 pairs of values at a measuring frequency of 500 Hz. Furthermore, the mean of the vacuum differences has been calculated for each test. For the measuring deviation also the standard deviations of each test has been calculated and given in Figure 3. This calculation has been done for all performed measurements. The hypothesis (H_o) for the statistic evaluation is that there is no significant difference between test series A and B. If this is true the vacuum recording method of test series A can be introduced to the vacuum control system, without changing the construction. The evaluation of the vacuum measuring deviation between test series A and B has been made by the use of parametric tests based on a linear model. The collected data of both test series have been compared with each other. The data have been analyzed with the statistic software SAS 9.2. For the calculations of mean values the MEANS procedure has been used, while the linear model has been formulated with the MIXED procedure. The model equation has been assumed as:

$$\underline{y}_{jik} = \mu + \alpha_i + \beta_j + \gamma_k + \underline{e}_{ijk}$$

with

$\underline{y}_{ijk}$ -observed absolute measuring deviation,

μ - general mean

α_i - (fixed) effect of i*th* level of test series,

β_j - (fixed) effect of j*th* level of flow rate,

γ_k - (fixed) effect of k*th* level of distance,

$\underline{e}_{ijk}$ - residual,

with test series i=(Test series A, Test series B), flow rate j=(0.8, 2.8, 4.8, 6.0) and the distance between the inserting point and the end of the teat cup k=(100.0; 140.0; 2,750.0).

Results and Discussion

The present study shows that generally the measuring within a casing inserted pressure sensor is possible. The installation of pressure sensors into the milk tube can take place with the constructed casing in a cost-efficient way. Thus, it has been found, that the mean of the measuring deviation in test series A, at each flow rate laid fewer than 1.25 kPa and in test series B fewer than 1.30 kPa (Fig. 3). By comparing both test series, the in total lower measuring deviation has been found in test series B in comparison to test series A. The standard deviations at all flow rates are higher in test series A than in B.

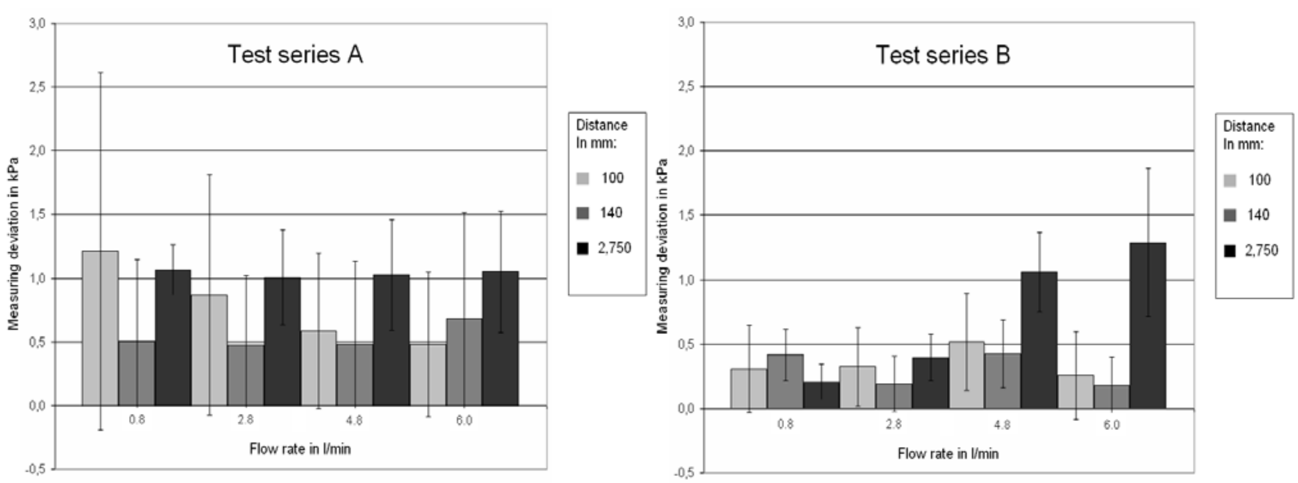


Figure 3. Measuring deviation on the test set-up of test series A and B at different flow rates and at different distances to the teat cup.

Furthermore, it is shown in test series B at a distance of 2,750 mm that with higher flow rates there are higher measuring deviations. In test series A the lowest deviation has been found at the distance of 140 mm. In test series B the difference between a distance of 100 and 140 mm is marginal but at the distance of 2,750 mm there has been a higher difference. Over all tests, the values of the carried out repetitions fit well together.

In Table 2 and 3 the calculation results for the measuring deviation are tabulated. The test for fixed effects showed that test series and distance have a significant effect on the measuring deviation. The flow rate has no significant effect (Table 3). Table 2 shows the model data which have been found out. With the data the influence of the test series, the flow rate and the distance on the measuring deviation can be predicted.

Table 2. Least square means of measuring deviation for both test series A and B.

Effect	Value of effect	Estimate	Standard Error	DF	t-Value	Pr > |t|
Test series	Test series A	**0.7829**	0.064	41	12.22	<.0001
	Test series B	**0.4629**	0.064	41	7.23	<.0001
Flow rate	0.8	**0.6142**	0.091	41	6.78	<.0001
	2.8	**0.5417**	0.091	41	5.98	<.0001
	4.8	**0.6792**	0.091	41	7.50	<.0001
	6.0	**0.6567**	0.091	41	7.25	<.0001
Distance	100	**0.5888**	0.078	41	7.50	<.0001
	140	**0.3938**	0.078	41	5.02	<.0001
	2,750	**0.8863**	0.078	41	11.30	<.0001

Table 3. Type 3 test for fixed effects.

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 have been not perfect and have a difference to the ideal case, which would show 0.0 kPa. 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 in comparison to the ideal case. Thus, the mean values of both test series show an estimated standard error of 0.064 kPa. By comparing test series A and B in general it can be stated that in test series B the significant lower deviations have been found. This is an advantage. The advantage of the recording method of test series A is that the sensor in the casing can be introduced into the milk tube completely and it is robust and will not be damaged from the rough environment around the teat cup. The hypothesis H_o for this study has been found not to be true. Thus, the conclusion out of this is that the casing with the sensor should be optimized. This should happen in a way that the device will record vacuum deviations which will show no significant difference, by comparing the two test series.

Rose et al. (2006) found out, that at some conventional milking clusters the vacuum reduction can raise up to 14 kPa at a machine vacuum of 42 kPa. If there is a measuring deviation of about one kPa between the tested sensor and the reference, the result is good enough for the development of a permanent, online, teat-end vacuum control system. Even with the measuring deviation a big share of the vacuum reduction can be prevented with the already designed vacuum control system and so the main vacuum level can be adjusted to a lower level. One purpose is now to produce lower vacuum fluctuations with the vacuum control system than Öz et al. (2010) found in the conventional milking cluster in the mentioned study. For the vacuum reductions the aim is to reach values like Rasmussen and Madsen (2000) stated for milking at low vacuum. Additionally the control system should be realized in a way that the teat-end vacuum is much lower at low milk flow rates and in release phase in comparison to suction phase, because machine–on time will only slightly increase during milking at low vacuum, if the low vacuum is only produced for the mentioned time-intervals in release phase. There are many arguments for the development of a vacuum control system for all milking machines. The highest measuring deviation in test series A at different flow rates is 1.25 kPa. The research for a vacuum control system should be pursued with the casing developed for this study, because there are different possibilities to improve the measuring results, for example with a mathematical error reduction.

Conclusions

According to the statistical analysis, it can be concluded that the casing with the sensor (Test series A) should be geometrically improved in order to decrease the measuring deviation in comparison to test series B. The recorded measuring deviation for test series A should be lower for developing the vacuum control system, but the data built a good foundation to improve the measurement with permanently inserted pressure sensors. It was found that the deviation is low enough to decrease the vacuum reductions of the milking systems at high flow rates.

Further research is needed to find out, which measuring deviation exists between the teat end of an ISO teat and the planned inserting point of the casing. This can be found out along the lines of this study. Furthermore, those results are definitely necessary for developing a vacuum control system. If there is only a pour measuring deviation between the two measuring points then the control system can be developed more easily. Actually, the data transfer from the sensor from the casing to the computer can be realized by a wireless data connection. In fact, there is a lot of work to do. With a good adjusted vacuum control system the comfort of the milking systems and the udder health of dairy cows will be improved soon.

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