Measuring Milking Machine Liner Slips

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ABSTRACT

Liner slip or rapid air leakage past the mouthpiece of the milking machine liner has been identified as a cause of new infection in the bovine mammary gland. A device has been developed to differentiate and count the abrupt losses of milking vacuum due to liner slips from the many other vacuum fluctuations that occur in the clawpiece during milking. A Microswitch® transducer converts vacuum to an analog direct current output voltage. An electronic comparator monitors the transducer output and closes a gate switch to a digital counter when a large, high speed vacuum change occurs. This vacuum change is initially set to activate the initial slip counter when the vacuum change is greater than 8 kPa in less than .25 s. The magnitude threshold is adjustable; however, the time base is fixed. The counter is then blocked from responding to a new signal for 5 s, because subsequent large fluctuations (squawks) may occur following the initial slip. A second major fluctuations digital counter responds to all large fluctuations beyond an adjustable vacuum threshold without a time base element.

(Key words: liner slip, vacuum, milking machines)

INTRODUCTION

Wilson (11) in 1958 first suggested that vacuum fluctuations in the milking machine might be related to new infections in dairy cattle. Nyhan (2) observed higher bulk tank SCC when vacuum reserves were low; low reserves resulted in irregular vacuum fluctuations. Researchers at The National Institute for Research in Dairying in the United Kingdom determined that combinations of large cyclic and irregular vacuum fluctuations increased the new infections rate (8). They also observed a phenomenon known as the impact mechanism, which was postulated to be the transfer means by which pathogens moved to the interior of the cow's teat (9).

Irish workers (5), while attempting to repeat and elucidate upon the work in England, determined that new infections increased with large cyclic and irregular fluctuations only when these conditions were accompanied by liner slip. Thompson et al. (10) demonstrated a marked increase in new infections in a challenge study when cows were subjected to an abrupt loss of milking vacuum. Simulated liner slips by Woolford (12) also increased new infections. Cornell workers (1) measured reverse pressure gradients across the teat canal during periods of low milk flow when bursts of air were admitted below the teat end.

The importance of liner design was demonstrated by trials with liners prone to slip compared to low slip frequency liners. Cows milked with low slip liners had fewer infections than cows milked with liners with numerous slips (4). Milking machine factors such as vacuum reserve (7), pulsation rate and phase, and pulsator ratio have little influence on liner slip (6).

Liner slips result in massive, high speed vacuum changes at the teat end (3, 9). The resulting increase in air flow that occurs in the milking unit was measured by heated wire anemometry techniques by O'Callaghan and O'Shea during the period 1975 to 1984. In 1984, a computer-based system was installed at the Moorepark Research Centre in Ireland to mea-
sure liner slips (personal communication).

Our objective was to develop a device to detect and measure the frequency of liner slip. Two approaches to a liner slip measurement system were considered: 1) measurement of air flow as a consequence of the slips, or 2) identification of the rapid vacuum changes that take place below the teat end.

**MATERIALS AND METHODS**

Attempts were made to duplicate the air flow method used in Ireland to measure liner slips. However, the necessary air and milk separation equipment was not available. It was also attempted to measure the air flow in the supply hose to weigh vessels to detect liner slips. The vacuum reserve within the vessel attenuated the signal so that slips were difficult to identify.

Analysis of numerous strip chart recordings taken at the clawpiece revealed that liner slips have unique vacuum change characteristics that could be sorted electronically from numerous other vacuum fluctuations. Liner slips occur at random and are characterized by having an acute vacuum drop characteristic (Figure 1). These high speed vacuum changes are the potential source of energy that provide the mode of the infection process rather than the resulting air flow. It was therefore decided to pursue measuring the rapid changes of vacuum that occur in the clawpiece as a result of liner slip. In choosing this method, it was deemed necessary to avoid measurement of cyclic vacuum fluctuations in the clawpiece as a result of liner wall movement. It was found that cyclic vacuum fluctuations with simultaneous pulsation (4 x 0) have a rise and fall time of about 1 s at the clawpiece when pulsation rate is 60 pulsations/min. The cyclic variation in the clawpiece with alternating pulsation (2 x 2) at 60 pulsations/min was .5 s at about half the magnitude of simultaneous pulsation. The vacuum drop or fall time of the cycle in the clawpiece is approximately .5 s. Part of the cycle may have a fall time of less than .2 s due to liner wall movement, but the magnitude is less than 4 kPa (3.38 kPa = 1 inch Hg).

It was also deemed necessary to measure the vacuum drop from the mean milking vacuum since differences in claw vacuum are dependent upon individual cow milking rate. Measurement from the mean milking vacuum also reduces the effect of cyclic variation to half the magnitude of the drop. Fluid flow variation during milking may result in some high speed vacuum changes in the clawpiece; however, rapid changes of this type were less than 4 kPa in magnitude. Thus, it was decided to design the liner slip counter based upon a vacuum drop from the mean milking vacuum of 8 kPa in less than .25 s. Using these criteria, the fluctuations as a result of liner wall movement and fluid flow variations would not be counted. A potentiometer permits an increasing or decreasing adjustment of amplitude with fixed time base from this starting specification.

Observation of numerous strip chart recordings revealed that an initial liner slip is sometimes followed by a sequence of large vacuum variations that are often audible liner squawks. It was decided to avoid counting those variations as initial liner slips, since squawks are a consequence of the initial slip. Therefore, a 5-s hold was applied to the initial slip counter, since, in most instances, a machine operator is able to make manual machine adjustments to stop the squawk sequence in this time allotment. Using these criteria, the initial slip could be assigned to the liner performance and operator performance omitted in the count. The reset counters also permit avoidance of operator-induced fluctuations by resetting the counter immediately after applying the milking units. It is

![Figure 1. Strip chart recording of clawpiece vacuum showing abrupt loss of milking vacuum due to liner slip. Read chart right to left.](image)
recognized that if correction by the operator is not accomplished in 5 s, an additional slip is assigned to the liner.

However, it seemed important to be able to count the number of large fluctuations to which the cow was subjected. A second counter was incorporated into the design, which counted all variations of a large magnitude, nominally at 20 kPa below atmospheric pressure. A potentiometer permits adjustability and calibration from this specification.

An electronic circuit was designed to detect and count liner slips using the sudden vacuum drop as a slip indicator. Clawpiece vacuum is sensed using a solid state Microswitch® (Division of Honeywell, Freeport, IL) transducer #141PC15GL, which contains active interface electronics to translate vacuum into a d.c. output voltage. Although the output signal voltage will tolerate a small amount of loading, it was thought useful to buffer that voltage to minimize any loading effects presented by subsequent circuitry. The sensor output was therefore buffered in one operational amplifier stage connected in the noninverting unity gain configuration. The buffered voltage was then divided into two paths for further analog processing leading to the two output digital event counters.

The more complex path ends in the "initial slips" counter. The buffered sensor signal feeds an operational amplified differentiator stage, which, in conjunction with the following comparator stage, outputs a pulse when the input signal represents a vacuum drop of 8 kPa or more in less than .25 s. The circuit criteria for pulse output are determined by differentiator time constant and comparator trip voltage setting, (the initial slips control). The resultant pulse triggers the initial slips digital counter and indexes it one count. Simultaneously the pulse triggers a 5-s, one-shot logic circuit that prevents the counter from being further indexed for 5 s. In this way “squawks” are ignored, thus assuring a more accurate initial slips count. A potentiometer permits sensitivity adjustment and calibration of the circuit to respond to vacuum drops of a greater or lesser magnitude if desired. Although magnitude is adjustable, time base is fixed.

The second path ends with the "major fluctuations" counter. The buffered sensor signal feeds directly into a comparator stage with adjustable trip threshold without a time constant. This comparator stage is generally set to trip, and thus shift output voltage, when at any time the sensor voltage represents a vacuum drop of 14 kPa or more from the initial setting. The abrupt shift in comparator output voltage at threshold triggers the major fluctuations digital counter, thus indexing it one count. No squawk notch is applied to this counter; it is immediately able to be reindexed. A potentiometer permits changing or calibrating the vacuum threshold to desired criteria of a major fluctuation. Settings at 20 kPa from atmospheric pressure are utilized arbitrarily. Machine removal results in activating this counter so the results must be recorded as N minus 1.

The digital counters used in this device are separate vendor supplied subassemblies (Digit-Key Corp., Thief River Falls, MN) with built in lithium battery power said to provide a life of several years. Each counter has a front panel "zero" pushbutton for ease in clearing the display when desired.

The completed device (Figure 2) was designed to operate from either an internal 9-V alkaline battery, which can provide several hours service, or from an external 12-V d.c. source. The internal circuitry is arranged to operate the device automatically from the 12-V source, if present, and to default to internal 9-V operation if not. The circuit was designed to minimize battery drain through the

Figure 2. Line slip detection and counting unit.
use of low power active circuits and moderately large impedances. This circuit solves the needs posed by the device criteria mostly through the use of analog circuitry. This was done in the interest of simplicity and low cost.

Simplicity, ease of assembly, and low cost also influenced the choice of method of construction. One single-sided printed circuit card attached to the rear of the front panel contains nearly all of the circuitry. The front panel also mounts the controls and digital counters. The Microswitch® sensor, the 9-V battery, and 12-V connector are mounted to the bakelite case, which along with the front panel, assemblies to make a compact, fairly rugged finished device. It is attached to a hanger bracket to fit standard milk meter attachments for optimum portability.

RESULTS

Ten units were constructed to equip up to a 10-stall milking parlor. Each unit was bench tested to calibrate and check for meeting design criteria. The results of the transducer tests are shown in Figure 3. The results of the electronic comparator reference voltage relative to potentiometer dial position are given in Figure 4.

Two units were tested at cowside and simultaneously compared to an electronic strip chart recorder (Technical Industries, Fort Lauderdale, FL), which was assumed as the standard. The detection unit was connected to the top of the clawpiece with a .5-cm x 1.5-m tube. The recorder transducer was placed 15 cm from the detector transducer on a teepiece of the connecting tube. Cows were milked in a single-side, eight-stall, herringbone parlor equipped with automatic takeoff units located 1.2 m above the cow platform. Milking vacuum was 47 kPa with alternating pulsation at a 60:40 ratio and 55 pulsations/min.

Milking vacuum recordings of 16 cows for each of the two slip detectors were observed. The detector counts on the upper and lower counters were noted on the strip chart as they occurred and later compared with the fluctuations appearing on the strip chart. There were 31 slips with 16 cow milkings on unit 1 and 36 slips on unit 2 (16 cow milkings) observed on the strip chart recorder for a total of 67 slip observations from 32 cows. The slip detector recorded 64 of the 67 initial slips. There was one false positive on each unit tested where the unit counted but the vacuum drop reflected on the recorder chart did not indicate an 8 kPa drop in less than .25 s. Considering the three slip events that occurred and were not counted and the two false positives, the device in actual use had an accuracy of 92.5% on the initial slip counter circuit. There were 88 major fluctuation events with 32 cows on the lower counter with no errors in identification by the detection unit compared with the strip chart recorder. The overall accuracy of the unit using the combined data was 96.8%. The differences between the two circuits are thought to be related to calibration precision between the two instruments. The major fluctuations circuit is easier to calibrate since a vacuum setting only is considered.

Figure 3. Microswitch® transducer #141PC15L output using 8.0 d.c. V supply.

Figure 4. Comparator reference volts to rotary dial potentiometer setting.
while the initial slips counter is time and difference from mean milking vacuum based. The latter was not tested at cowside.

CONCLUSIONS

A slip detection unit has been developed with sufficient accuracy to identify milking machine liner slips. This unit can be used to evaluate the factors that relate to milking machine liner performance.

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