Development of a Computer Controlled System for the Evaluation of the Milking Machine Pulsator and Liner

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Summary
A computer-controlled system was developed in order to evaluate the working characteristics of the components (teatcups, pulsators) 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 systems: an electromagnetic pulsator and also a STIMO IQ one.
After the reliability of the system was confirmed, three types of milking teatcups were tested, in order to investigate the effect of the liner type over the pulsation cycle (duration of phases and pulsation ratio), when a hydropneumatic pulsator is used.

Key words: 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.

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" [CowTime Quick Note 4.3, 2003]. 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;
- counteract the possible ill effects of teat congestion or 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, 2003].

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/min. The preferred range for pulsator ratio (a+b)/(c+d) 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.

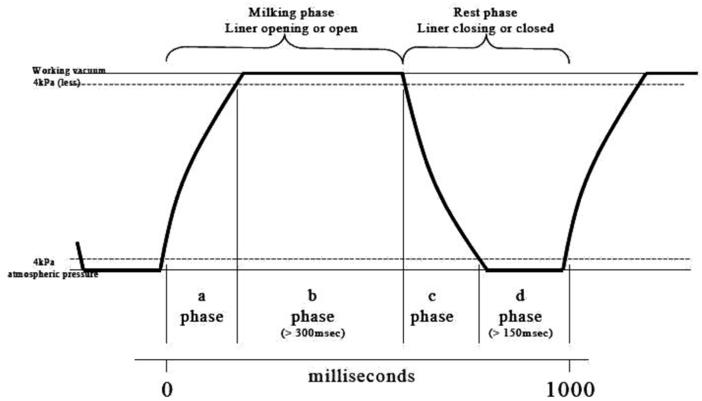


Figure 1: Definition of the phases of mechanical milking.

Taking into account the importance of the milking time to massage ratio (pulsation 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 and teatcups 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 air line supplying atmospheric air to the pulsators [CowTime Quick Note 4.3, 2003].

Material 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 a computer software, written in Visual Basic. *Figure 2* presents the flowchart of the computer software, while views of the impulses generator and electromagnetic pulsator are shown in *Figures 3* and *4*. The computer software allows the adjustment of the pulsation rate, between 10 and 120 cycles/min, and of extraction to massage ratio, between 10 and 90%.

The computer controlled pressure recording system consists of:

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

During all the tests an artificial teat was used, according to the requirements of the ASAE EP445.1 standard.

For the first tests a two pieces type teatcup was used; the main dimensions of the rubber liner (barrel) are presented in *Figure 7.* During these tests two types of pulsators were used: the electromagnetic pulsator and a STIMO IQ electronically controlled pulsator.

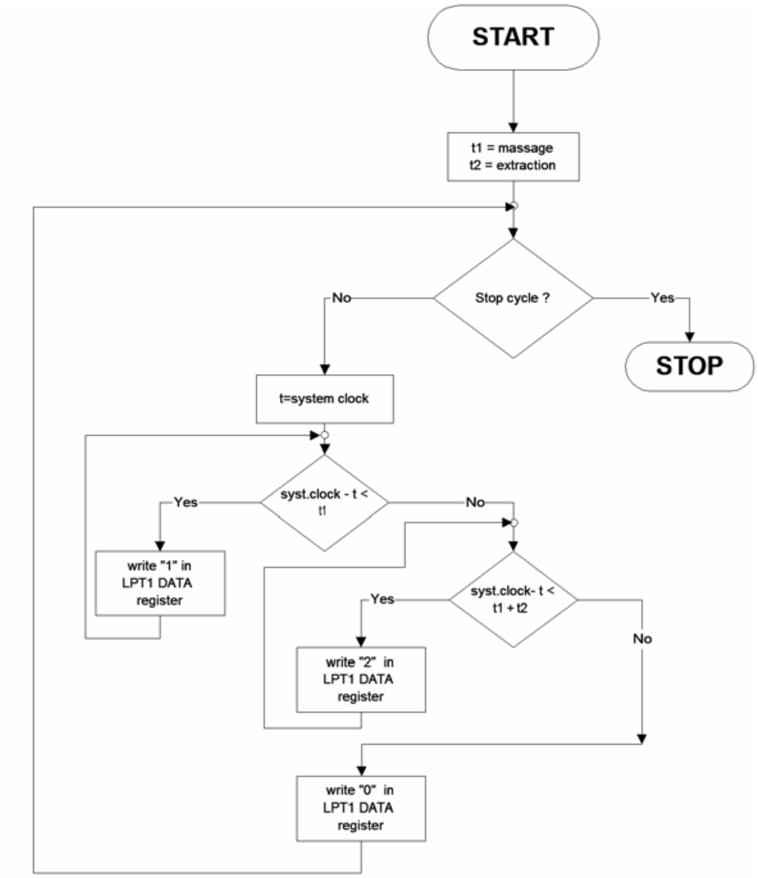


Figure 2: Flowchart of the computer software.

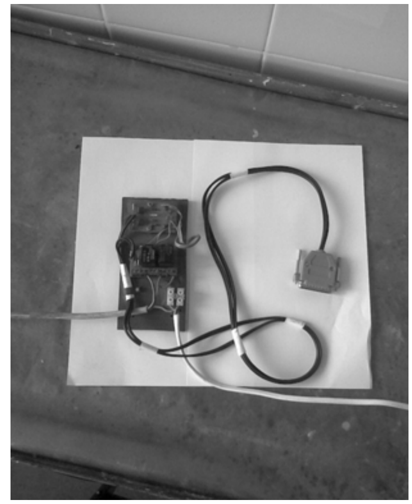


Figure 3: The impulses generator.

Figure 4: Electromagnetic pulsator.

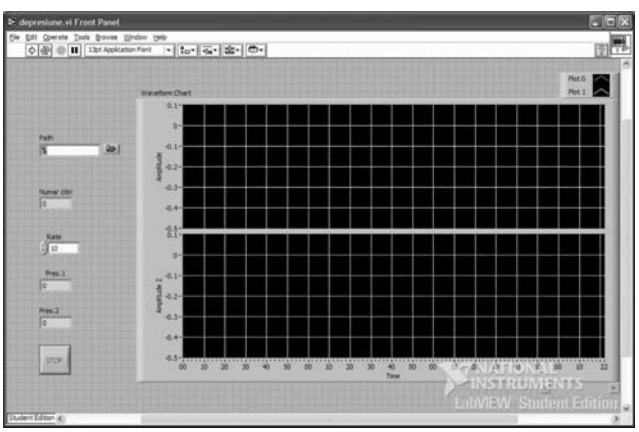


Figure 5: Graphic interface of the pressure recording system.

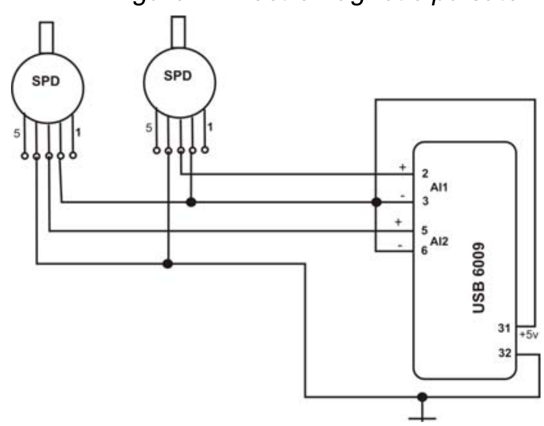
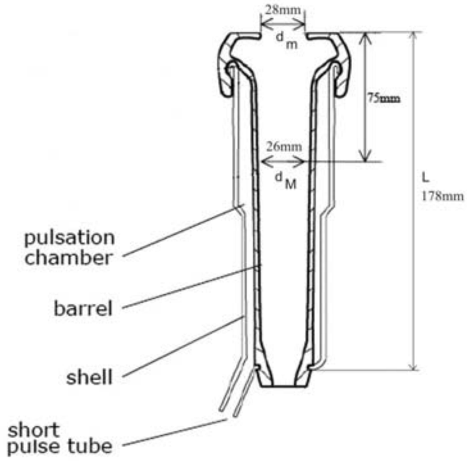


Figure 6: Electric diagram of the pressure recording system.

The STIMO IQ type pulsator is equipped with its own electronic pulses generator and has the following features: 60 cycles/min pulsation rate and 60/40 milking to massage ratio.

The pressure transducers were mounted on one teatcup, in order to record the permanent vacuum inside the barrel and also the alternating vacuum into the short pulse tube (*Figure 7*).

Figure 8 shows a general view of the testing systems; during the experiments, the durations of the phases of the pulsation cycle were calculated according to the schematics shown in *Figure 9* [CowTime 4.3 Quick Note, 2003].



a)

b)

Figure 7: Two pieces type teatcup:
a-dimensions; b-general view.

Figure 8: General view of the testing systems
1-electromagnetic pulsator; 2-pressure transducer; 3-tested teatcup; 4-computer driven pulses generator.

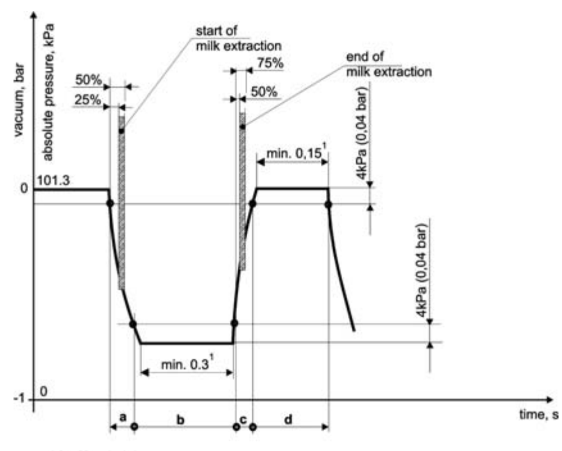


Figure 9: Durations of the phases of the pulsation cycle.

In a second series of experiments, the computer controlled pressure recording system was used in order to evaluate three types of milking teatcups when using different pulsation rates; the mechanical milking system was equipped with a hydropneumatic pulsator (*Figure 10*). The characteristics of the milking teatcups are summarized in Table 1.

Table 1.Characteristics of the tested liners.

Item	Type of teatcup (according to fig. 10)	Dimensions (according to fig. 7)		
		mouthpiece diameter, d_m [mm]	barrel bore, d_M [mm]	overall length, L [mm]
1	1 piece, plastic shell	25	25	168
2	2 pieces, metal shell	28	26	178
3	1 piece, metal shell	25	28	181

During these tests, the pulsation rate was modified in three steps and the pulsation cycle characteristics (pulsation rate and ratio and duration of the phases) were assessed, using the recorded data. For each of the pulsation rates taken into account, the adjustment of the hydropneumatic pulsator was kept the same for all the tested teatcups.

The vacuum level in the vacuum line was 42 kPa (59.3 kPa absolute pressure), for all the tests.

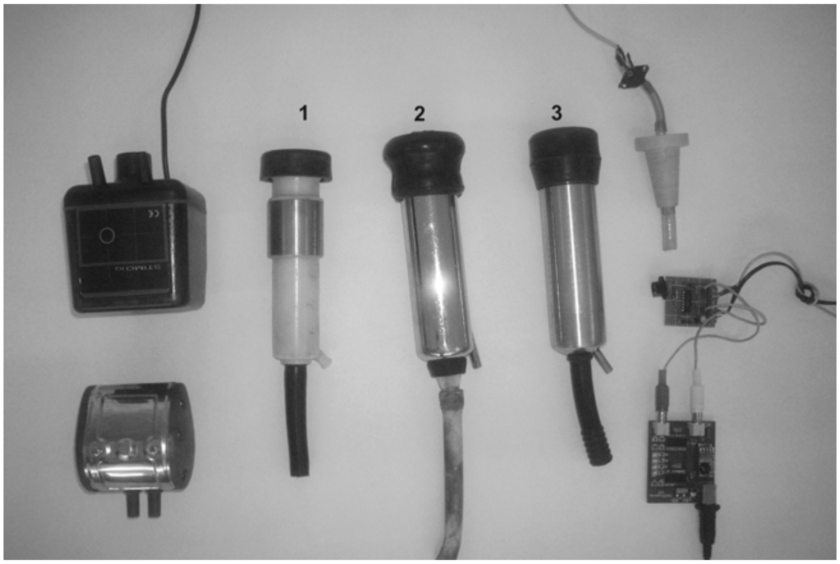


Figure 10. General view of the tested components (teatcups, STIMO IQ pulsator, hydropneumatic pulsator, artificial teat).

Results and Discussion

In order to calibrate and verify the 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.

Then the electromagnetic and STIMO IQ pulsators were then compared, in the same working conditions: 60 cycles/min and 60/40 pulsation ratio.

The results of the tests concerning the electromagnetic pulsator are presented in *Figure 11*. For the 50/50 pulsation ratio, 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 duration 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 duration 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.

In these experiments the pulsation ratio was evaluated as the ratio between the time the pulsator coil was energized and the time it was at rest; the percentage duration of the maximum vacuum phase and of the atmospheric phase into the overall cycle duration is presented in Table 2. It is clear that, for the 50/50 pulsation ratio, the requirements of the ISO 5707 standard are not fulfilled, as phase b should not be less than 30% of the pulsation cycle [Billon, 2001; ISO 5707, 2007].

Figure 12 presents the comparative results for the STIMO IQ pulsator and the electromagnetic pulsator. There is a minor phase shift 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 then 50 ms.

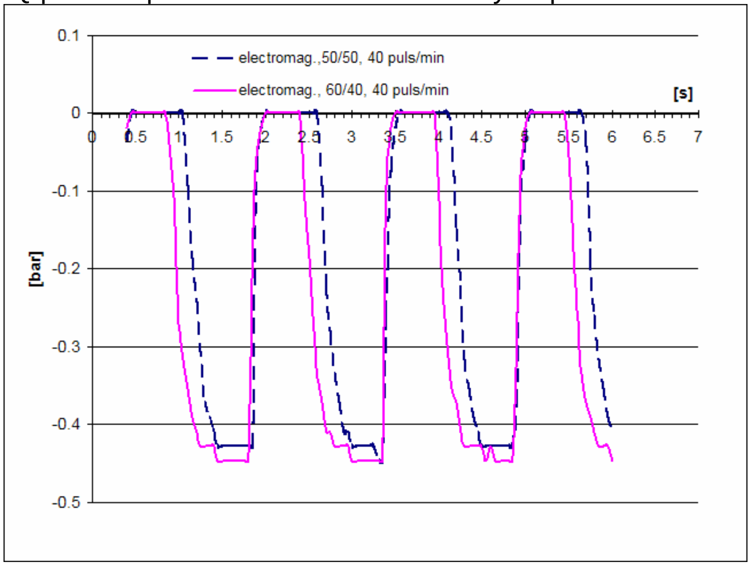


Figure 11. Experimental results for the electromagnetic pulsator (40 cycles/min).

Table 2. Percentage duration of phases (40 cycles/min; electromagnetic pulsator).

Phase	Pulsation ratio: 50/50	Pulsation ratio: 60/40
Maximum vacuum (***b***-phase)	27%	37%
Atmospheric pressure (***d***-phase)	40%	27%

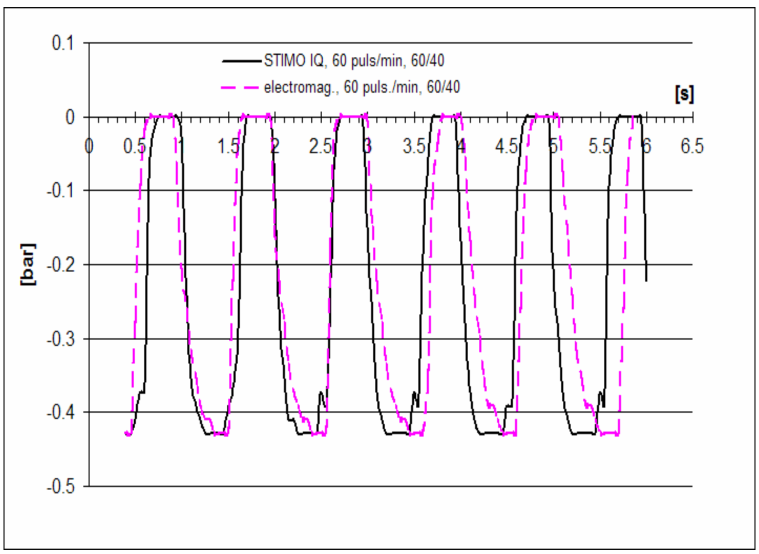


Figure 12. Comparative analysis of the pulsators (60 cycles min, 60/40 pulsation ratio).

The STIMO IQ pulsator registered a shorter ***a***-phase (0.3 s) than 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].

Consideration of the above mentioned intervals for milk flowing (*Figure 9*) 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.

Table 2 presents the ratio of the b and respectively d-phase to the entire cycle duration.

Table 2. Percentage duration of the b and d phases (60 cycles/min, 60/40 pulsation ratio).

Phase	Pulsator type	
	STIMO IQ	electromagnetic
Maximum vacuum (***b***-phase)	35%	30%
Atmospheric pressure (***d***-phase)	25%	30%

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.

In the second series of tests, three different teatcups were tested at three pulsation rates; the results (mean values) are summarized in Table 3.

Table 3. Experimental results concerning the three types of teatcups.

Item	Type of teatcup (according to fig. 10)		
	1	2	3
Pulsation rate [cycles/min]	**45.8±0.202**	**45.7±0.233**	**45.3±0.23**
Pulsation ratio [%]	58/42	57.8/42.2	57.7/42.3
a phase [s]	0.200	0.340	0.263
b phase [s]	0.560	0.420	0.506
c phase [s]	0.133	0.120	0.180
d phase [s]	0.417	0.433	0.373
Pulsation rate [cycles/min]	**54.2±0.416**	**53.6±0.260**	**54.2±0.300**
Pulsation ratio [%]	58.1/41.9	57.9/42.1	58.5/41.5
a phase [s]	0.186	0.326	0.253
b phase [s]	0.456	0.316	0.383
c phase [s]	0.137	0.116	0.170
d phase [s]	0.327	0.360	0.300
Pulsation rate [cycles/min]	**58.6±0.200**	**57.8±0.497**	**58.1±0.366**
Pulsation ratio [%]	58/42	57.8/42.2	57.4/42.6
a phase [s]	0.180	0.313	0.243
b phase [s]	0.413	0.283	0.350
c phase [s]	0.130	0.113	0.173
d phase [s]	0.300	0.323	0.266

The ISO 5707 standard requires phase ***d*** to last at least 0.15 s in order to overcome the congestion induced by the milking vacuum [Mein, 2003]; the experimental results show that all the tested teatcups are compliant with this requirement.

The same standard states that the ***b***-phase should not be less than 30% of a pulsation cycle; from this point of view, the two pieces teatcup (type 2) failed to achieve this requirement at higher pulsation rates (28.3% at 53.6 cycles/min and 27.4% at 57.8 cycles/min).

Because the working principle of the hydropneumatic pulsator uses the line vacuum in order to operate the slide valves which create the pulsation cycle, it is to be expected that the aerodynamic characteristics of the teatcup would affect the pulsation rate. From this point of view, the highest pulsation rate is achieved when the type 1 teatcup is used; in our opinion, there are two reasons for this result:

- the rubber liner has the smallest dimensions of all;
- the rubber liner has the highest mounting tension (6.3% percent liner stretch, compared to

4.3% for the type 3 teatcup and 1.7% for the type 2 teatcup).

The mounting tension as defined by Mein [2003] is also the cause of the shorter ***b***- phase achieved by the type 2 teatcup: the effect of a lower mounting tension is a longer time required by the rubber liner in order to expand to its initial shape, or, in other words, a longer ***a***- phase; the experimental data from Table 3 clearly show that the longest duration of the ***a***-phase was recorded by this type of teatcup.

The same characteristic of the type 2 teatcup (low mounting tension) is the cause of a shorter ***c***-phase; according to Kochman et al. [2003], a shorter ***c***-phase can cause physical discomfort to cow and diminish the milk production.

Conclusions

A computer controlled system was developed in order to test and diagnose some of the components 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 computer controlled impulses generator, together with the electromagnetic pulsator, allowing the adjustment of both the pulsation rate and ratio, could prove to be useful in detailed researches referring to the effect of the pulsation cycle characteristics over the milk production, udder health etc.

The computer controlled pressure recording system allows the evaluation of the pulsator and teatcups characteristics. During the comparative tests regarding three types of teatcups, the use of this system led to the diagnosis of a non-compliant teatcup (shorter ***b***-phase, with reference to the ISO standard; shorter ***c***-phase, leading to a sensation of physical discomfort and, possibly, to diminution of the milk production).

Further researches will necessary imply the use of a force transducer placed between the teat and the rubber liner, as the one presented by van der Toll [2010]; the evaluation of the pressure distribution at the teat-liner interface during the pulsation cycle, together with the parameters referring to the pulsation cycle characteristics, will lead to a more complete and realistic picture of the liner-teat interaction during the mechanic milking.

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