Evaluation of the Milking Machine Pulsator Characteristics by the Means of a Computer Controlled System

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Abstract. A computer-controlled system was developed in order to evaluate the working characteristics of the pulsator of a mechanical milking machine. The system contains a pulse generator, allowing the adjustment of both the pulsation rate (between 10 and 120 cycles/min) and extraction to massage ratio (between 10 and 90%), and a cyclic pressure indicator, which monitors the pressure applied to the teatcup short pulse tube. Two types of pulsators were tested in order to evaluate the precision and parameters of the developed system.

Keywords: milking machine, pulsator, milking to massage ratio.

INTRODUCTION

We have been milking cows with the same basic assembly of teatcup shell and liner for the past 100 years. The basic concepts of milking cows quickly, cleanly and gently have, indeed, remained unchanged. There has been a steady advance, however, in our understanding of the milking process from the perspective of the cow and the machine. Many of these advances have occurred because the challenges of performing “successful” milking have increased as milk production and milking frequencies have steadily increased over the past 100 years. These challenges have been the mother of invention and the advance of science and practice has resulted in milking machines and milking procedures that can successfully milk cows with a wider range of teat size and producing over 10 times more milk than when teatcup and liners were first introduced. As a matter of necessity, advances in milking technology and milking procedures have also resulted in considerably faster milk removal that is at the same time gentler on the cow.

One of the major advances in mechanical milking was the introduction of the pulsation principle. Pulsation is defined as "cyclic opening and closing of a teatcup liner”. The development of pulsation was a major turning point in the adoption of mechanical milk harvesting systems, the main purpose of pulsation being to limit the development of congestion and edema in the teat tissues during machine milking. In addition to, or because of, this primary function, pulsation helps to:

• maintain a high rate of milk flow from the teat within each pulsation cycle;
• reduce the rate of new mastitis infections;
• counter the possible ill effects of teat congestion on the level of discomfort or pain experienced by the cows;
• stimulate good milk letdown.
An example pulsation cycle (at a pulsation rate of 60 cycles/min) is shown in figure 1. Milk starts to flow from the teat during the $a$-phase (or opening phase) of pulsation. Typically, milk will start flowing at a time corresponding to a point about 25 – 50% up the $a$-phase curve. The exact time at which milk flow starts depends mainly on the mounting tension and wall thickness of the liner. Milk flow continues throughout the $b$-phase (the open phase) and into the first part of the $c$-phase (the closing phase). Milk stops flowing at a time corresponding to a point about 50 – 75% down the $c$-phase curve and the teat canal remains closed throughout the $d$-phase and into the first part of the opening phase (CowTime Quick Note 4.3).

Both field experience and research have shown that a relatively narrow range of pulsation rates and ratios is required to ensure good teat-end health, good udder health and to optimize milking speed. The preferred range for pulsation rate is about 55 to 65 cycles per minute. The preferred range for pulsator ratio is about 55:45 to 65:35. At a pulsator ratio of 80:20, the peak milk flow rate is often lower than at 65:35 or 70:30, probably because there is insufficient time for an adequate compressive load to be applied to the teat-end at such a wide ratio.

![Fig. 1. Definition of the phases of mechanical milking](image)

Taking into account the importance of the milking time to massage ratio and the above-mentioned facts about the real duration of the extraction phase, it is important to develop a system allowing the evaluation of the pulsator characteristics. Moreover, such a system is useful when diagnosing pulsator faults.

For example an unusually slow $a$-phase combined with a rapid $c$-phase indicates the likelihood of an air leak from atmosphere; the combination of a normal $a$-phase, an unusually long $c$-phase and a short $d$-phase often means there is a partial blockage in the pulsator air port.

A $d$-phase that does not reach atmospheric pressure even though the graph is more or less horizontal during the $d$-phase usually indicates foreign matter stuck between the pulsator valve and the valve seat, while the combination of a slow $a$-phase and a slow $c$-phase usually indicates a restriction to air flow in both directions; finally, a transient jump in vacuum during the $d$-phase may indicate dirty filters or insufficient capacity of the filters in the fresh airline supplying atmospheric air to the pulsators (CowTime Quick Note 4.3, 2003).
MATERIALS AND METHODS

Two different systems were designed:

- a computer controlled impulses generator, controlling an electromagnetic type pulsator;
- a computer controlled pressure-recording system.

The impulses generator consisted of an electronic interface, connected to the computer parallel port, and computer software, written in Visual Basic, which allowed modification of the pulsation rate and of the extraction/massage ratio. Fig. 2 presents the electromagnetic pulsator, while the graphic interface of the software is shown in Fig. 3.

![Fig. 2. Electromagnetic pulsator](image)

The pulsation rate may be adjusted between 10 and 120 cycles/min, while the extraction to massage ration may be adjusted between 10 and 90%.

The computer controlled pressure recording system consists of:

- absolute pressure transducers type SPD015AAsil (Fig. 4), with analogical output and absolute pressure range between 15 and 102 kPa;
- data acquisition board type USB6009 (National Instruments), with a sample rate of 48 ksamples/s and 4 differential analog input channels; Fig. 5 shows the electric diagram of the system;
- a virtual instrument, designed with the LabView 7.1 software package, allowing both the visualization and the recording of the pressure signals; Fig. 6 shows the graphic interface of the virtual instrument.

Two types of pulsator were tested:

- an electromagnetic one (Fig. 2);
• a STIMO IQ type pulsator, equipped with its own electronic pulses generator, with the following features: 60 cycles/min pulsation rate and 60/40 milking to massage ratio.

In order to record the pulsator signals, the pressure transducer was mounted on the short pulse tube of the teatcup shown in Fig. 7 (CowTime Quick Note 4.1, 2003).
Fig. 8 shows a general view of the testing systems and a chart of the pressure signal is shown in fig. 9.

The durations of the a…d phases were evaluated according to the schematics presented in Fig. 10.

RESULTS AND DISCUSSIONS

In order to calibrate and verify the test systems, two series of experiments were developed; in one series, the electromagnetic pulsator was tested in the following conditions:

- pulsation rate – 40 cycles/min;
- milking to massage time ratio – 50/50 and 60/40;

In the second series of tests the electromagnetic and STIMO IQ pulsators were compared in the same working conditions: 60 cycle s/ min and 60/40 milking to massage duration ratio.

The results of the tests concerning the electromagnetic pulsator are presented in fig. 11. For the 50/50 pulsation rate, the study of the recorded data and chart leads to the following conclusions:

- the measured pulsation rate is 40 cycles/min, thus confirming the accuracy of the computer controlled pulses generator;
- for the 50/50 pulsation ratio, the real value of the d-phase is 0.6 s, while the duration of the b-phase is 0.4 s;
- if the above mentioned intervals for milk flowing are taken into account (25..50% of
the a-phase + b-phase + 50...75% of the c-phase), the maximum time for milk flowing is 0.775 s and the minimum milk flowing time is 0.65s;

- the duration of the c-transition phase is 0.1 s, while the duration of the a-transition phase (teatcup liner opening) is 0.4 s.

For the 60/40 pulsation ratio, the real value of the maximum vacuum (b) phase is 0.55 s, while the atmospheric pressure (d) phase lasts 0.4 s. The total milk flowing time would be comprised between 0.825 and 0.962 s.

![Fig. 11. Experimental results for the electromagnetic pulsator](image)

In these experiments the pulsation rate was evaluated as the ratio between the time the pulsator coil was energized and the time it was at rest; the real pulsation ratio, showing the percentage of the maximum vacuum phase and of the atmospheric phase in the overall cycle duration, is presented in Tab. 1.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Theoretical pulsation ratio: 50/50</th>
<th>Theoretical pulsation ratio: 60/40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum vacuum (b-phase)</td>
<td>27%</td>
<td>37%</td>
</tr>
<tr>
<td>Atmospheric pressure (d-phase)</td>
<td>40%</td>
<td>27%</td>
</tr>
</tbody>
</table>

From Tab. 1 it is clear that, for the 50/50 pulsation ratio, the pulsator does not meet the requirements of the ISO 5707 standard, that states that the phase b shall not be less than 30% of the pulsation cycle.

Fig. 12 presents the comparative results for the STIMO IQ pulsator and the electromagnetic pulsator. There are minor phase differences between the two diagrams because the two pulses generators (the computer driven one and the generator of the STIMO IQ pulsator) are not synchronized and no special measures were taken in order to stabilize the frequency. The STIMO IQ pulsator presented variations of the cycle period lower than 50 ms.

The STIMO IQ pulsator registered a shorter a-phase (0.3 s) then the electromagnetic pulsator (0.35 s), while the opposite situation occurred for the c-phase (0.1 s for STIMO IQ and 0.05 s for the electromagnetic pulsator). As a result, there were differences in the duration of the maximum vacuum phase (b-phase): 0.35 s for STIMO IQ pulsator and 0.3 s for the electromagnetic pulsator.

The shorter c-phase of the electromagnetic pulsator shows that a larger cross-section
duct is available in order to connect the distributor to the atmosphere; in the meantime, a shorter c-phase could lead to a lower milk flow rate (Kochman et al., 2008), but we should take into account that the physical presence of the teat could cause the prolongation of this phase.

Consideration of the above mentioned intervals for milk flowing led to the following results:

- for the STIMO IQ pulsator, milk flow duration may be comprised between 0.55 s and 0.65 s;
- for the electromagnetic pulsator, milk flow duration is comprised between 0.5 and 0.6 s.

Tab. 2 presents the ratio of the b and respectively c-phase to the entire cycle duration.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Pulsator type</th>
<th>STIMO IQ</th>
<th>electromagnetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum vacuum (b-phase)</td>
<td></td>
<td>35%</td>
<td>30%</td>
</tr>
<tr>
<td>Atmospheric pressure (d-phase)</td>
<td></td>
<td>25%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Both pulsators presented a threshold during the transition phases (during the a-phase for the electromagnetic pulsator and during the d-phase for the STIMO IQ); these are probably due to the aerodynamic properties of the pulsators.

CONCLUSIONS

A computer controlled system was developed in order to test and diagnose the pulsators of a mechanical milking machine. The system was comprised of:

- a computer controlled impulses generator, controlling an electromagnetic type pulsator;
- a computer controlled pressure-recording system.
In order to test the system, two types of pulsators were tested: an electromagnetic one, driven by the computer-controlled impulses generator, and a STIMO IQ pulsator, with its own electronic pulses generator.

The use of the computer controlled system allowed the evaluation of the duration of the a...c phases, showing significant differences between the pulsation rate defined as the ratio between the time the pulsator coil was energized and the time it was at rest and the real pulsation ratio, defined as the percentage of the maximum vacuum phase and of the atmospheric phase in the overall cycle duration.

In the absence of the real teat inside the liner, the duration of the c-phase was comprised between 0.05 and 0.1 sec, in all the testing conditions. According to Kochman et al. (2003), a shorter c-phase can cause physical discomfort to cow and diminish the milk production. It is obvious that further researches must be conducted, using an artificial teat (as the one presented in the ASAE EP445.1 standard) inserted into the liner, in order to obtain the values of the c-phase in conditions as close to real ones as possible. In the meantime, the use of a force transducer placed between the artificial teat and the liner (as presented by van der Toll et al., 2010) would allow the evaluation of the pressure distribution at the teat-liner interface during the c-phase and its relationship with the duration of this phase.

REFERENCES