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Influence of pulsation parameters on the intensity of the milk flow through the collectors of cow milking machines

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Abstract. *The main parameters of pulsation systems in milking machines for cows are pulsation rate and ratio (pulse fill factor). They are generated and fed to the system in alternating mode. In the present material, the influence of the ratio on the temporal structures of the pulse is studied. The effect of "phase overlap" at ratios other than 50/50 and its effect on alternating mode operation is described. The analysis is focused on the nature of milk movement through the collector and the probability of occurrence of the so-called "backflow". A reasoned recommendation concerning the device and the volume of the collectors in milking machines for cows is derived.*

Keywords: milk flow, milk reflux, phase overlap

Introduction

The genetic progress of specialized breeds of milk cattle (Holstein Friesian, Simmental, etc.), as well as the intensive technologies of their breeding led to a sharp jump in the productive indicators of lactating animals (Tiantong et al., 2021). In a large part of specialized farms, the average daily milk yield from a cow exceeded 30÷35 l, which represents an increase of nearly 30% compared to the period of 2001÷2005.

Regardless of the dynamics of the productive trend, the average duration for machine milking has remained in the interval of 6÷7 minutes (Enokidani et al., 2016). The comparison of the given data shows (albeit indirectly) the scale of the increase in milk production flow rate and the integral indicators describing the speed of machine milking (Enokidani et al., 2016).

One of the main factors determining high milk yield is the pulsation mode of milking machines (Whittlestone,1968; Ishida et al., 2006). The applied systems for electronic control of the frequency parameters allow to refine the time phases structuring the period of the working pulses (Banev et al., 2013; Dineva, 2021). The duration and ratio of the individual components are regulated in the international standard ISO 5707 and have been established as the main criteria for regulating the pulsation systems of milking machines (ISO 5707, 2007).

In their physical essence, established norms have a conditional or rather indicative character. They describe the temporal structure of the impulses but do not present the real hydromechanics in the milk chambers and the collectors of the milking machines (so-called clusters). References of "good practices" are in the direction of pulsation rate of the order of 65 ÷ 67 min^{-1} and ratio in the range 65/35 - pulse filling factor $\gamma = 0.65 \div 0.67$ (Dineva et al., 2020; Dineva, 2021). The values of the indicated parameters are empirical in nature and allow the

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machine milking time to be preserved regardless of the increased milk productivity (Dineva et al., 2020). The data are without analytical justification and the feedback describing the specifics of the hydraulic flow through the milk line of the milking machines is missing. There is a lack of information regarding the functional relationship between the pulsation parameters (pulsation rate and ratio) of the milking machines and unwanted effects such as low vacuum fluctuations, reverse milk flow, cross-infections on the udder, TSCC (total somatic cell count), etc.

The purpose of the present material is related to the analysis of several interrelated aspects of machine milking:

- The influence of the pulsation parameters (rate and ratio) of the milking machines on the dynamics of the milk flow passing through their collector systems;

- The prerequisites for the occurrence of aperiodic low-vacuum fluctuations and the related backflow of milk to the milking cups;

- Derivation of a model describing the theoretical probability of the occurrence of cross-infections as a result of the reverse flow of milk from the collectors of the milking machines.

Material and methods

The time components and frequency parameters of the working pulses are interpreted graphically, according to the standard profile as per ISO 5707 (Figure 1).

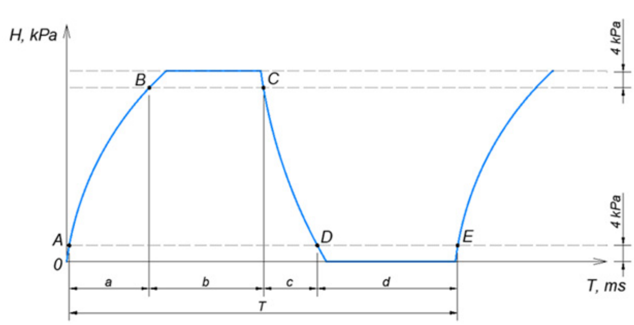

Figure 1. Graphical profile and time components according to ISO 5707: AB – leading edge of the pulse; BC – vacuum peak; CD – trailing edge of the pulse; DE – atmospheric peak; a – phase of vacuuming the pulsation chambers in the milking cups; b – actual milking phase; c – vacuuming phase of the pulsation chambers; d – actual massage phase; T – period of a single pulse

The main functional parameters concerning the analysis in the presentation are derived as derivatives of the described time components (phases):

- pulsation rate – $f = \frac{1}{T}$, min^{-1}; (1)

- milking phase - $a_i + b_i$, ms or %T; (2)

- massage phase - $c_i + d_i$, ms or % T; (3)

- ratio - $\gamma = \frac{a_i+b_i}{c_i+d_i}.100$, % (4)

The overlap of the milking phase from the two channels of the pulsation system or the so-called simultaneous effect (hypothetically accepted as the cause of the backflow of milk) is represented by an absolute and relative value of duration:

- absolute value - $S_a=\pi(2a+2b)-T$, ms (5)

- relative value - $S_o=(\gamma-50).2.T$, % (6)

The reasoning resulting from equations (5) and (6) is correct under two imperative conditions:

- the pulsogram coincides with the real movement of the milking liner (milking membrane);

- the limping value (the relative error between the parameters of the two channels of the pulsation system) tends to zero.

As an indicator of the changing probability of indirect contact between the teats, the possible number of permutations for combined connections in a conventional and modified collector was used:

$P_n = n!$, number (7)

$P^{1,2}_n = n_1! + n_2!$, number (8)

Where:

P_n - the number of possible permutations in a conventional milking machine manifold;

$P^{1,2}_n$ – the number of possible permutations for a modified collector, with two isolated chambers

$n!; n_1!; n_2!$ – the factorial of the number of milking cups connected in a common collector chamber.

Results and discussion

The data in Table 1 are obtained based on equations (5) and (6) describing the variation of the ratio overlap (simultaneous effect) as a function of the pulsation rate (f, min^{-1}) and the ratio (fill coefficient of pulse - γ,%).

Within the same pulsation mode, increasing the ratio (ratio asymmetry) leads to a significant increase in the simultaneous milking effect in the single pulse period. The noted growth is strongly manifested and the difference of the variables between the smallest and the largest gradation for ratio (55÷70%) is exactly 4 times. The trend is absolutely the same for the four pulsation rate levels (60, 65, 70, 75 min^{-1}) of analysis and has a typical linear character (the step of the differences is the same in all gradations).

Changing the pulsation rate within a given ratio does not change the relative duration of the simultaneous effect. There is a certain reduction in the absolute values of the ratio overlap, which is completely reasonable and represents the time constant as a result of shortening the pulsation period (respectively, increasing the rate).

Table 1. Effect of pulsation rate and ratio on simultaneous overlap duration

Rate min^{-1}	**Parameters**	**Ratio, %** 55	60	65	70
60	T, ms	1000	1000	1000	1000
	S_o, %	10	20	30	40
	S_a, ms	100	200	300	400
65	T, ms	925	925	925	925
	S_o, %	10	20	30	40
	S_a, ms	93	185	278	370
70	T, ms	857	857	857	857
	S_o, %	10	20	30	40
	S_a, ms	86	172	257	343
75	T, ms	800	800	800	800
	S_o, %	10	20	30	40
	S_a, ms	80	160	240	320

The summary finding of the analysis shows that pulse fill factor of 0.5 (beat ratio other than 50/50) causes a simultaneous effect of milk flow in the manifold as a result of the milking phase overlap in the four teats. The effect is interpreted graphically on the image on Figure 2.

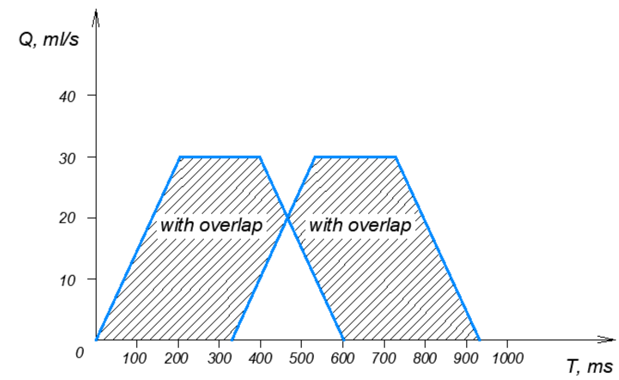

Figure 2. Graphical interpretation of the effect of overlapping half-cycles of the milking phase in the two channels of the pulsation system

The two graphs describe the sample milk flow from each 'pair' of milking cups. The transgression zone represents the moment of "simultaneous mode" when the four milk chambers of the milking units are simultaneously in milking phase. At a pulse fill factor of 0.5 (50/50 ratio), the transgression will approach zero and the mode will be typically "alternating". Any change in the ratio above 0.5 leads to a progressive increase in the overlap of the milking phase in the four milking cups and a pulsed increase in the milk flow rate through the collector system (Figure 3).

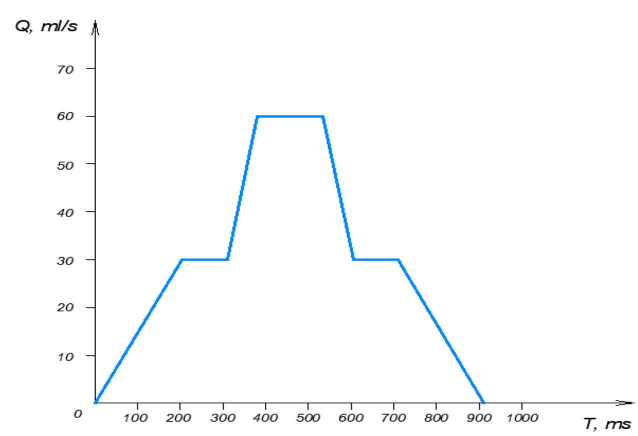

Figure 3. Example illustration of the pulsed milk flow within the simultaneous overlap

The sudden peak in flow (albeit short-lived) is expected to cause a momentary fluctuation of the vacuum and a fluctuation of the milk back to the teats (Figure 4).

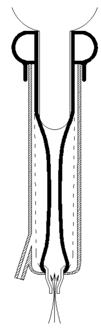

Figure 4. Visualization of the effect of the backflow of milk to the milking cups as a result of the sudden vacuum fluctuations

The described effect was investigated by Whittlestone (1968) and defined as ‘milk reflux’. Ishida et al. (2006) formulated a hypothesis of reverse “transport” of bacteria, creating prerequisites for inflammatory processes in the mammary gland. Their conclusions are supported by the simulation studies of Masafum et al. (2023) who emphasized the negative role of reverse milk flow as a cause of udder cross-infections.

In milking machines with a conventional collector, the theoretical probability of cross-infection of the quarters can be described by 24 combinations for indirect contact between the teats, by returning (reflux) the common milk from the collection chamber to the milking cups (factorial of 4 - expression 5).

The probability of such anomalies could be significantly reduced if the milk chamber of the collector was divided longitudinally (with a tight partition) into two isolated halves corresponding to the pulsation channels (Figure 5).

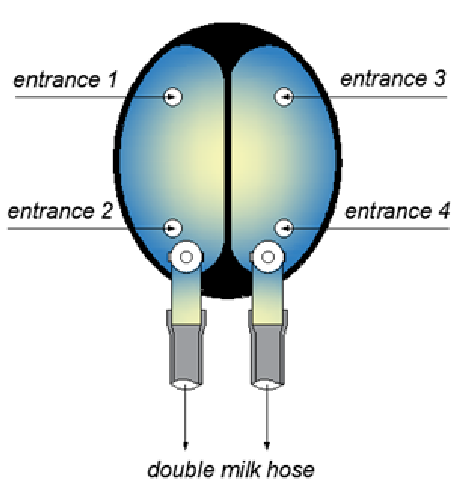

Figure 5. Conceptual model of a milk collector with two isolated collection chambers

The idea of the partition is that each chamber receives the milk from two quarters of the udder and its delivery to the milking system is with a double hose. The effect of such a modification is expected to lead to a 6-fold reduction in the risk of cross-infections. The theoretical probability of indirect contact between teats in “split chambers” is described by only 4 possible combinations for indirect connection of the udder quarters (2 x factorial of 2 - expression 6).

Conclusion

Pulse fill factors other than 0.5 cause overlap and conditions for pulse oscillations in the milk flow. Relative and absolute overlap durations increase in direct proportion with positive ratio asymmetry (γ>0.50). Increasing the pulsation rate shortens the absolute ratio overlap time within the period (one pulse) but the effect has the character of a time constant. Modifying the milk collectors by dividing them into two independent chambers reduces the theoretical probability of indirect contact between the quarters by six times.

Recommendation: It is recommended that in dairy herds with a high relative proportion of subclinical mastitis, pulsation systems to be operated at a pulse fill factor of 0.5 (ratio 50/50).

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