Paper No. 963018
An ASAE Meeting Presentation

TEST EQUIPMENT AND ITS APPLICATION FOR MEASURING VACUUM IN THE SHORT MILK TUBE

Douglas J. Reinemann, Ph.D., Associate Professor
University of Wisconsin-Madison, Department of Biological Systems Engineering
Milking Research and Instruction Lab

Morten Dam Rasmussen and Erik S. Frimer
Danish Institute of Animal Science, Dept. of Animal Health and Welfare.

Graeme A. Mein, Visiting Professor
University of Wisconsin-Madison, Dept. of Dairy Science and School of Veterinary Medicine
Milking Research and Instruction Lab

Written for presentation at the
1996 ASAE Annual International Meeting
sponsored by
THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS
The Society for engineering in agricultural, food, and biological systems
July 1996

Summary:

Both ASAE and ISO standards cite recommendations for the minimum requirements of recording equipment to evaluate vacuum stability in the various parts of the milking machine. Milking-time tests require the use of instruments with response characteristics which are appropriate for the measurement of expected rates of vacuum change. This paper presents the results of a study conducted to determine the characteristics of vacuum fluctuations in the short milk tube during milking and during wet tests with flow simulators.

Keywords: Milking machines, performance testing, test equipment

TEST EQUIPMENT AND ITS APPLICATION FOR MEASURING VACUUM IN THE SHORT MILK TUBE

D. J. Reinemann, M. Dam Rasmussen, E.S. Frimer, G.A. Mein

Introduction

Test procedures recommended by both ASAE and ISO have performance-based specifications for various system components. These procedures are based primarily on tests done with the milking machine running but with no milk or other liquids flowing in the system. One of the limitations of the current testing procedures is that they provide only indirect information about the effects of the machine on the cow. Attempts are being made in several countries to move the point of testing closer to the cow. This complicates testing and raises the requirements of the test equipment. The test environment is moved beneath the cow and the vacuum fluctuations encountered in the claw and short milk tube are faster than those in the milkline and receiver. This paper will present the results of studies performed to determine the minimum requirements of test equipment and test procedures required to accurately measure vacuum during milking in the short milk tube.

As new test methods are developed new terminology is required to describe these various types of tests. The term "static testing" has traditionally been used to describe tests that are performed with the machine running but only air flowing through the system. This term is misleading and should be dropped. During these types of tests air is moving into and through the system, liners are opening and closing. The key feature of so-called "static testing" is that the milking machine is running but not milking. More particularly, no liquid is flowing through the system. The system is dry. Most dry tests measure vacuum levels, air flow rates, and the cyclic vacuum changes in the pulsation system. Additionally, some tests are conducted with the machine running and a test liquid flowing through individual components, or groups of components, to simulate milking conditions.

The use of testing equipment and procedures for measurement of vacuum levels and vacuum changes during milking has been defined loosely as "dynamic testing". This term has been used for at least thirty years (3, 6) and is an integral part of the folklore of milking machine testing. However, the term "dynamic" has no particular descriptive association with mechanical tests conducted at milking time. It is misleading and imprecise in that it does not adequately distinguish this type of testing from dry or wet tests which are conducted with the machine running but not milking. "Milking-time testing" is a simpler, more accurate and more descriptive alternative to the term "dynamic testing". Our proposal for a more descriptive classification of mechanical performance tests is:

- **Dry tests** - tests conducted with the machine running but not milking and only air flowing through the machine.
- **Wet tests** - tests performed with the machine running but not milking with both air and liquid (water, milk or artificial milk) flowing through the machine using flow simulator or artificial udder.
- **Milking-time tests** - observations or measurements made while milking live animals.

Recommendations for test equipment have been presented previously for milking time tests as specified by the new ASAE standard S518 (2) and *Practice* ASAE EP445 (1), "Test equipment and its application for measuring milking machine operating characteristics," and the revised draft international standard DIS/ISO 5707 (4). These tests are performed in the receiver, milkline, and claw. The National Mastitis Council recommends measuring *the bandwidth (maximum - minimum)* ***claw vacuum*** during milking in the new, "Procedures for Evaluating Vacuum Levels and Air Flow in Milking Systems" (8).

The revised International Standards Organization draft standard (4) has similar recommendation for milking-time tests of vacuum stability in the receiver and milkline as in ASAE S.518. In addition, it includes a bench test method, for ***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].*

A previous study (11) found that the most rapid vacuum fluctuations in the milkline and at the claw outlet were caused by slugging of milk in the milkline and long milk tube. The rate of vacuum change in these 'wet' parts of the system in the absence of unplanned air admission is usually less than 150 kPa/s (45 in. Hg/s) with occasional fluctuations up to 500 kPa/s (150 in. Hg/s).

Previous studies provided recommendations for testing vacuum stability in the receiver, milkline and the range of vacuum at the claw outlet during milking (7, 10). The range of vacuum fluctuations (maximum - minimum) prescribed in the NMC, ASAE and ISO standards and recommended accuracy for the milking-time 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

Most commercial vacuum recorders are capable of meeting these specifications if the proper connection fittings are used and care is taken in the measurement technique. This objective of this study was to determine the characteristics of vacuum recording systems required to make accurate measurements of vacuum changes in the short milk tube during wet and milking time tests.

Materials and Methods

Flow simulators: Measurements were made at the UW Milking Research and Instruction Laboratory using the type of flow simulator specified in the ISO test standard (5). The vacuum recording device used for these tests is described in (9). A sampling rate of 500 Hz was used for the short milk tube tests. Average and range (maximum - minimum) vacuum during one pulsation cycle in the short milk tube were measured. For the first series of tests only one teatcup was used The short milk tube was connected directly to a 73 mm milkline with a 16 mm diameter milk hose. Water, at room temperature, was used as the test liquid with flowrates of 1.0 and 2.0 L/min per teatcup. Air was admitted through a solenoid valve to one of the tubes feeding water into one teat of the artificial udder. The airflow rate was 150 L/min. Air was admitted, as the liner opened, for two consecutive pulsation cycles to simulate a severe liner slip.

A variety of connection fittings were used to connect to the short milk tube including: 12, 14 and 16 gauge needles with the bevel both facing toward and away from the flow stream and metal tubes which were fitted so that the end of the tube was flush with the inner surface of the short milk tube. Various hose lengths were used to connect from these fittings to the vacuum transducers.

Comparisons of short milk tube and claw outlet vacuum were made between the reference recording system and four commercial vacuum recorders. These tests were done with all four teatcups connected to a Germania top outlet claw. The claw was fitted with Alfa Laval 06 shells and 01 liners. The claw was connected to a 73 mm diameter milkline with 1.5 m x 16 mm long milk tube. The milkline was 800 mm below the top of teat cups. The ISO flow simulator supplied 5 L/min water flow rate to the milking unit. Pulsation was supplied by Bou-Matic alternating pulsator at 52 pulsations per minute. The commercial recorders were connected to the test fittings with 3 mm internal diameter tube 2 m long. Milking time measurements were also made at the UW Dairy Cattle Research and Instruction Center milking parlor.

Results and Discussion

Short Milk Tube Tests: The characteristics of vacuum measurements for the short milk tube tests for 1 and 2 L/min water flow rates both with and without 150 L/min air admission and are summarized in Table I. The average vacuum and standard deviation for three repeated tests are given in the first row. The vacuum range (maximum - minimum) and the standard deviation for three repeated tests are given in the second row. The maximum rate of change (kPa/second) over 0.002 second and 0.02 second sample times and standard deviations for three repeated tests are given in rows 3 and 4. The standard deviations of repeated measures were small indicating that the test method had good repeatability. The maximum rate of change was under 500 kPa/s with only water flowing in the short milk tube. When air was admitted to simulate a liner slip, the maximum rate of change exceeded 3000 kPa/s.

Comparisons of the reference system to a variety of connection fittings are given in Table II for 1 L/min water flow and in Table III for 2 L/min both with and without air admission. The average vacuum was generally within 2% of the reference systems for all connection fittings. Considerable error was introduced in both the range and rate of change for all fittings which protruded into the flow stream. The addition of 1 and 2 m tubes to the connection mounted flush with the inner surface of the short milk tube also introduced considerable error. Tubes of 10 cm and less in length had the same readings (data not shown). Water in the connecting hose to the transducer was found to reduce the vacuum range by up to 50% (data not shown). Connecting tubes must be mounted in a manner that allows liquid to freely drain to avoid this measurement error.

Needles with the bevel facing toward the flow stream are able to measure average vacuum within 1% (0.5 kPa) of the reference system. Needles with the bevel facing away from the flow stream measured an average vacuum about 1% higher than the reference method for water flow but read 1 - 3% high during simulated liner slip. For a SMT diameter of 7 mm average vacuum was 6% higher than the reference (data not shown). Damping of the minimum vacuum reading was the major source of error for small diameter needles which likely had water trapped in the needle shaft. The 12 G needle was probably able to drain which reduced damping of the minimum vacuum readings but indicated higher values during 1 and 2 L/min water flow probably because of impact of water on the needle tip.

Comparisons of the reference system with commercial recorders are presented in Table IV. The average vacuum levels measured with the commercial recorders were within 1% of the reference system. The vacuum range (Maximum - Minimum) and values were 48 to 68 percent of the reference value for electronic recorders and as low as 13 percent of the reference values for water flow only. Note that all commercial recorders were fitted with 2 m connecting tubes. Previous measurements (7, 9) were made with parallel connections of the reference system and the commercial recorders which were all fitted with 2 m connecting tubes. This acted to damp the fluctuations and under-report the error in vacuum range.

Milking time tests: Several tests were performed during milking. The maximum rate of change recorded with a sample rate of 100 Hz during a liner slip was 1060 kPa/s. When a sample rate of 500 Hz was used the maximum rate of change recorded during a liner slip was 2500 kPa/s.

Conclusions and Recommendations

We propose that one set of criteria be established for routine field measurements, such as those performed by milking machine service personnel to ensure that the milking machine is operating withing the generally accepted standards. Another set of criteria should be established for purposes of research into cause and effect relationships between the cow and the milking machine. These second set of criteria are more demanding.

For research purposes, all measurements made in the Short Milk Tube (SMT) should be made so that the fitting is flush with the inner surface of the short milk tube and is as close as possible to the inlet of the short milk tube. The fittings and connections to the vacuum transducer should have a minimum internal diameter of 2 mm and a maximum length of 10 cm. This will require that the vacuum transducer be mounted on or very near the short milk tube. The extra volume introduced by connecting tubes acts to damp vacuum fluctuations.

For field measurements, the average vacuum level in the short milk tube can be measured with commercial vacuum recorders but considerable error will be introduced in the measurement of the vacuum range and the rate of change. Measurements at the claw outlet do not necessarily reflect average vacuum or rate of change in the short milk tube.

References

1. ASAE. 1996. 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. Fairbanks, W.C., 1968. Proceedings of the Symposium on Machnien Milking, H. Hall, editor, National Institute for Research in Dairying, Shinfield, UK

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

5. ISO. 1996. *ISO/DIS 6690,* Milking Machine Installations - Mechanical Tests. International Standards Organization, Geneva, Switzerland.

6. Mein, G.A., 1969. Testing the performance of milking machines. Victoria Department of Agriculture, State Research Farm, Werribee, Australia.

7. 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.

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

9. Rasmussen M.D. et al, 1996. Dynamic testing during milking. Proc of National Mastitis Council Annual Meeting 170-171.

10. Reinemann, D.J., K. Muthukumarappan, and G.A. Mein, 1996. Equipment Specifications and Methods for Dynamic Testing. Proc. 35th Annual Meeting, National Mastitis Council Inc., February 18-21, Nashville, Tennessee.

11. 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.

Table I. Vacuum Characteristics in the Short Milk Tube

	1 L/min water flow	1 L/min water Flow 150 L/min air flow	2 L/min water	2 L/min water 150 L/min air flow
Average Vacuum, kPa (Standard Deviation)	45.9 (0.04)	44.9 (0.09)	45.8 (0.03)	44.0 (0.11)
Vacuum Range, kPa (Standard Deviation)	1.96 (0.05)	31.0 (0.49)	6.76 (0.59)	33.6 (2.2)
Max kPa/s over 0.002 s, (Standard Deviation)	357 (78)	4087 (789)	412 (29)	2602 (639)
Max kPa/s over 0.02 s, (Standard Deviation)	56 (4.8)	1482 (29)	264 (16)	1121 (69)

Table II. Comparison of connection methods for Short Milk Tube Tests with 1 L/min water flow rate.

Connection	hose length	Average Vacuum (% reference) no slip / slip	Vacuum Range (% reference) no slip / slip	Max. Rate of Change, 0.002 s (% ref) no slip / slip	Max Rate of Change, 0.02 s, (% ref) no slip / slip
2 mm ID tube, flush	10 cm	100 100	100 100	100 100	100 100
2 mm ID tube, protruding	10 cm	100 102	73 93	128 99	66 102
2 mm ID tube, flush	1 m	100 101	35 55	20 99	33 55
2 mm ID tube, flush	2 m	100 101	20 46	25 62	23 48
12 G needle, bevel up	10 cm	100 100	252 74	210 99	216 73
12 G needle, bevel down	10 cm	100 103	180 84	494 229	205 92
14 G needle, bevel up	10 cm	100 100	31 100	49 146	66 101
14 G needle, bevel down	10 cm	101 102	102 137	177 102	60 90
16 G needle, bevel up	10 cm	99 100	34 74	71 117	18 81
16 G needle bevel down	10 cm	101 102	72 74	133 201	86 103

Table III. Comparison of connection methods for Short Milk Tube Tests with 2 L/min water flow rate.

Connection	hose length	Average Vacuum (% reference) no slip / slip	Max-Min Vacuum (% reference) no slip / slip	Max Rate of Change, 0.002 s (% ref) no slip / slip	Max Rate of Change, 0.02 s, (% ref) no slip / slip
2 mm tube, flush	10 cm	100 100	100 100	100 100	100 100
2 mm tube, protruding	10 cm	100 102	77 79	289 134	93 96
2mm tube, flush	1 m	100 101	33 49	19 66	18 43
2 mm tube, flush	2 m	100 101	19 38	11 32	11 31
12 G needle, bevel up	10 cm	100 100	252 74	210 99	216 75
12 G needle, bevel down	10 cm	100 102	93 64	106 212	66 65
14 G needle, bevel up	10 cm	99 100	63 78	89 136	65 86
14 G needle, bevel down	10 cm	101 102	139 81	242 184	96 80
16 G needle, bevel up	10 cm	99 100	34 74	71 117	48 81
16 G needle bevel down	10 cm	101 102	72 74	133 201	86 105
2 mm tube, flush	10 cm 6 cmr?	100 101	45 100	68 122	73 104
16 G needle bevel down	7.2 mm hose	102 106	126 93	178 109	86 121

Table IV. Comparison of commercial vacuum recorders with reference system.

Recorder and fittings	SMT, Average Vacuum % of Reference	SMT Range, no slip % of Reference	SMT Range, slip % of Reference	Claw Outlet, Average Vacuum % of Reference	Claw Outlet, Range, no slip % of Reference	Claw Outlet, Range, slip % of Reference
Reference, 5 cm tube	100% (42.6 kPa)	100% (11.5 kPa)	100% (28.4 kPa)	100% (45.0 kPa)	100% (10.2 kPa)	100% (23.2 kPa)
Reference, 2 m tube	100	64%	88%			
Triscan, 2 m tube	101	62%	88%	98%	62%	90%
Digimet, 2 m tube, filter	101	68%	82%	99%	72%	86%
SAII, 2m tube, filter	101	65%	87%	100%	48%	76%
Detco, 2m tube, filter	99	22%	45%	102%	13%	24%