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Prediction and Comparison of Vacuum Related Variables in Conventional and Quarter Individual Milking Systems

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Abstract: The objective of this study was to develop mathematical functions in order to predict vacuum related variables in both, conventional and quarter individual milking systems. The tests at different flow rates ranging between 0 and 8 l/min were carried out in the laboratory using a special test stand and wet test procedure in ISO 6690 was followed. The data related to average liner vacuum in b and d –phase, average vacuum in pulsation chamber and vacuum fluctuations in b and d –phase and in claw were obtained. The mathematical functions that allow predicting these vacuum related variables were developed using these data for both, conventional and quarter individual milking systems.

Key words: Milking machines, quarter individual milking, average vacuum, mathematical modeling

INTRODUCTION

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

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

The studies using automated milking systems mostly focused on udder health. Rasmussen et al. (2003) and Wirtz et al (2002) found an increase in the number of bulk-milk somatic cell count once AMS was used. This shows the necessity of having an additional method to detect clinically infected cows and measuring the milk composition especially SCC per each udder quarter is important (Berglund et al., 2007).

The technical condition of milking equipment may have a direct or indirect influence on udder health and milk quality. Milk flow rate, vacuum level, pulsation characteristics, the type of claw and liner used affect cyclic variations at different locations of milking clusters (Rasmussen et al, 2003).

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

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

But there exists no mathematical based study that enables one to predict vacuum fluctuations under the given conditions such as system vacuum and milk flow rate. Hence a study was conducted and the objective of the study was to determine effects of vacuum and milk flow rate on the cyclic vacuum fluctuations at different locations of the cluster and to develop mathematical functions to predict vacuum fluctuations using wet-test method under the laboratory conditions.

MATERIALS and METHOD

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

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

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

Vacuum measurements using wet test procedure (ISO 6690, 2007) were conducted. During the experiments, ISO artificial teat was used (ISO 6690, 2007). Water at room temperature was used to simulate the effects of milk flow ranged between 0-8 l/min and 0 – 6 l/min for conventional and Multilactor, respectively as its physical properties are very close to milk. The vacuum recording device named "Bovi Press", A & R Trading GmbH was used at the sampling rate higher than 300 Hz and measuring accuracy of ± 0,1 kPa. The vacuum was recorded for 21 pulse cycles for each measurement at the ISO-teat end, pulsation chamber, claw and main vacuum line, simultaneously. The sensors were connected with 16-gauge injection needle (BD Nokor Admix Kanüle 16G 1) to short pulse tubes and claw. From the data recorded, average liner vacuum in b and d –phase, average vacuum in pulsation chamber and vacuum fluctuations in b and d –phase and in claw were obtained. The mathematical functions that allow predicting these vacuum related variables were developed using these data for both, conventional and quarter individual milking systems.

The cycles mentioned above are defined as in the following;

The average liner vacuum during phase b (see Figure 1 of ISO 3918:2007) of pulsation waveform is the average of the average registered values during phase b of the pulsation waveform in each measured pulsation cycle during measuring period.

The average liner vacuum during phase d (see Figure 1 of ISO 3918:2007) of pulsation waveform is

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the average of the average registered values during phase d of the pulsation waveform in each measured pulsation cycle during measuring period.

The average vacuum is the arithmetic average of all values of vacuum registered in Pulsation chamber and claw by an automatic data acquisition system (2.7.2 of ISO 3918:2007).

The vacuum fluctuations (F) were determined as the difference between the highest (V_{max}) and lowest vacuum (V_{min}) at randomly selected sequential 12 cycles and calculated as in the following.

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

RESULTS and DISCUSSION

The average liner vacuum in b (V_b) and d phase (V_d) and fluctuations in these phases (F_b and F_d), fluctuations in claw (F_{claw}), the average vacuum (V_{sys}) and average claw vacuum (V_{claw}) are shown in Figures 2 thru 5 for conventional system. The lines on figures represent the best fitted lines and the models for these lines are tabulated in Table 1.

As seen from Figure 2, the average liner vacuum in b and d phase goes down while the fluctuations in these phases increase as the flow rate increases by following a quadratic line (figure 3) . Fluctuations in claw within the 0 – 8 l/min flow rate range show an increasing trend as shown in Figure 4. Changes in average vacuum in pulsation chamber and claw in different flow rates are depicted in Figure 5 . As similar to vacuum changes in phase b and d, average vacuum in pulsation chamber and claw goes down as the flow rate increases.

The changes in the vacuum related variables as a function of flow rate for Multilactor are depicted in Figure 6 thru 9. The trend in vacuum related variables for this milking system is similar to conventional one except the fluctuations in phase b and d as seen from Figure 7.

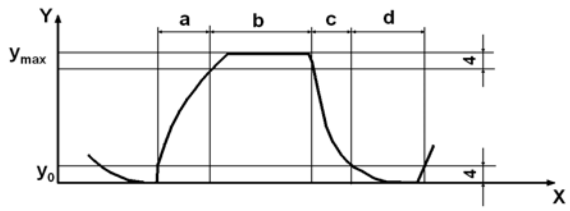

Figure 1. A typical pulsation waveform and phases

KEY

X	time
Y	vacum in kilopascals
Y_{max}	maximum pulsaton chamber vacuum
Y_0	atmospheric pressure
a	increasing vacuum phase
b	maximum vacuum phase
c	decreasing vacuum phase
d	minimum vacuum phase

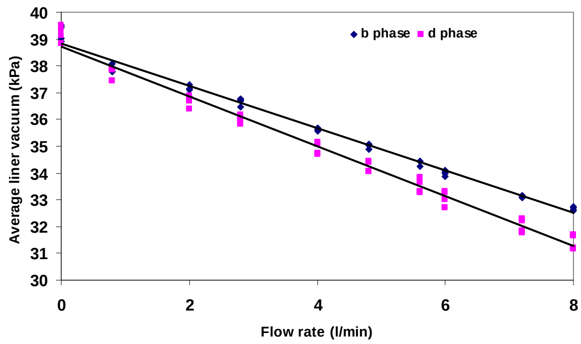

Figure 2. Average liner vacuum in b and d-phase as a function of flow rate in conventional system

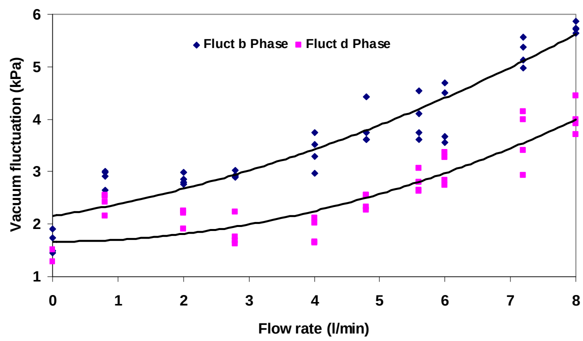

Figure 3. Vacuum fluctuations in b and d-phase as a function of flow rate in conventional system

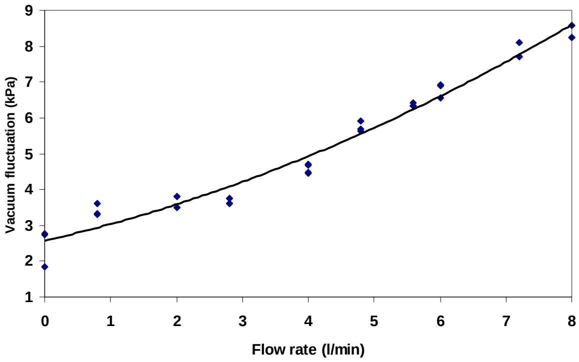

Figure 4. Vacuum fluctuation in claw as a function of flow rate in conventional system

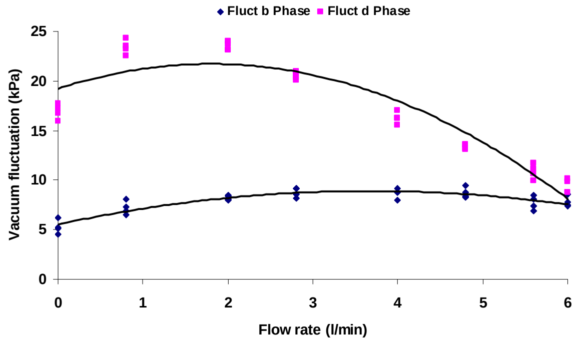

Figure 7. Vacuum fluctuations in b and d-phase as a function of flow rate in quarter individual system

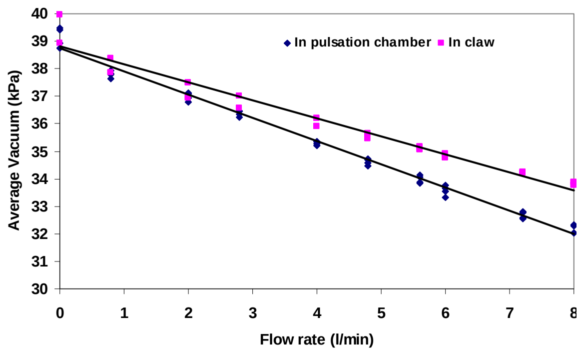

Figure 5. Average vacuum in pulsation chamber and claw as a function of flow rate in conventional system

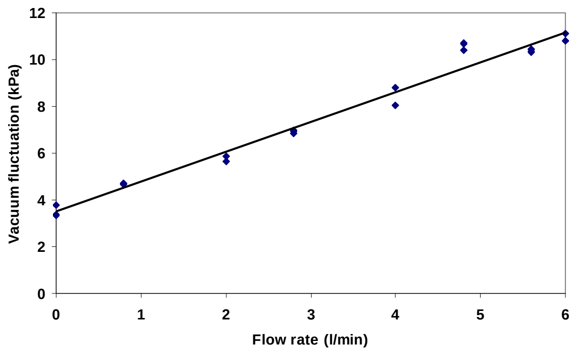

Figure 8. Vacuum fluctuation in claw as a function of flow rate in quarter individual system

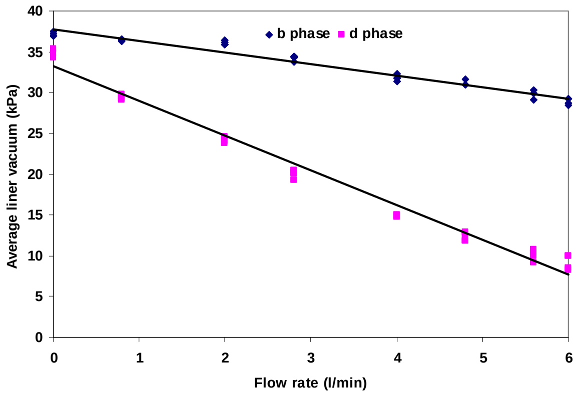

Figure 6. Average liner vacuum in b and d-phase as a function of flow rate in quarter individual system

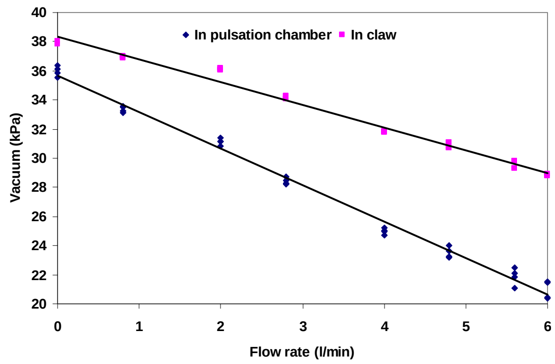

Figure 9. Average vacuum in pulsation chamber and claw as a function of flow rate in quarter individual system

Table 1. Models for vacuum related variables in conventional system

Model	Model coefficients and standard errors*	R^2 (%)
$V_b = b_1 + b_2 Q$	b_1=38.82 [0.065] ; b_2=-0.789 [0.013]	98.84
$V_d = d_1 + d_2 Q$	d_1= 38.78 [0.087] ; d_2= -0.934 [0.018]	98.59
$F_b = f_1 + f_2 Q + f_3 Q^2$	f_1= 2.15 [0.155] ; f_2= 0.203 [0.088] ; f_3= 0.028 [0.01]	89.46
$F_d = f_4 + f_5 Q + f_6 Q^2$	f_4= 1.67 [0.177] ; f_5= 0.0005 [0.101] ; f_6= 0.036 [0.012]	75.27
$F_{claw} = f_7 + f_8 Q + f_9 Q^2$	f_7= 2.57 [0.138] ; f_8= 0.424 [0.079]; f_9=0.041 [0.009]	96.95
$V_m = m_1 + m_2 Q$	m_1= 38.74 [0.07] ; m_2= -0.846 [0.014]	98.89
$V_{claw} = c_1 + c_2 Q$	c_1= 38.82 [0.106] ; c_2= -0.655 [0.021]	95.92

* given in the brackets next to the coefficients; R^2 is the coefficient of determination of the model

Table 2. Models for vacuum related variables in quarter individual milking system (Multilactor)

Model	Model coefficients and standard errors*	R^2 (%)
$V_b = b_1 + b_2 Q$	b_1=38.8 [0.201] ; b_2=-1.421 [0.052]	96.1
$V_d = d_1 + d_2 Q$	d_1= 33.16 [0.409] ; d_2= -4.242 [0.106]	98.1
$F_b = f_1 + f_2 Q + f_3 Q^2$	f_1= 5.524 [0.234] ; f_2= 1.84 [0.184] ; f_3= -0.25 [0.029]	79.8
$F_d = f_4 + f_5 Q + f_6 Q^2$	f_4= 19.21 [0.763]; f_5= 2.77 [0.601] ;f_6= -0.77 [0.094]	88.5
$F_{claw} = f_7 + f_8 Q$	f_7= 3.51 [0.141] ; f_8= 1.275 [0.036]	97.5
$V_{sys} = m_1 + m_2 Q$	m_1= 35.67 [0.168]; m_2= -2.51 [0.043]	99.1
$V_{claw} = c_1 + c_2 Q$	c_1= 38.37 [0.134]; c_2= -1.56 [0.035]	98.5

* given in the brackets next to the coefficients; R^2 is the coefficient of determination of the model

The derivatives of the quadratic functions given in Table 2 with respect to flow rate for phase b and d show that the maximum vacuum fluctuations occur at 1.8 and 3.7 l/min for b and d phase, respectively. Beyond these peak values the fluctuations for both decrease as the flow rate increases. The comparison of both systems indicate that the gap between the vacuum in b and d phase enlarges as the flow rate increases but the magnitude of this enlargement is very significant for Multilactor. Based on the models developed, it can be calculated that the vacuum in b and d phase for conventional system at 6 l/min flow rate is 34.08 and 33.13 kPa while the system working vacuum was set to 40 kPa. The difference between these phases is nearly 1 kPa. The similar calculations for Multilactor result in 29.27 and 7.7 kPa for b and d phases respectively at 6 l/min flow rate at a system working vacuum of 38 kPa. The largest difference between the phases is nearly 21.5 kPa in Multilactor.

The reason for a big difference between two systems is considered to be normal since Multilactor has Biomilker system that allows periodic air inlet in the pulse chamber. Worstorff et al. (1983) asserted that periodical air inlet led to substantial improvement in teat hardness, teat end lesions, milk production and cell count. Additionally MULTI could be very helpful to reduce udder problems especially teat liaisons. Further, Hamann et al. (2001) showed that a positive pressure system caused significantly smaller teat end diameters and lower thickness values compared to the conventional system.

CONCLUSIONS

The followings were concluded from the study:

- For both, conventional and Multilactor, the teat end vacuum decreases with increasing flow
- Multilactor may provide an improvement in teat health and protect teat against mastitis since the system provides individual milking for each teat.
- The reductions in b- phase for both systems are considered to be normal since the system working pressures are different and 2 kPa lower in MULTI than CON.
- The reduction of the mean vacuum level in d-phase as the flow rate increases can provide an effective message on teat and this could be considered as an advantage of MULTI and BioMilker system.

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