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# CHARACTERISTICS OF VACUUM CHANGES IN THE SHORT MILK TUBE, AND LINER MOUTHPIECE DURING MILKING

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**Summary:**

Vacuum measurements were made in the short milk tube, pulsation chamber, and mouthpiece during normal milking and during a liner slip. The measurement techniques and equipment required to accurately characterize these vacuum fluctuations will be discussed.

**Keywords: Machine Milking, Dairy Cows, and Measurement**

## CHARACTERISTICS OF VACUUM CHANGES IN THE SHORT MILK TUBE AND LINER MOUTHPIECE DURING MILKING

### Introduction

Annex A of the ISO Standard 6690 (1996), Milking Machine Installations - Mechanical Tests, states that for laboratory tests of vacuum in the milking unit the recording instrument should have a range of 60 kPa, accuracy of ± 0.6 kPa and repeatability of ± 0.3 kPa. The standard further states that the frequency response of the recorder should be greater than 500 Hz and be filtered to less than 1000 Hz. This reference to frequency response is unclear. It is recommended that the internal volume of connections to the measuring equipment should be kept to a minimum to avoid damping of the vacuum fluctuations. The vacuum fluctuation (maximum minus – minimum within one pulsation cycle) should be measured with a precision of +/-10 %. The specification makes no reference to the method of connection to the various test points.

A vacuum recording system is made up of the electronic components and vacuum transducers used in combination with various connections and fittings. Most modern recorders are digital devices that record vacuum measurements at the sample rate of the instrument. Various algorithms may then used to filter, analyze and report this data. The 'laboratory' tests specified in the ISO 6690 are usually performed with artificial udders and have been referred to as 'wet tests'. Modern electronic equipment has allowed more sophisticated measurements to be done during milking in research and commercial herds.

Recent research has shown that the fittings and connections can introduce significant measurement error for digital recording systems. This is especially true for measurements made in the short milk tube. Recommendations have been published for a method to characterize the response rate of vacuum recording systems and for the recommended fittings and methods for making vacuum measurements in the receiver, milkline and claw during milking (Reinemann et al, 1996a). Further investigation using an artificial udder were reported and recommendations for measurement connections used in the short milk tube were made by Reinemann et al, (1996b).

This study was undertaken to refine specifications for measuring in the various parts of the milking unit during milking. The specific objectives of this study were to:

1. Characterize vacuum fluctuations in the claw, pulsation chamber, short milk tube, and mouthpiece chamber during normal milking and during a liner slip
2. Develop recommendations for the sample rate required for digital recording equipment for making laboratory measurements of vacuum in the milking unit during milking.
3. Clarify the specifications given in ISO 6690 and extend the scope to include wet test measurements made in the laboratory as well milking time tests in research herds.

## Materials and Methods

The tests were performed at the University of Wisconsin Dairy Cattle Research and Instruction Center. The facility is a side opening milking parlor with arm type detachers and milk meters. The milk flow rate was manually recorded from the milk meters. One of the objectives of this study was to measure worst case conditions occurring during a natural liner slip. A 500-g weight was attached to the claw and the support tension was removed from the detacher arms to promote liner slips. A BouMatic FlowStar claw with 11-mm diameter short milk tubes and 16 mm diameter long milk tube was used. The low-level milkline was located about 600mm below the claw.

A computer based vacuum recording device was developed for this study. The recording system had four vacuum recording channels each with response rate of greater than 20,000 kPa/s. These tests were performed using a sample rate of 3000 samples per second on each of the four recording channels. The four channels were connected to the

1. Short milk tube on the right-front teat cup
2. Short pulse tube on the right-front teat cup
3. Mouthpiece chamber on the right front teat cup
4. Claw bowl

The connections to the short milk tube, short pulse tube and mouthpiece chamber were made so that the fittings were flush with the inner surface of the liner or tube according to the recommendations in Reinemann et al (1996b).

The data was stored to the computer hard drive and processed later to simulate a lower sample rate using a subset of the data. Digital filtering was also applied to some data sets using a Blackman type low-pass filter.

## Results and Discussion

Simultaneous recordings of claw bowl (claw), mouthpiece chamber (mpc), pulsation chamber (pcv), and short milk tube (smt) vacuum are shown in Figure 1. These data were collected with a sample rate of 3000 Hz. The milk flow rate at the time of these recordings was about 7 kg/min. This milk flow rate is higher than more than 95% of high producing Holstein cows in the US and France and hence is representative of a high milk flow rate. Simultaneous recordings of claw, mouthpiece chamber (mpc), pulsation chamber (pcv), and short milk tube (smt) vacuum during an audible liner slip are shown in Figure 2.

There are several distinct frequency components to the vacuum in the milking unit. The fundamental frequency in all components is one to two times the frequency of pulsation, typically 1 to 2 Hz. This is true for both normal, high-flow milking and for liner slips. This fundamental pulsation frequency is to be expected as the flow of milk starts and stops at the pulsation frequency or twice this frequency for alternating pulsation. Liner slips typically occur as the liner is opening. Vacuum changes are caused by changes in the static and frictional losses in the long and short milk tube due to milk and airflow. Static losses are proportional to the milk flow rate. Frictional losses in the long and short milk tubes are mainly influenced by the air admission rate from air vents and liner slips.

Smaller vacuum fluctuations occur within each pulsation cycle in the claw and short milk tube during normal milking and in the liner mouthpiece during a liner slip. The highest frequency component (about 500 Hz) was measured in the mouthpiece and short milk tube during a liner slip. Higher frequency components were measured in the short milk tube relative to the claw bowl mainly because of frictional losses occurring in the short milk tube. The frequency of the main within-pulsation-cycle fluctuations in the short milk tube during normal milking was about 10 Hz.

The effect of sampling rate is illustrated in Figure 3. Recordings of claw, mouthpiece chamber and short milk tube vacuum during an audible liner slip with sample rates of 3000 Hz (upper left and expanded scale in lower left), 100 Hz (upper right) and 10 Hz (lower left). These are subsets of the event recorded in Figure 2. A summary of the average vacuum, vacuum difference (maximum – minimum) and maximum rate of vacuum change in the short milk tube for varying sample rates is given in Table I for both normal milking and liner slip.

The effect of filtering is illustrated in Figure 4. Recordings of short milk tube vacuum sampled at 3000 Hz and filtered to 1000 Hz, 250 Hz and 100 Hz during an audible liner slip are shown on the left. This is a subset of the event shown in Figure 2. Recordings of short milk tube vacuum sampled at 3000 Hz and filtered to 1000 Hz, 250 Hz and 100 Hz during the high flow period shown in Figure 1 are shown on the right of Figure 4. These figures confirm the general recommendation that data should be filtered to ½ to 1/3 of the sampling frequency to eliminate noise of a digital recording system. Filtering below the frequency of the true signal results in a loss of information.

**Summary and Conclusions**

The fundamental frequency of vacuum fluctuations in the milking unit is 1 to 2 Hz depending on whether simultaneous or alternating pulsation is used. The frequency of the main within-pulsation-cycle fluctuations in the short milk tube during normal milking was about 10 Hz.

Liner slips caused vacuum fluctuations of about 500 Hz in the mouthpiece, short milk tube, claw bowl and pulsation chamber. The amplitude of the 500 Hz component was highest in the mouthpiece and short milk tube and was present at lower levels in the claw and pulsation chamber. This was associated with the rapid motion of slugs of milk in the short milk tube and by the intermittent air admission at the mouthpiece produced by the opening and closing (fluttering) of the seal between the liner and mouthpiece during a liner slip.

The error in measurement of average vacuum was less than 0.1 percent at all measurement locations for sample rates as low as 100 Hz.

Measurement error of 5% or less for vacuum fluctuation in the short milk tube was achieved with a sample rate of 250 Hz during a liner slip (absolute error of 1.2 kPa) or 100 Hz during normal milking (absolute error of 0.2 kPa). Measurement error for vacuum fluctuation of 1% or less was achieved with a sample rate of 1000 Hz during a liner slip (absolute error of 0.5 kPa) or 100 Hz during normal milking (absolute error of 0.2 kPa). A higher sample rate (on the order of 10,000 Hz) may be required for accurate timing between events in the short milk tube, mouthpiece and claw during a liner slip.

The Annex A of ISO 6690 should expanded to include milking time tests in research herds as well as wet test measurements made in the laboratory. A statement of the sampling rate for digital recorders and response rate of recording systems should be made. If filtering is used for digital recorder the filtering frequency should be filtered to 1/2 to 1/3 of sample rate to reduce noise introduced by the device. The acceptable measurement error should be stated as the greater of the percentage of the true value and some minimum absolute value.

**References**


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Table I. Vacuum recording data summary for measurement in the short milk tube during normal milking with milk flow rate of 7 kg/min and during an audible liner slip.

Average vacuum (kPa / *% Error*)

| | Samples per second | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3000 | 1500 | 1000 | 500 | 250 | 100 | 10 |
| Normal Milking | 40.8 / 0 | 40.8 / 0 | 40.8 / 0 | 40.8 / 0 | 40.8 / 0 | 40.8 / 0 | 40.3 / 1 |
| Liner Slip | 37.1 / 0 | 37.1 / 0 | 37.1 / 0 | 37.1 / 0 | 37.1 / 0 | 37.1 / 0 | 37.0 / 0 |

Vacuum Difference (maximum – minimum) (kPa / *% Error*)

| | Samples per second | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3000 | 1500 | 1000 | 500 | 250 | 100 | 10 |
| Normal Milking | 17.3 / 0 | 17.3 / 0 | 17.2 / 1 | 17.1 / 1 | 17.1 / 1 | 17.1 / 1 | 12.5 / 28 |
| Liner Slip | 39.4 / 0 | 39.4 / 0 | 38.9 / 1 | 38.2 / 3 | 38.2 / 3 | 32.7 / 17 | 28.6 / 27 |

Maximum Rate of vacuum change (kPa/s / *% Error*)

| | Samples per second | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3000 | 1500 | 1000 | 500 | 250 | 100 | 10 |
| Normal Milking | 1485 / 0 | 928 / 0 | 743 / 1 | 619 / 3 | 526 / 3 | 495 / 17 | 87 / 27 |
| Liner Slip | 14900 / 0 | 13900 / 7 | 10500 / 30 | 4580 / 62 | 3930 / 73 | 1130 / 92 | 281 / 98 |