EQUIPMENT SPECIFICATIONS AND METHODS FOR DYNAMIC TESTING

D.J. Reinemann, K. Muthukumarappan and G.A. Mein
University of Wisconsin, Milking Research and Instruction Lab
Madison, Wisconsin

National Mastitis Council Annual Meeting Proceedings (1996)

Both the new ASAE S518 standard (2) and the revised draft international standard DIS/ISO 5707 (3) incorporate performance standards for vacuum stability in milking systems. New NMC procedures for system evaluation include dynamic tests for vacuum stability to demonstrate the adequacy of new or existing milking systems (7) . Such dynamic (i.e. "milking-time") tests require the use of test instruments with response characteristics which are appropriate for the measurement of expected rates of vacuum change in a milking system.

The dynamic tests specified by the American Society of Agricultural Engineers in ASAE S518, “Milking Machine Installations - Construction and Performance” (2) are as follows:

> *6.2 Effective reserve. In addition to meeting the operating requirements in 6.1, the vacuum pump(s) shall have sufficient effective reserve capacity so that the vacuum drop in or near the* ***receiver*** *does not exceed 2 kPa (0.6 in. Hg) during the course of normal milking, including teatcup attachment and removal, liner slips, and cluster fall-off. Effective reserve capacity shall be determined in accordance with ASAE EP445.*

> *14.1 Milkline systems should be designed so that stratified flow is the normal condition during milking. Stratified flow occurs when milk flows in the lower part of the milkline and air flows in a clear, continuous path above the milk. A* ***milkline*** *having a maximum vacuum drop of 2 kPa (0.6 in. Hg) from the receiver to any point in the milkline, under normal milking conditions, is considered to have stratified flow. The normal flow condition means slug free conditions for at least 95% of the milking time. Occasional slugs in the milkline, which are almost unavoidable in practice, should not be regarded as evidence of an improperly designed system.*

ASAE EP445, “Test equipment and its application for measuring milking machine operating characteristics”, is also being revised at present (1). The current version of EP 445 specifies that 90% of any abrupt change in vacuum level is recorded within 200 ms. This specification is too slow for dynamic testing.

The National Mastitis Council specifies another dynamic test in the new, “Procedures for Evaluating Vacuum Levels and Air Flow in Milking Systems” (7), as follows:

> *The average fluctuation in* ***claw vacuum*** *is estimated as the band width (maximum - minimum) of the typical vacuum record obtained in or near the claw during the peak flowrate period of milking for individual cows. An average vacuum fluctuation of less than approximately 2 in. Hg (7 kPa) on a lowline system and less than approximately 3 in. Hg (10 kPa) on a highline is considered desirable.*

The revised International Standards Organization draft standard (3) has similar specifications for dynamic tests of vacuum stability in the receiver and milkline as in ASAE S.518. In addition, it includes a bench test method, adapted from current Nordic standards, specified as follows:

> *Except where the **liner vacuum** is deliberately varied by cyclic air admission, one-way valves or other means of regulating liner vacuum, the manufacturer shall state the maximum milk flow .... to meet the test conditions ...." [of not more than 15 kPa cyclic fluctuation in liner vacuum when using an artificial udder and test conditions specified in DIS/ISO 6690].*

It is clear that the characteristics of the various vacuum recording systems (meter and fittings), and measurement techniques can influence these dynamic measurements. A study was conducted to determine the dynamic characteristics of various vacuum recording systems and their suitability to perform the dynamic tests indicated in these standards and guidelines. Methods for performing these tests were also investigated, with respect to repeatability and error. The specific objective of this study was to develop recommendations for the minimum requirements of vacuum recording systems for dynamic testing of milking machine performance.

Rates of Vacuum Change in Milking Systems

Tan and Reinemann (8) showed that the most rapid vacuum fluctuations in milking systems are caused by slugging of milk in the short milk tube, long milk tube and milkline. The most rapid vacuum fluctuations usually occur at the claw outlet due to the unavoidable slugging in the milk hose. Occasional slugging in the milkline, due to air admission during unit attachment or fall-off, can also contribute to rapid vacuum fluctuations in or near the claw. The rate of vacuum change in these 'wet' parts of the system is usually less than 150 kPa/s (45 in. Hg/s) with occasional fluctuations up to 500 kPa/s (150 in. Hg/s). Air provides attenuation of the rapid vacuum fluctuations associated with slugging. The rate of vacuum change in the receiver and in the 'dry' parts of the milking system are therefore much slower, typically less than 50 kPa/s (15 in. Hg/s).

Two factors affect the ability of a vacuum recording system to accurately record the vacuum fluctuations in a milking system. First, the response rate of the vacuum recording system determines its ability to follow the vacuum changes. If the response rate is less than the maximum rate of change, the peak and valleys will not be measured and vacuum fluctuation will be underestimated. In most cases, the response rate is limited by the connecting tubes and fittings rather than by the recorder itself. The second factor is the sampling rate of the recorder. If the vacuum recorder samples at a rate which is slower than the fastest fluctuations, there is a high probability that the peaks and valleys will be missed so the vacuum fluctuations will be underestimated.

Response Rate of Vacuum Recording Systems

Most commercial vacuum recorders have automatic procedures to determine the duration of the 'a-phase' of pulsation. This provides a handy method for measuring the response rate of a vacuum recording system. The a-phase of pulsation is the phase in which the liner opens. According to international convention (ISO 3918, 1977) the a-phase is determined by the time for the vacuum to increase from 4 kPa (1.2 in. Hg) above atmospheric pressure to 4 kPa (1.2 in. Hg) below the pulsation vacuum level (Figure 1).

Measurements of the a-phase were made by direct connection of the vacuum recording system to a commercial electronic pulsator as shown in Figure 1. The vacuum change produced at the pulsator is a square wave with rise time of about 4 ms. The lower vacuum level is zero (atmospheric pressure) and the upper limit is equal to the pulsation system vacuum. The response rate of each vacuum recording system (kPa/s) was taken as the change in vacuum during the a-phase (system vacuum - 8 kPa) divided by the duration of the a-phase.

Sampling Rate of Vacuum Recording Systems

The sampling rate of commercial vacuum recorders ranges from 16 to 1000 Hz (samples per second) for the digital, electronic recorders. Mechanical recorders (such as the Detco) are analog devices and have an infinite sampling rate. Because sampling rate of electronic recorders influences their ability to measure vacuum fluctuations accurately, the sampling rate for all recording modes and calculation algorithms should be included in the specifications supplied by the instrument manufacturer.

Dynamic Test Methods

Dynamic measurements were made on the milking system in the UW Milking Research and Instruction Laboratory. Measurements at the claw outlet were made using a milking unit attached to an artificial udder. This test apparatus simulated a high line system with 1.3 m of lift between the top of the teatcups and the milkline as specified in the ISO test standard (4). The water flowrate through the artificial udder was 4.5 L/min (1.2 gal/min). Vacuum fluctuations for each pulsation cycle were typically between 9 and 11 kPa.

Measurements made with the vacuum recording systems were compared with a computer-based data acquisition system, sampling at 1000 Hz (Kiethly DAS20 A/D board interfaced with a pressure transducer with 1 millisecond response time). The reference system was connected directly (without tube, trap or needle) to the measurement point. A simultaneous reading was made with the vacuum recording system being tested (including hoses, trap and/or needle) connected to the same measurement point. The vacuum fluctuations were taken as the maximum minus the minimum values within an individual event. The error was taken as the fluctuation of the reference system minus that of the system being tested.

Note that the measurements taken for this study were performed during “normal milking” conditions, i.e. no transient air was admitted to the claw or liner. This differs from previously reported results in which a major liner slip was simulated (6). This method also differs from that reported by Johnson et al (5) in which a moisture trap was used for all measurements.

Results

Response Rate: The response rates of various vacuum recording systems are shown in Tables 1 and 2. The predominant effect on response rate for all of the electronic vacuum recorders tested was the fittings used to connect to the measurement point. There was no significant effect of vacuum level on the response rate over the range from 30 to 50 kPa (9 to 15 in. Hg).

Table 1. Response rate of vacuum recorders and recording systems measured at system vacuum of 45 kPa. (2m Tube = 3 mm internal diameter, 2 meter long connecting tube; 12G, 14G, 16G = 12, 14 or 16 Gauge Needle, Tr = Moisture Trap, F = Filter)

Recorder	**Connection**	**Response Rate (kPa/s)**
Reference	Direct	6500
TriScan	Direct	6500
	2m Tube, Tee	1200
	2m Tube, 12G	790
	2m Tube, 14G	600
	2m Tube, Tr, Tee	650
	2m Tube, Tr, 12G	460
	2m Tube, 16G	250
	2m Tube, Tr, 14G	200
	2m Tube, Tr, 16G	140
Pulsotest	Direct	4880
	2m Tube, Tee	1500
SA II	Direct	3200
	2m Tube, Tee	1700
	2m Tube, 12G	1200
	2m Tube, F, Tee	1070
	2m Tube, F, 12G	900
	2m Tube, Tr, Tee	900
	2m Tube, F, Tr, Tee	700
	2m Tube, Tr, 16G	200
	2m Tube, F, Tr, 16G	180
DecTrace	Direct	1100
	2m Tube, Tee	1000
Detco	Direct	660
	2m Tube, Tee	510

TriScan distributed by Babson Bros. Co. Inc., Naperville, IL
Pulsotest distributed by Westfalia Systemat, Elk Grove Village, IL
SAII and DecTrace distributed by Bou-Matic, Madison, WI
Detco distributed by F.L. Hawes, Chino, CA

Vacuum Level, kPa	Connection	a-phase, msec	Response Rate (kPa/s)
30	2m tube, F, Tee	21	1050
40	2m tube, F, Tee	30	1070
50	2m tube, F, Tee	40	1050
30	2m tube, F, Trap, 16G	125	180
40	2m tube, F, Trap, 16G	180	180
50	2m tube, F, Trap, 16G	232	180

Effects of Sampling Rate and Response Rate: The results of vacuum fluctuation tests performed at the claw outlet are shown in Figure 2 and Table 3. The average measurement error increased with decreasing response rate and sampling rate (Figure 2). The variability of readings also increased with lower response rates and slower sampling rate.

Table 3. Standard Deviation of error for various sampling rates and response rates.

Sample Rate, Hz	Tee, 1200 kPa/s	14G Needle, 600 kPa/s
10	0.59	0.65
20	0.54	0.58
50	0.48	0.50
125	0.07	0.42
250	0.07	0.43
500	0.04	0.43
1000	0.03	0.43

Conclusions and Recommendations

All of the recording systems we tested can measure mean vacuum levels within +/- 1.5 kPa as specified in ASAE S.518. However, considerable error is introduced in the measurement of vacuum fluctuations when recording systems with slow response rates and/or slow sampling rates are used.

The range of vacuum fluctuations (maximum - minimum) prescribed in the NMC, ASAE and ISO standards and our recommended accuracy for the dynamic measurements are as follows:

Test	Range (kPa)	Accuracy (kPa)
Receiver Vacuum	< 2 kPa	+/- 0.2 kPa
Milkline Vacuum	< 2 kPa	+/- 0.2 kPa
Claw Vacuum	7 to 10 kPa	+/- 1.0 kPa

<u>Vacuum Recording Systems</u>

A simple method has been developed to measure the response rate of a vacuum recording system. This test should be performed for the various recorders and test connections used by service personnel. The sampling rate of digital recorders should also be noted.

The predominant effect on response rate for all of the electronic vacuum recorders tested is the fittings used to connect to the measurement point. Hose lengths should be limited to 2 meters. Because milk in the connecting tubes causes considerable damping, tubes should be connected so that they are vertical for at least 0.5 m from the measurement point to allow for self drainage. If filters are used, wet or dirty filters may significantly affect the response rate of the recording system.

Moisture traps introduce considerable damping and change the form of the vacuum traces. More milk tends to be drawn into connecting tubes when traps are used. It is recommended that translucent tubes be used rather than moisture traps. The tubes should be inspected often and bled frequently to avoid milk in the tubes. Tubes should be connected to the vacuum recorder only when a measurement is being taken and disconnected otherwise.

Measurement Techniques

Dynamic tests should be performed:

1) as a commissioning test of any new milking system.
2) before and after any major change in the milking system is made, or
3) when the dairy owner/manager is concerned about poor system performance.

These dynamic tests are not necessary for the routine inspection of milking systems.

Vacuum Stability in the Receiver and Milkline: When performing the test of vacuum stability in the receiver and milkline, the preferred method for connection is directly into the milkline and/or receiver with no needles or traps. The connection to the milkline should be made through an unused milk inlet at least 3 meters (10 feet) from the receiver on the milkline slope that is most heavily loaded. If needles are used for measuring milkline vacuum use a 12 or 14 gauge needle inserted through a milk hose so that it extends into the milkline. Ensure that the open beveled end of the needle is positioned within the top of the milkline, facing toward the receiver and, as much as possible out of the milk stream from the milking unit to which it is attached. When these readings are completed, remove the needle and push the milk hose over the milk nipple so that the puncture hole made by the needle is covered by the inlet nipple.

The connection to the receiver should be made as near as practical to the receiver, making sure that the connection is not in the milk stream. It is preferred that the milkline and receiver tests be done simultaneously. If a two-channel recorder is not available, perform the milkline test first. If this test fails, perform a test in the receiver to determine if the fluctuation is due to poor effectiveness of vacuum regulation or by milkline slugging. These tests should be performed during normal milking as units are attached and removed for at least two turns of cows in a parlor or two complete cycles of unit attachment (15 - 20 minutes) in Round-The-Barn pipeline systems.

Claw Bowl or Claw Outlet: All electronic recorders can measure to within 1 kPa of the true vacuum fluctuation in the claw if the appropriate connections are used. Some mechanical recorders can meet this requirement if connections are made directly to a tee and hose lengths are less than 2 meters.

The preferred method for measuring claw vacuum is with a connecting tube 2 m or less in length connected directly to a Tee in the long milk hose at the claw outlet (response rate greater than 1000 kPa/s). This method is the least likely to introduce errors because of improper placement of needles or plugged needles. Average error with this connection method will be less than 1 kPa for sample rates as slow as 16 Hz. Accuracy will be improved at faster sampling rates.

If the sample rate of the recorder is low, or if needles are used, take at least three measurements of 2 seconds duration. The average range of these three readings will be within 1 kPa of the true vacuum fluctuation. The maximum range of these three readings will be within 0.5 kPa of the true vacuum fluctuation.

The technique used for placement of needles can have a large influence on the measurement (1-3 kPa). Needles can be used but require careful measurement technique and only 12 or 14 gauge needles should be considered. The sampling rate of the recorder should be more than 32 Hz when needles are used to keep the average error below 1 kPa. Needles should be placed so that the bevel of the needle points in the direction of the flow stream and be inserted so that they just enter the hose and do not interfere with the flow of milk (Figure 3). If a needle is inserted into the claw body or milkline it should be placed so that milk slugs or droplets do not impact the end of the needle.

Short Milk Tube: Accurate measurement of the true fluctuations and rate of change of vacuum in the short milk tube requires extremely careful technique and vacuum recording systems with a response rate of at least 1000 kPa/s and a sampling rate of at least 250 Hz.

References

1. ASAE. 1993. EP445, Test Equipment and its Application for Measuring Milking Machine Operating Characteristics. American Society of Agricultural Engineers, St. Joseph, MI, USA.

2. ASAE. 1996. S518, Milking Machine Installations - Construction and Performance Standards. American Society of Agricultural Engineers, St Joseph, MI, USA.

3. ISO. 1995. *ISO/DIS 5707*, Milking Machine Installations - Construction and Performance. International Standards Organization, Geneva, Switzerland

4. ISO. 1995. *ISO/DIS 6690,* Milking Machine Installations - Mechanical Tests. International Standards Organization, Geneva, Switzerland.

5. Johnson, A., Stewart, S., Reinemann, D.J. and G.A. Mein. 1994. Factors Affecting Vacuum Level and Vacuum Stability in the Milking Cluster. ASAE paper No. 943570. American Society of Agricultural Engineers, St. Joseph, MI, USA.

6. Muthukumarappan, K, D.J. Reinemann, and G.A. Mein. 1995. Evaluation of Vacuum Recorders for Milking Machine Performance Testing, ASAE Paper No.953273, American Society of Agricultural Engineers, St. Joseph, MI, USA.

7. NMC. 1996. Procedures for Evaluating Vacuum Levels and Air Flow in Milking Systems. The National Mastitis Council, Madison, Wisconsin, USA.

8. Tan, J. and D.J. Reinemann. 1994. Frequency characteristics of vacuum fluctuations in milking systems. ASAE paper No. 943569. American Society of Agricultural Engineers, St. Joseph, MI, USA.