Evaluating Milking performance
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# Evaluating Milking Performance

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by Edward Hopkin

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Evaluating milking performance

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Foreword

IDF’s experts on machine milking, working under the aegis of the Standing Committee on Farm management, continue to produce an impressive number of authoritative texts for the Bulletin of IDF while, at the same time, making a very significant contribution to the work of the International Organization for Standardization (ISO) on milking machine installations (ISO/TC23/WG1).

The dairy sector and the manufacturers of milking machines are especially indebted to the authors of this report on the Evaluation of milking performance

- D J Reinemann (US)
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Introduction

The performance of the milking process is evaluated subjectively at every milking by the operator(s) and by the cows. However, there may be quite different interpretations of what is implied by ‘successful’ milking. This paper provides an overview of common machine and operator related problems and offers some guidelines for evaluation methods. The main purpose of any evaluation is to clarify and highlight the interactions between milking equipment, the cow and the operator. This paper focuses mainly on information that can be gathered during milking-time observations and, to a lesser degree, upon measurements made between milkings or from other sources.

A summary of milking related problems and some of their characteristics and causes is given in Table 1. Milking problems fall into several broad categories such as: labor efficiency, low milk yield, poor milk quality, nervous cows or unhappy operators. Within each of these areas, a wide range of characteristics can be measured that may be directly or indirectly related to the problem. Some are more obvious than others and observers may have different preferences for some tests or measurements. The characteristics can be subdivided into measurements or observations that are performed on the cow, the operator, the machine or the environment. Although the environment may have a large influence on specific factors, its impact is not the main purpose of this paper. Guidelines for selecting the types of tests or observations that may be appropriate for trouble-shooting particular types of milking-related problems are offered in the following sections.

A previous IDF monograph (Hamann, 1997) presented guidelines for evaluating the influence of operator actions, animal behavior, milking machine characteristics and housing conditions on the milking process based on a review of the published scientific literature. In the intervening eight years researchers and practitioners have used these methods, added new evaluation methods and assessed their usefulness for field application. This monograph updates the review of scientific literature and presents the methods that have proven useful for practical application in the field by dairy advisers, udder health specialists and competent milking machine technicians. Our aim is to provide suggestions for measurements to quantify various aspects of milking performance. This quantification can provide the basis for making recommendations for changes in the milking process and in determining whether a prescribed intervention has produced a positive benefit.
1. Simple machine checks and milking-time observations

This level of testing is not intended to replace regular machine testing and service by qualified technicians. A field study in France indicated that the most common problems of milking machines were improper vacuum level, pulsator defects and poor condition of cluster components all of which require the attention of a service technician (Sauvee et al., 1998). Rather these simple checks are intended to help identify possible machine or milking management causes of slow or incomplete milking, teat condition problems or sanitation problems that may indicate the need for more frequent service or adjustments to the machine by a service technician.

Test equipment

The equipment required for this entry level testing includes a stopwatch, a spirit level and a vacuum gauge of known accuracy. Because of the potential health and safety risks associated with mercury, a mercury column is not recommended for on-farm measurements.

Observations with machine not running

1.1 Teatcups and Liners

Record the condition of the liners and short milk tubes, noting the fraction that have visible cracking or are distorted (mouthpiece opening not round, liner barrel not round, mouthpiece lip not flat, etc.). Teatcup liners should be in good condition with no cracks in the short milk tube connecting to the claw, and no surface crazing evident on the mouthpiece lip or inner barrel. Swelling and the associated distortion of the liners is an indication that they have been used beyond their rated life (Davis et al., 2000, Boast et al., 2004). Liner performance degrades as liners age and their physical properties change (Gleeson and O’Callaghan, 1998).

Teat cup liners are designed to fit specific types of teatcup shells. When the liner is mounted in the shell it should be held firmly enough not to twist easily and the mouthpiece should not be distorted. The length of the shell must match the design length of the liner so that it is mounted under the correct tension (Capuco et al., 2000, Davis et al., 2000, Muthukumarappan et al., 1993, Szlachata et al., 2001, Mein et al., 1983). Measure the length of the shells and compare with the manufacturer’s recommendation for the type of liner being used.

Note the diameter of the liner barrel relative to the average size of teats in the herd. A liner barrel diameter (measured 75 mm from the mouthpiece lip) 1 to 2 mm less than the average teat barrel diameter (about 22 mm for typical Holstein herds) appears to allow the teat canals of most cows to open fully while also limiting the tensile stress applied to the tissues of the teat wall (Williams & Mein, 1982). If the barrel diameter is substantially larger than the teat diameter the liner will ride high on the teat and mouthpiece vacuum will be relatively high, while liners with barrel diameter substantially smaller than the teat diameter will tend to ride very low on the teat (Rasmussen et al., 2004).

The liner must collapse around the end of the teat in order to relieve the stresses to the teat tissues induced by milking vacuum. The effective zone of collapse for a liner is the part of the liner barrel that the walls touch when milking vacuum is applied to the liner while mounted in the teatcup shell (Mein et al., 2004). The distance from the mouthpiece lip to the TOP of the collapse zone should be short enough so that the liner will collapse around the end of the shortest teats in the herd. The distance from the mouthpiece lip to the BOTTOM of the collapse zone should be long enough to collapse around the longest teats in the herd at the end of milking. Large diameter (wide-bore) liners need to be longer because
the teat penetrates further into a liner with a larger diameter. According to Mein (1992), the distance from the mouthpiece lip to the bottom of the collapse zone for liners made from natural or synthetic rubber should be greater than:

- 135 mm for liners with 21-22 mm inner diameter at mid-barrel
- 140 mm for liners of 23-24 mm inner diameter at mid-barrel
- 145 mm for liners of ≥25 mm inner diameter at mid-barrel.

### 1.2 Claws

Note the condition of air vents in the claws or liners. The air vent in the claw should be clear and unblocked. The air vents in claws typically range from about 0.5 mm to 1.2 mm in diameter. The minimum air admission to the claw recommend in ISO 5707 is 4 L/min of air at atmospheric pressure. However for fast milking cows 7 to 12 L/min of air admission will minimize vacuum drop and improve vacuum stability (Bruckmaier et al., 1996, Johnson et al., 1994). Blocked air vents will reduce milking vacuum. Measure the diameter of the air vents using special tools available from the manufacturer or measure the air admission of the claw air vents using an appropriate airflow meter. Compare these values to the manufacturer’s specification to determine if the air vents are clear and not over-sized. Automatic shut-off valves in the claw reduce the amount of unintended air and debris admitted during unit fall-offs.

### 1.3 Milkline

If vacuum stability in the milkline during milking indicates that milkline slugging may be occurring, measure the slope of the milkline. The milkline should slope continuously towards the receiver. To facilitate the drainage of milk and cleaning solutions a minimum slope of 1% is recommended. Slopes of up to 2 % have been shown to increase milking carrying capacity and further improve drainage (Reinemann et al., 1995). It is especially important to maintain adequate slope of the milkline near the receiver and in areas of bends and fittings. Milk inlets should enter the upper half of the milkline. High-level milk-lines should be mounted as low as practicable above the cows and never more than 2 m above the cow standing level.

### Dry Testing - Machine running but not milking

#### 1.4 Operating Vacuum level

Check the operating vacuum and the reading on the farm vacuum gauge compared to a separate vacuum gauge of known accuracy. Farm gauges are often damaged and inaccurate. Sometimes the indicator needle sticks and will not move above the operating vacuum level to indicate a high operating vacuum if the regulator fails. If the farm vacuum gauge is not functional or inaccurate a functional gauge should be installed. The regulator vacuum should be set so that the average claw vacuum is 32-40 kPa during peak flow (see section 2.2 and ISO 5707). Lower milking vacuum extends machine-on time (Provolo et al., 1998), increases frequency of liner slips, decreases milk flow rate and may reduce milk yields (Rasmussen & Madsen, 2000) whereas higher milking vacuum level can lead to teat tissue congestion, poor teat skin condition and incomplete milk out (Hamann et al., 1994; Mihina et al., 1998; Rasmussen and Madsen, 1998; Reinemann et al., 2001a).

#### 1.5 Regulator Response

A simple test of regulator response is to listen to the sound of air entering a conventional regulator, or the speed of the vacuum pump if fitted with a variable frequency drive (VFD), when air is admitted through milking units. Open enough milking units so that the air admitted reduces the receiver vacuum by about 3 kPa. This should cause a conventional regulator to close, thereby resulting in a noticeable reduction in the hiss caused by air en-
tering the regulator. The increase in vacuum pump RPM should also be readily apparent in response to this air admission. If the system does not appear to be responding, examine regulator filters and airlines to regulator sensors. If cleaning these components does not improve response then call the company service technician.

1.6 Fall-off Test
A milking machine should have sufficient airflow capacity to supply the normal operating requirements of the milking machine plus unintended air admission that may occur during unit attachment or unit fall-off (ISO 5707). A unit fall-off test can be performed to determine if the milking machine has sufficient reserve capacity. Measure the average vacuum in the receiver with all units in operation and all teatcups plugged. Then open one milking unit to admit air through all four teatcups and measure the average vacuum in the receiver again (ISO 6690). If the average vacuum level in the receiver falls by less than 2 kPa the system has sufficient reserve capacity to cope with a unit fall-off (ISO 5707).

1.7 Pulsation
Listen closely to each pulsator as a first check for uniformity between units. The sound of air entering the pulsator should be regular and intermittent. This simple check is made more sensitive by partially covering the air inlet with a finger. A continuous hiss indicates a leak (usually grit or dirt) under the pulsator valve seat. Check that the pulsator air filter or air inlet is clean and free of obstruction. Look inside each liner to ensure that the liners are not twisted in their shells. Look behind at least one liner in each cluster for signs of milk residues that may indicate a split liner. Feel that all liners are at least opening and closing fully in a pulsation cycle by turning on the vacuum shut-off valve to each cluster in turn and inserting a thumb into each teatcup in turn. These simple tests are a good indication of the uniformity of pulsation. If there is any doubt about pulsator performance, call a qualified technician to perform pulsator testing (section 2.1). Assessing average milk flow rates by stall in milking parlors equipped with parlor monitoring software and milk meters is another way to locate malfunction in pulsators or the malfunctions in components at an individual stall (Eicker et al., 2000).

Milking-time Observations
Milking management can have a far greater influence on the success of the milking process than milking machine factors. A systematic review of milking procedures is perhaps the most important part of determining the source of milking related problems.

1.8 Cow Cleanliness
Note the condition of cows before milking. Cow cleanliness is a major determinant of both milking efficiency and the rate of intramammary infection. It is estimated that cow preparation time is doubled for cows that enter the milking parlor with dirty udders, resulting in reduced parlor throughput (Reneau & Chastain, 1995). Management practices that reduce teat end exposure to environmental organisms will reduce the risk of developing mastitis. Studies in France (Doumalin, 1995) and the USA (Schreiner and Ruegg, 2003) have demonstrated that teat and udder cleanliness is correlated with reduced herd average somatic cell count. The incidence rate of clinical mastitis caused by Streptococcus uberis and Escherichia coli were associated with factors related to housing in a large field study by Barkema et al., (1999).

Bedding sources that are clean, dry and comfortable will minimize pathogen growth. Inorganic bedding such as sand will reduce the number of pathogens if manure is removed from stall beds daily and sand is replenished when needed. Further improvements in cow cleanliness can be made through removal of udder hair. It is a good practice to routinely
remove udder hair twice yearly and keep tails trimmed. Cleanliness of teats and parts of udders that come in contact with the liner during milking can be recorded on scale from 1=clean and dry to 4=completely covered in dirt (Schreiner and Ruegg, 2003). Less than 5% of cows should be scored as wet and/or dirty before prepping\(^1\) and all teats should be clean at attachment.

### 1.9 Cow Handling and Behavior

Cow handling techniques should be examined if cows are hesitant to enter the milking area or are defecating frequently during milking. It is clear from research that human/cow interactions can have a large influence on the milking process (Bondar, 1992; Seabrook, 1994; Munksgaard et al., 2001; Rushen et al., 2001). If cows are handled well, very few should react aggressively to pre-milking preparation (Bondar, 1990). Cow handling is an important determinant of milking efficiency. The release of adrenaline within 30 minutes of the start of milking can interfere with milk letdown and prolong unit-on time (Svennersten-S¿juna et al., 2003). Calm cows enter the milking parlor readily and do not generally defecate in the milking parlor. If more than 5% of cows defecate or kick at the milking unit or operator during milking cow-handling procedures should be reviewed.

### 1.10 Cow Grouping

Observe whether cows are grouped according to mastitis infection status. Uninfected cows should be grouped and milked in an order to minimizing exposure to cows known to be infected with sub-clinical mastitis. Also note the methods used for detection, handling and recording of clinical cases of mastitis. It is safe to assume that cows with several linear scores of 4 or more (SCC>250 000) are chronically infected. Most cows that consistently have linear scores <4 are uninfected. Cows that have a single elevated score or fluctuating scores fall into the unknown category. Fresh heifers are generally put in the uninfected group until their first SCC is obtained. Fresh mature cows should be classified based upon their previous SCC status or cultures obtained at calving. CMT-scoring (California Mastitis Test) of foremilk can help in pointing out suspicious quarters differing more than CMT 2 scores on a 5-point scale from the lowest quarter. It is recommended to CMT test and score all newly calved cows, cows ready to dry off, and cows treated for mastitis before they enter the normal herd again. In freestall-parlor operations, uninfected cows should be grouped together and milked first. Cows of unknown infection status are milked next and the infected cows are milked last. In stall-barns, infection status can be used to order the cows within the barn so that infected cows are always milked last. Alternatively, one or more milking units can be identified and always used on infected cows. The risk of new infection is high immediately pre and post calving. Special care should therefore be taken to milk fresh cows with a sanitary milking machine.

### 1.11 Pre-Milking Cow Preparation

Observe pre-milking cow preparation procedures and measure the total amount of time spent in contact with each cow. Pre-milking preparation is performed to clean teats before unit attachment, to check for clinical mastitis and abnormal milk and, to stimulate milk letdown.

If milk quality issues are of concern, note the completeness of pre-milking teat sanitation. Teat end sanitation is important in reducing the number of bacteria at the teat end before the milking unit is attached thus reducing transfer of organisms from cow to cow by the milking machine. Proper teat end disinfection can reduce teat surface bacteria by 75% (Ruegg et al., 2000; Galton et al., 1984; Galton et al., 1986). Pre-dipping with a sanitizer

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1. The abbreviation “prep”, meaning preparation of a cow for milking, is widely used, as noun or verb, and is retained in this text.
was associated with reduced pathogen content in milk (Hassan et al., 1999) and has been shown to be effective in the control of environmental pathogens (E. coli and environmental streptococci) but has limited effectiveness against coagulase-negative staphylococci (Pankey, et al, 1987; Ruegg and Dohoo, 1997). While cleaning teats with water and wiping dry reduces the number of microorganisms on the teat skin, the reduction is significantly higher when teats are disinfected (Brito et al., 2000). Contact time of 20-30 seconds is needed for effective disinfection for most sanitizers.

If washing is required to remove excess manure, the following methods have been demonstrated to significantly reduce pathogen numbers: 1) only teats should be washed, 2) minimal water should be used, 3) teats should be thoroughly dried (Rasmussen, 2000). The most important portion of the teat disinfection process is thorough drying of teat ends. Air-drying is not a satisfactory substitute for manual drying with an individual cloth or paper towel. Water on teats aids in transporting bacteria and concentrating them at the opening of the teat canal. Cloth towels were more effective than paper at removing pathogens in a study by Rasmussen et al., (1991). When cloth towels are used they should be disinfected by washing with bleach or very hot water and drying at high temperature in an automatic dryer (Fox, 1997). To check the effectiveness of teat sanitation and drying, a clean swab can be rubbed across the end of the teat prior to unit attachment. A swab from a properly prepared teat will remain clean. A dirty swab indicates that teat preparation methods should be improved.

If milk quality is of concern, note whether fore-stripping is practiced. Fore-stripping plays a crucial role in reducing bulk tank somatic cell counts by identifying cows and quarters with abnormal milk. Examination of foremilk has been shown to be associated with reducing pathogens in bulk tank milk (Hassan, et al., 1999). The failure of milkers on 20% of dairy farms to strip cows before milking is identified as having significant effects on bacterial and somatic cell counts (Helmuth, 1996). Fore-stripping should be practiced in such a way to avoid transferring pathogens from cow to cow on the workers’ hands. In large herds with long working hours, forestripping can be a demanding task for the workers. In such cases, forestripping could be focused on groups of cows at risk, that is, during the first month of lactation, high SCC cows and cows prone to be dried off.

If average milk flow rates are low observe the milking routine to document the stimulation time and prep-lag time (Worstorff and Dethlefsen, 1994; Reneau and Chastain, 1995). Also note the percentage of cows that are injected with oxytocin as part of the pre-milking preparation routine. Chronic oxytocin treatment should not be necessary if proper stimulation is part of the pre-milking routine. Furthermore it has been shown that chronic oxytocin treatment causes reduced milk ejection in dairy cows (Bruckmaier, 2003). Estimates can be made of preparation and lag times using data from milking parlors equipped with milk meters (Eicker et al., 2000). Pre-milking teat stimulation causes induction of alveolar milk ejection before the start of milking, thus avoiding bimodal milk flow curves (that is, interruption of milk flow after removal of the cisternal milk) and reducing the amount of time that the milking machine is on the cow (Bruckmaier and Blum, 1996, Bruckmaier and Blum, 1998, Bruckmaier et al., 2001). In a large field study prep-time and prep-lag time had a significant effect on milk flow duration and machine-on time (Turki and Winnicki, 2001).

The combination of effective teat cleaning and fore-stripping will usually provide sufficient stimulation for milk letdown in dairy cows. Ten to 20 seconds of tactile stimulation is considered sufficient to elicit the milk let-down response in Holstein cows. However, different breeds may have differing stimulation requirements (Bruckmaier, 1998; Costa and Reinemann, 2003), for example, longer preparation significantly increased milk yield for Danish Jersey cows, but not for American or Danish Holstein cows (Rasmussen et al., 1992). Cows in later lactation have a higher stimulation requirement (Kliiman and Savelli, 2000) and the delay in milk ejection after the start of teat stimulation changes during the course of lactation and depends on the interval from previous milking (Bruckmaier et
A delay of about 1 minute between stimulation and unit attachment has been shown to minimize milk harvesting time (Rasmussen et al., 1992; Reneau and Chastain, 1995; Turki and Winnicki, 2001).

1.12 Unit Attachment
If vacuum stability in the milkline, milking unit slips and falls, or uneven milk-out are of concern record the method of unit attachment. The amount of air admitted during unit attachment has the largest single influence on slugging in the milkline and the resulting vacuum drops (Reinemann et al., 1995). Observe if air is being admitted by a single teatcup or by multiple teatcups during unit attachment. Also observe if efforts are being made to limit the amount of air admitted during unit attachment. Observe whether units are adjusted to hang evenly on the udder and if hose supports are being used and/or used effectively. Effective support should be provided for the long milk tube and units should be adjusted so that cluster weight is evenly distributed on the 4 teats. Even weight distribution of the cluster and adequate support for the long milk tube will result in fewer liner slips and unit fall-offs, and more even milk-out between quarters.

1.13 Unit Removal
If milking speed or completeness of milking are of concern, observe methods for unit removal and assess the amount of stripping yield (see section 1.17). Early unit removal may result in reduced milk yield and promote the development of sub-clinical mastitis to the clinical stage. Over-milking is the time of highest risk for damaging teat tissues (Hillerton et al, 2002b). A Danish experiment demonstrated that when the threshold setting on Automatic Cluster Removers (ACR) was raised from 0.2 kg/min to 0.4 kg/min the average unit-on time was reduced by 0.5 minutes and teat condition improved (Rasmussen, 1993). Milking units should be removed promptly when the milk flow rate from the udder drops below an endpoint of about 0.3 to 0.5 kg/min. Higher threshold settings and shorter detacher delays, resulting in improved teat condition and milking speed, have been successfully applied to herds milking three times per day and using milking routines with optimal stimulation and prep-lag times (Reid and Stewart, 1997; Stewart et al., 2002).

Disconnecting the removal mechanism from the claw and observing milk flow in relation to the time that the unit is removed can assess ACR function. For both manual and automatic removal, clusters should be removed by first shutting off vacuum to the claw and then removing teatcups so that little or no air is admitted to the teatcups as they are removed. Abrupt unit removal in the presence of vacuum was shown to be associated with increased risk of reverse pressure gradients across the teat canal (Rasmussen et al 1994). Machine stripping should not be routinely practiced.

1.14 Post-Milking Management
Evaluate the adequacy of post-milking teat spraying or dipping by wrapping a paper towel around the teat. Post-milking teat antisepsis was initially developed to reduce the transmission of contagious mastitis pathogens and has been widely accepted. Spray applicators are preferred by some operators because of convenience and to keep teat dip from becoming tainted with contaminated milk. While it is possible to adequately cover the teat using a spray applicator, it is difficult to accomplish in practice.

The last step in an effective milking routine is to ensure that the cows remain standing for as long as possible after milking is completed. This recommendation is based on studies showing that teat tissues require from 30 minutes up to several hours to recover to pre-milking conditions (Hamann et al., 1993; Neijenhuis et al., 2001a). Providing water and fresh feed after milking will encourage this behavior.
1.15 Milking Routines

The objectives of a milking routine are to provide teat sanitation, abnormal milk and clinical mastitis detection and pre-milking stimulation in a manner that is friendly to the cow and efficient for the workers. There are many ways to incorporate these performance goals into a work routine in a tie-stall barn or milking parlor. If labor efficiency is of concern document the time taken to perform the various aspects of the milking routine.

**Tie-stall barns**: Milking routine standardization in tie-stall or stanchion barns has been shown to improve milk yield (Rasmussen et al., 1990). Cows should be prepped and units attached in one step with a teat preparation time of at least 20 s. If less time is spent on prepping, unit attachment should be delayed for 20 to 30 s to avoid milking empty teats. If ACRs are not used special attention needs to be paid to detaching units in a timely fashion to avoid over-milking. Assess both the average and variability of prep and attach timing as well as milking unit-on times and over-milking to determine the adequacy of milking routines. Where ACRs are used the operator should milk with one unit more than required (in respect to the machine-on time) in order always to have a free unit for attachment on a newly prepped cow.

**Milking Parlors**: Good parlor performance starts with good cow entry, requires proper cow positioning, correct cluster alignment and prompt cow exit (Hillerton et al., 2002a). Evaluation of a milking parlor work routine should include measurements of:

- Time to moving cows into and out of a milking parlor
- Time spent for pre-milking cow preparation and unit attachment
- The time that the milking unit is on the cow
- Time to remove milking units (if ACRs are not used)
- Time for post milking sanitation.

The milking parlor management software that is used in milking parlors equipped with milk meters can also be used to monitor the work routines (Eicker et al., 2000). These task timings can be used to predict theoretical parlor productivity in cows milked per hour (Armstrong and Quick, 1986; Reinemann, 1993; Chang et al., 1994; Thomas, et al., 1996a, 1996b; Thomas et al., 1997). This figure can be compared to the actual productivity to estimate the efficiency of execution of the work routine and factors that will have the largest improvement on productivity (Armstrong et al., 1994; Helmuth, 1996; Smith et al., 1998; Hansen, 1999; Reppo and Lindsaar, 2001).

1.16 Milking Time and Average Milk Flow Rate

The average rate of milk harvest is a good indicator of the efficiency of milking (effectiveness of pre-milking cow stimulation, proper milking unit attachment timing, and point of detachment). The average harvest rate is calculated as the total milk yield divided by the total machine-on time. In milking parlors equipped with milk meters and automated data collection systems the average harvest rate for the entire milking herd can be easily obtained (Eicker et al., 2000). If automated data collection is not available a random sample of cows from the herd should be measured. A random sample of 10 cows from a typical herd will yield an estimate of the average flow rate of most herds to within about +/-0.5 kg/min. A random sample of 30 cows will improve the estimate to within +/- 0.25 kg/min (LeMire et al., 1998).

Field studies conducted in England (Clough et al. 1973) and the USA (Stewart et al. 1993) yielded the following equations for average milking time for cows yielding 10 to 20 kg of milk per milking.

\[ t_m = 2.8 + 0.21 Y \quad \text{(Clough et al. 1973)} \]
\[ t_m = 3.6 + 0.26 Y \quad \text{(Stewart et al. 1993)} \]

where: \( t_m \) = Average milking time per cow (minutes)
\( Y \) = mean milk yield per cow per milking (kg)

In general, settings of automatic cluster removers that produce earlier detachment have a
larger influence on average milking time than increasing milking vacuum level and introduce less risk to teat tissue.

Low milk harvest rate and longer milking times can result from interference with the letdown response due to uneasiness of the cows, inadequate cow stimulation, improper timing of unit attachment in relation to milk letdown, milking machine problems or over-milking because of improper detachment procedures.

1.17 Completeness of Milking
The completeness of milking can be assessed by hand stripping each quarter immediately after the milking machine is removed (Davis and Reinemann, 2001). If milking units are being removed at the proper time the majority of quarters will have little or no milk present after unit removal. It is common for the slowest milking quarter to have some milk left in the lower parts of the udder after unit removal. As a practical guide, suspect a problem of incomplete milking if more than 20% of quarters yield more than 100 mL of milk when hand-stripped immediately after unit removal (Davis and Reinemann, 2001). Consistent differences between strip yields from rear versus front quarters, or between quarters on the right versus the left side of udders, usually indicate a problem of poor cluster positioning or uneven weight balance between the four teatcups.

1.18 Teat Condition
Teat ends that are roughened because of excessive hyperkeratosis are more difficult to clean and appear to have a slightly higher risk for mastitis infections than teats with moderate roughness (Rasmussen et al., 2003; Neijenhuis et al., 2001b; Huusko, et al., 2002). If mastitis is of concern, score teats for the severity of teat-end rings or hyperkeratosis immediately after units are removed. Teats that are noticeably red or blue colored after unit removal also indicate circulatory impairment, which may contribute to discomfort of cows and prolonged teat recovery time. Record the number of teats with good condition (no ring or small ring with smooth skin, no roughness or fronding at the teat end, normal color after milking) and the number of teats in poor condition (raised ring that is rough and cracked giving the teat-end a flowered appearance or teats that have a bluish discoloration after milking). The criterion suggested is that less than 20% of cows should have a teat condition considered to be problematic. Of the milking management or machine factors, the total time per day when milk flow rate is less than about 1 kg/min appears to have a major effect on teat-end condition. This is influenced by pre-milking udder preparation practices or degree of over-milking, as well as milking equipment, such as the settings for ACR, high milking vacuum or liners with stiff mouthpieces. Greater detail on methods to assess bovine teat condition is presented by Mein et al. (2001), Hillerton et al. (2001), and Reinemann et al. (2001b).

1.19 Frequency of slipping or falling teatcups
Note the number of times the units must be adjusted by operators because of slipping or fall-off. A practical goal is less than 5% of cow milkings requiring correction by the operator(s) (Mein and Reid 1996). Heavy clusters, uneven weight distribution within the cluster, blocked air admission holes, and cows kicking at clusters are other common causes of slips and fall-offs. Note the stage of milking when the slips and falls occur. Flooding clusters or milklines tend to cause slipping or falling early in milking. Poor liner design, uneven distribution of weight between the four teatcups within a cluster, and cows kicking at clusters are the most common causes of slipping and falling late in milking.
1.20 Bacterial Quality of Milk

Bacterial evaluation of bulk tank milk is performed periodically on all farms to assure compliance with national, state, and local milk processing requirements. These tests typically include the somatic cell count (SCC), standard plate count (SPC) and may also include the preliminary incubation count (PI) or other tests. These tests provide an overall measure of milk quality but they have little diagnostic value in determining the source of bacterial contamination.

The two main sources of bacteria in raw milk are organisms transported from the environment into the milking system and mastitis organisms from within the udder. Bacterial growth may occur during milking and can be a significant concern as milking time increases. The bulk tank coliform count provides an indication of the cleanliness of the cows’ environment between milking and the effectiveness of cow preparation procedures during milking (see section 1.8). If the milking system and milk handling equipment are not properly cleaned and sanitized, bacteria deposited may multiply and become a major source of raw milk contamination. Elevated thermoduric bacteria counts are the best indicator of a milking cleaning failure. Further detail on test methods to diagnose bacterial milk quality problems are given by NMC (2004) and Ruegg and Reinemann (2002).

1.21 Working conditions

Note the hours of work expected of the operators and the number of breaks provided. Also note the body position and repetitive motions of the workers. The working posture in an elevated milking parlor should be as close as possible to an erect stance with arms and hands in a natural working position. The dimensions of the parlor and location of milking stations and stalls must be designed to accommodate good working postures (Gaudin et al., 1998). Note if the work routine requires repeated bending of the back and unnatural motions of the wrists when the workers are preparing cows and attaching milking units.

The risk of repetitive stress injury is high for the task of milking cows (Gustafsson and Lundqvist, 1987; Lundqvist, et al., 1997). Hand and wrist problems are very common when working with milking (Stal and Juliszewski, 2001). After 2 h of uninterrupted work, the efficiency of even highly trained and experienced operators can decrease because of physical tiredness, resulting in interruptions to milking and errors (Vostrikov, 1995). Milking in round-the-barn highline systems is stressful to the knees, hips and lower back, while milking in parlors with elevated cow platforms introduces stresses to the wrists, elbows, shoulders and upper back. High values of dorsiflexion and radial deviation were found which might contribute to the high prevalence of hand and wrists symptoms for example carpal tunnel syndrome among milkers. Furthermore, the velocity and repetitiveness were close to those values described in repetitive work with a high risk of elbow and disorders (Stal and Juliszewski, 2001). The high muscle loads in combination with extreme positions and movements of the hand and forearm might contribute to the development of injuries among milkers (Pinzke, et al., 2001). For milking with high-level pipeline systems, a stool tied to the back can reduce stress on the workers’ knees. Milking machines mounted on rails or cables carry much of the weight of the milking unit and relieve stress on the workers’ shoulders and back.

1.22 Statistical Considerations

An understanding of some basic statistical concepts can help field investigators make the best use of their time to collect data in the most efficient way to support and appropriate diagnosis of milking performance. An example of a common methodology to assess changes in the milking process is to make a change and “see what happens”. This approach does not account for chance bias over time that might affect the response. The most likely result of such an effort is an indeterminate conclusion (for example, the new liners may have affected something but we cannot say for sure). This approach does little to advance the knowledge of the dairy manager or investigator.
Field tests are limited by the amount of time, resources and number of cows available. Tests often need to be performed in one or two milkings or over one or two days. On a large dairy farm with automated data collection systems one of the practical limitations of performing a milking-time test is the organization of cows to receive the intended treatment. On dairies without automated data collection systems a single person will likely collect data. In this scenario a method to design an experiment with the best resolution that uses the fewest number of cows is highly advantageous. This can be accomplished by using careful experimental design which controls for the many sources of variability.

Milking parlours equipped with milk meters and electronic data collection systems offer the possibility of automated assessment of short-term milking performance. Data that can be used to assess operator or milking machine performance include milking time, average and peak milk flow rates, and milk yield for individual cows.

Statistical analysis can be a powerful tool to distinguish between real effect and random occurrence but all statistical analysis is built upon a set of basic assumptions. If these assumptions are violated the subsequent statistical analysis will have little value. Too few data or the wrong type of data will result in an unsupportable diagnosis. Too many data result in time spent in an unproductive manner. A review of statistical methods and some examples of their application to milking performance evaluation have been presented by Engelke et al., 1996; LeMire et al., 1998; LeMire et al., 1999; Reneau, 2000.

2. Basic tests of Pulsator Function and of Vacuum during milking

Proper pulsator function is critical to the success of the milking process. Pulsator function can be assessed either during a dry test or at milking time. Milking-time tests are the most direct method to determine the adequacy of vacuum production and vacuum regulation in any milking system. More detailed testing (as described in Section 3) can be used to diagnose the causes of any failures noted during the conduct of these basic tests.

Test equipment

A single-channel unit or multi-channel vacuum recorder and at least 4 teatcup plugs are required for correct testing of pulsators. Because most pulsator testers include an option for measuring vacuum level, the pulsator test unit can be used as an accurate digital vacuum gauge and for measuring vacuum stability in the milkline and claw.

Vacuum stability tests require the use of a recorder that can display the average, minimum and maximum vacuum recorded over a known or pre-set measurement period and with a response rate and sampling rate appropriate to the test location and test conditions (Reinemann et al., 2001c; Rasmussen et al., 2003). A list of test equipment has been assembled by an International Dairy Federation group of experts (IDF, 1999). A flow simulator (Stewart, 1997; O’Callaghan et al., 2001) can be used for a wet test of average vacuum levels in the claw at known flow rates and vacuum drop through components in the milkline.

2.1 Pulsator Testing

These tests are done with milking units connected, pulsators operating and liners fitted with teat cup plugs. The objective of these tests is to determine if the pulsation system and all pulsators are operating according to the manufacturer’s specifications. Pulsator testers are used to determine the pulsation rate and the duration of the four phases of pulsation. The main parameters of interest for pulsators are (ISO 5707; Hamann and Mein, 1996):

- Pulsation Rate should be repeatable from day to day and should not deviate more than
cycles per minute from one unit to the next.
• Pulsator Ratio should not differ by more than 5 percentage units from manufacturer's specifications or from one pulsator to another.
• The B Phase (milking or liner-open phase) of pulsation should be at least 30% of the cycle
• The D Phase (massage, rest or liner-closed phase) of the pulsation cycle should not be less than 15% and not less than 150 milliseconds.

Manufacturers provide more detailed specifications for individual pulsator types. If any pulsation characteristics fall outside these guidelines, further checks by the manufacturer's representative are recommended.

Vacuum Measurement during milking
The most fundamental vacuum specification for milking is that the vacuum level in the claw be maintained in an appropriate range during milking. To support this objective, the vacuum in the milkline and in or near the receiver should be within a reasonable range during normal milking. Normal milking is considered to be the time that milking units are attached to cows, including events such as teatcup attachment and removal, liner slips and cluster fall-off. Recommendations for measurement methods and interpretation for each measurement site follow.

2.2 Average Claw Vacuum
The recommended average claw vacuum is from 32 to 42 kPa (averaged over 5 to 10 seconds) in the claw during peak milk flow for the majority of cows (See section 2.5 and ISO 5707). The vacuum at the regulator sensing point should be adjusted to achieve this objective. Connect a suitable vacuum recorder to the claw using one of the following methods:
• Connect a suitable test T-piece between the long milk tube and the claw outlet (except for top-outlet claws).
• Insert a 12 or 14 gauge needle through the short milk tube of the liner. The needle should be at least 60 mm long to ensure proper location of the needle through the claw nipple and into the top of the claw bowl. The end of the needle should be located out of the milk flow stream.
• Use a claw fitted with a test port that is located out of the milk flow stream.
Measure average claw vacuum during peak milk flow on a representative sample of cows from the herd according to the methods in Rasmussen et al., 2003.

2.3 Vacuum Stability in the Milkline and Receiver
The vacuum in the receiver should not differ by more than 2 kPa from the working vacuum during normal milking (ISO 5707). In addition, the vacuum in the milkline should not differ by more than 2 kPa from the receiver vacuum at any point in the milkline for at least 95% of the normal milking period. Make sure that recordings are taken during the operation of all equipment that is normally operated during milking. Vacuum at these sites should be recorded while the system is under full milk and air flow conditions, that is, while clusters are being attached, while all clusters are on cows, and then as clusters are detached. These tests should be performed for at least 3 cluster changes (detach from one group of cows and attach to the next) in a milking parlor or stanchion barn.

Connect the vacuum recorder to the milkline. If the vacuum change in the milkline (average minus minimum, and maximum minus average) does not exceed 2 kPa the milkline vacuum stability meets international standards. If the system passes the milkline vacuum stability test it is not necessary to record vacuum stability in the receiver. Additional measurements should be made in the receiver to determine if vacuum fluctuations in excess of 2 kPa in the milkline are caused by milkline slugging or by inadequate vacuum production or regulation (Rasmussen et al., 2003).
2.4 Vacuum in the mouthpiece chamber
The mouthpiece vacuum during milking can be measured for diagnostic purposes to determine if this is a cause of rings at the base of the teat and/or discolored or swollen teats after milking. According to Rasmussen, 1997, the average MPC vacuum should be at least 10 kPa less than the average claw vacuum during peak milk flow. This is an indication that the liner is able to close around the teat end during the collapse or massage phase of pulsation. Teat congestion and ring marks at the base of the teat appear to be reduced when average MPC vacuum does not exceed 20 kPa. Vacuum in the mouthpiece chamber decreases as teats penetrate deeper into the liner and a marked change in MPC vacuum occurs at the start of over-milking (Borkhus and Rønningen, 2003). Large diameter liners produce greater vacuum in the MPC (O’Callaghan, 2001).

2.5 Wet Tests with a Flow Simulator
A flow simulator is a useful tool to help determine the correct system vacuum level. A flow simulator provides an easy, convenient and reliable method of measuring average claw vacuum, and vacuum drop through the long milk tube and through ancillary equipment such as sensors and milk meters at known water flow rates. The vacuum at the regulator should be set to achieve the desired average claw vacuum during peak milk flow. Flow rates of 3.5 L/min to 5.5 L/min cover the range of expected peak flow rates for high producing cows. The results of vacuum measurements made using a flow simulator can be compared with the average claw vacuum recorded during milking to estimate the peak milk flow rate of individual cows. Flow simulators can be used as a reasonable estimate of the average vacuum in the claw but do not provide a reliable estimate of vacuum fluctuations in the claw or short milk tube during milking (Stewart et al. 1996).

3. Complete Professional Machine Evaluation
A milking machine technician should perform a complete system evaluation after each 500 - 1000 hours of operation as part of a regular testing service and maintenance contract. In addition a complete system evaluation should be performed on any new system, whenever modifications are made to the milking machine, or when milking time tests indicate that there may be a problem with the milking machine. A complete evaluation of the vacuum level and airflow in milking machines includes the following measurements:
- Rate and ratio of all pulsators (Section 2.1)
- Detachment threshold for automatic cluster removers
- Operating vacuum in the receiver and vacuum difference between the receiver and the vacuum pump, regulator and pulsator air line.
- The ‘fall-off’ test to determine if the system has enough reserve capacity to cope with a unit fall-off (Section 1.6).
- Effective Reserve and Manual Reserve;
- Regulator “undershoot” or “overshoot” when 1 unit is opened and then closed
- Air used by components: Pulsation system, clusters, regulator, and other ancillary equipment.
- System Leakage
- Vacuum Pump Capacity
Priority of Recommendations
It is important to realize that there are many reasons to suggest changes to a milking system including:
• Improve milking performance (speed/completeness of milking).
• Improve mastitis control and milk quality
• Decrease power/energy consumption.
• Decrease wear on pump components.
• Improve cleaning performance.
• Aesthetic or cosmetic reasons.

When the evaluation of the milking machine is completed, recommendations should be listed in order of priority according to their likely cost-benefit for the client, as follows:
Priority 1 - Urgent and important changes
Priority 2 - Important but not urgent improvements
Priority 3 - Cosmetic or other improvements
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### Table 1. Concerns related to milking performance.

<table>
<thead>
<tr>
<th>Slow Milking</th>
<th>Milk Quality</th>
<th>Milk Yield</th>
<th>Teat Condition</th>
<th>Cow Behavior</th>
<th>Unhappy Workers</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
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<tr>
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<td>Parlour Efficiency, Cows Milked per Hour (cows/hr)</td>
<td>Somatic Cell Count (Bulk Tank and Individual cow SCC)</td>
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</tr>
<tr>
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<td>High Yield (1.16), Cow Behavior (1.9)</td>
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<td>Genetics</td>
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</tr>
<tr>
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<td>Control over work environment, level of pay, unit slips and falls (1.12, 1.19, 1.21)</td>
</tr>
<tr>
<td>ACR setting (1.13, 1.17), Milking vacuum level (1.2, 1.4, 1.5, 1.6, 2.2, 2.3), pulsation (1.7, 2.1), liner design (1.1), Maintenance (3)</td>
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<tr>
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<td>Cow Cleanliness (1.8) Ease of cow movement, gates, lanes, etc.</td>
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<td>Clean dry housing environment (1.8), chemical contamination, change in climate</td>
</tr>
</tbody>
</table>
EVALUATING MILKING PERFORMANCE
ABSTRACT

Overview of commonly-encountered problems in machine milking of cows and guidelines for methods for evaluating the milking installation, its operation and the interaction between equipment, cow and operator based on recent experience of dairy advisers, udder health specialists and milking machine technicians. Suggests measurements to quantify aspects of milking performance with a view to recommendations concerning the milking process and determining whether measures introduced have had an effect (102 references).

Keywords: ACR, automatic cluster removal, bovine, cow behavior, cow cleanliness, cow handling, cow preparation, liner, mastitis, milking equipment, milking routine, over-milking, pulsation, pulsators, SCC, somatic cell count, Streptococcus, sub-clinical mastitis, teat cleaning, teat condition, teat end, teatcup, udder cleaning, vacuum level

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* Usually double quotes and not single quotes
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± Half-space before and after
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Infra-red With a hyphen
et al Not underlined nor italic
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ml, mg,... Space between number and ml, mg,...
skimmilk One word if adjective, two words if substantive
sulfuric, sulfite, sulfate Not sulphuric, sulphite, sulphate (as agreed by IUPAC)
AOAC international Not AOAC
programme Not program unless a) author is American or b) computer program
milk and milk product rather than “milk and dairy product” - Normally some latitude can be allowed in non scientific texts
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No space between figure and % - i.e. 6%, etc.
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