Scientific Papers. Series D. Animal Science. Vol. LXVI, No. 2, 2023
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

SPATIAL LOCATION OF MILKING EQUIPMENT IN CONNECTION WITH TIME SPENT ON WORKING OPERATIONS

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Abstract

The study of the formalized characteristics' effect of the spatial location of milking equipment, cows and operators in connection with the time spent on working operations is presented. The material for the research was timekeeping of the milking process using different equipment. It has been established that the correlation coefficient between the length of the working area for milking and the duration of the working operation "transition between animals and equipment" is r=0.330 (p<0.001). The measure of effect size of milking trench's presence/absence factor on the time spent by the operator on milking 1 cow was η^2=0.779 (p<0.001). The time when the machine milking operator stays in a position with a strongly bent torso (over 40°) during milking using a trench is almost 50 times less (p<0.001) compared to the corresponding time during milking without using a milking trench. When working in the trench, the operator does not perform working actions in the "squatting" position at all. If milking occurs in stalls, then a small distance between adjacent cows makes it difficult for the operator to access the udder.

Key words: *cow, milking trench, ergonomics, timekeeping, working operation.*

INTRODUCTION

Radical changes are currently taking place in milk production technologies (Kaarlenkaski, 2018). However, to date, farmers still do not sufficiently use fundamentally new, modern approaches to the organization of production processes (Lubega, 2015; Mishra et al., 2020).

This situation is partly due to the fact that the technological processes of milk production are quite complex both in designing and in their implementation (Ivanyos et al., 2020; Gaworski, 2021). This difficulty is explained by the fact that when production is organized, the simultaneous functioning of equipment, animals and people in a unified system should be coordinated. At the same time, each link of this system is connected with others. But a human plays a leading role in this system with the help of active influences on other elements. (Kaarlenkaski, 2018; Ruban et al., 2018).

The interaction between the components of dairy farming is most evident in the machine milking of cows. This production process is key, as it is the core around which the entire technological chain is built.

Milking can also be considered as a complex process of interaction between animals, milking equipment and machine milking operator (Palii et al., 2020).

The milking machine differs from other mechanisms in that during its operation the operator is in close contact with the animal and actively affects one of the most important organs of dairy cows - the udder (Wildridge et al., 2020).

Many different technical and technological solutions can be found on modern farms. Each of these only to some extent corresponds to the biological characteristics of cattle in terms of unlocking the potential for adaptation, health, productivity and longevity (Siewert et al., 2018; Shablia & Tkachova, 2020).

At the same time, milking efficiency is influenced by additional factors. For example, careless operation of the milking machine by the operator, incorrect milking technology, incorrect settings and work with technically defective equipment can cause diseases in cows (Ministry of Agricultural Policy of Ukraine, 2005; Besier & Bruckmaier, 2016; Odorčić et al., 2019).

Milking equipment serves as a means of production for a human, and therefore determines certain labour costs for its operation. Unfortunately, despite the introduction of mechanization of the main technological processes, the work of machine milking operators still remains a type of manual labour with a significant load on the musculoskeletal system (Næss & Bøe, 2011).

In particular, this happens due to the fact that there is insufficient consideration of ergonomic requirements for the organization of operators' workplaces. That is often manifested in the irrational layout of the placement of animals, working units of equipment and control levers in space, as well as in the use of irrational non-mechanized tools (Ulbricht et al., 2014). All this leads to the formation of a high level of difficulty and intensity of work, contributes to a decrease in work capacity (Lubega, 2015).

The disadvantages listed above cause excessive labour costs for the performance of working actions and operations in the milking process, lead to a decrease in the labour productivity of machine milking operators (Næss & Bøe, 2011).

The analysis of the state of study of the problem shows that insufficient consideration of ergonomic requirements in milking technology is caused in a number of cases by the lack of clear, scientifically based knowledge on this issue.

This situation occurred due to the fact that methodical and practical approaches to ergonomic studies, and especially regarding animal husbandry, have only been partially developed.

Accordingly, the laws of influence of certain equipment characteristics, animals, and operators on the effectiveness of their interaction in the process of milking cows have not been sufficiently studied. And the conclusions from the analysis of the technological process of milking are mostly either too general or fragmentary.

In view of this, the study of the effect of formalized characteristics of the spatial location of milking equipment, animals and operators in connection with the time spent on working operations in the milking process is relevant.

MATERIALS AND METHODS

The material for the research was timekeeping observations of the milking processes on equipment of the "DAS-2" type ("Gontarivka" farm), "ADM-100" type ("Stepne" farm and "Mriya" farm), “UDS-2” type ("Agrosvit" farm), type "Herringbone" 2×7 ("Kutuzivka" farm), Kharkiv region and "Parallel" 2×16 type ("Terezino" farm), Kyiv region (Ukraine).

Labour and working operations of the technological processes of milking cows in stalls and in milking parlours were recorded by video recording them on dairy farms. Based on the materials of the video recordings, the timing of the main working operations and working actions was carried out according to the approaches outlined in Shablia (2012; 2018).

Thus, during research, the technological process of milking cows was divided into technological operations and working actions in such a way that each of its elements could be unambiguously attributed to one of the predetermined categories. Separate working actions did not overlap in time. And the same working action cannot be simultaneously attributed to several technological operations.

The duration of the following working operations (seconds) was taken into account as the result characteristics of the efficiency and ease of labour of machine milking operators:

- cows' driving;
- washing the udder;
- wiping the udder;
- preparation, rinsing and wringing of a napkin;
- moving the milking machine;
- transitions between animals and equipment;
- udder massage;
- milking the first streams of milk;
- turning on and off the vacuum;
- putting on milking teatcups;
- after-milking;
- disconnecting and removing the device;
- delivery of milk to the cooling tank;
- post milking teat spraying or dipping;
- manure cleaning;
- distribution of feed;
- observation.

In addition, more generalized characteristics of the time of performing labour actions were established, such as:

1. Time of concentrated observation;
2. The total time the body is in a tilted position, including:
   - torso at an angle of 20-40º from the starting position;

- torso at an angle of 41º or more;

3. Total time spent in the "squatting" position.

4. The total time of the upper arms being in an uncomfortable position - at an angle to the starting position (arms down), including:

- with upper arms at an angle of <90º;
- with upper arms at an angle ≥90º.

For all these indicators, the number, sequence and duration of separate movements were also taken into account.

On the basis of conducted research, databases were created, which included the characteristics of technological operations performed by machine milking operators. In total, milking processes of 412 cows using different milking technologies were studied.

The characteristics of the milking equipment and its spatial location, milk productivity of cows, milk quality, anthropometric and individual characteristics of operators, data on husbandry technologies, cow behaviour, linear evaluation of their exterior type, etc. were taken into account.

An evaluation of the correlations (r) between the studied indicators was carried out, as well as the measure of effect size (η^2) of the main ergonomic factors of the spatial arrangement on the result characteristics was established.

RESULTS AND DISCUSSIONS

In the process of analysing the materials, it was established that it is advisable to consider the ergonomics of the location of milking equipment in space relative to cows and operators in three aspects:

1. From the point of view of the overall dimensions of the working area, where animals, operators and equipment are located during milking.

2. From the point of view of compactness and convenience of location in the space of animals, equipment and operators relative to each other during the performance of basic and additional (accompanying) working operations and working actions.

3. From the point of view of completeness provision of operators and (or) cows with a certain amount of milking and other equipment.

Regarding the dependence of the time of working operations on the total size of working area where milking is carried out, it was established that the correlation coefficient between the length of the working area for milking and the total time spent by the machine milking operator per 1 cow is r = 0.395 (P < 0.001).

Accordingly, for an approximate calculation of the total time spent on milking 1 cow, based on the data on the length of working area, you can use the regression equation:

$$T_{m1c} = 1.572 + 0.0211 * L_{wz}$$

where:

T_{m1c} - time spent by machine milking operator per 1 cow, minutes;

1.572 - constant;

L_{wz} - length of the working area for milking, meters;

0.211 - regression coefficient of milking time on the length of the working area (minutes/ meter);

The influence of the working area length on the time spent for milking 1 cow is due primarily to the fact that when the working area length increases, additional time is spent on transitions of the operator between cows, as well as between cows and equipment (Figure 1).

Figure 1. The remote location of the milking equipment, the operator and the cows forces the operator to perform many inefficient, useless and unnecessary labour movements

In particular, the correlation coefficient between the working area length for milking and the duration of the operation "transition between animals and equipment" is r = 0.330 (P<0.001). At the same time, transitions are often accompanied by the movement of equipment and tools. These additional actions also cause more operator's fatigue. In researches of Jakob et al. (2012) and Jakob & Liebers (2017) the effect of the working area size on milking efficiency was also established.

In general, the total duration of work operations "transitions between animals and equipment" calculated per 1 cow for milking technologies (Table 1) in the milking parlour (compact placement of animals and equipment) is on the average M = 4.67 ± 0.267 s. And when milking is done in stalls, where cows are kept (stretched placement in space) the total duration of this work operations is M = 23.48 ± 1.690 s.

Table 1. Time spent on milking 1 cow and (including) on performing working operations "transitions between cows and equipment" depending on the place of milking (seconds)

Place of milking	Measures of variability	The time spent by the operator on milking 1 cow	Including the total duration of working operations "transitions between cows and equipment"
In the milking parlour	Number of milkings (N)	263	263
	Mean (M)	66.08	4.67
	Standard error of the mean (SEM)	2.23	0.27
	Standard deviation (SD)	36.22	4.32
	Coefficient of variation (CV), %	54.81	92.55
In places where cattle are kept (in stalls)	Number of milkings (N)	149	149
	Mean (M)	222.11	23.48
	Standard error of the mean (SEM)	5.03	1.69
	Standard deviation (SD)	61.34	20.63
	Coefficient of variation (CV), %	27.62	87.84
In general	Number of milkings (N)	412	412
	Mean (M)	122.51	11.47
	Standard error of the mean (SEM)	4.36	0.77
	Standard deviation (SD)	88.46	15.72
	Coefficient of variation (CV), %	72.21	137.02

The measure of effect size of the factor "place of milking" (milking parlour/in stalls) on the duration of operator's transitions is $\eta^2 = 0.332$ ($P<0.001$), and on the time spent by the operator on milking 1 cow – $\eta^2 = 0.720$ ($P<0.001$).

If we consider the compactness and convenience of the location of animals, equipment and operators in the space relative to each other (Figure 2), then the key influencing factor is the presence of an equipped milking trench as an element of equipment that significantly brings the object of labour (udder) closer to the milking machine and to the operator's arms (Jakob et al., 2012; Jakob & Liebers, 2017).

In particular, factor of "milking trench presence/absence" significantly affects the duration of most work operations in the process of milking cows (Table 2). Thus, the measure of effect size of this factor on the time spent by the operator on milking 1 cow was $\eta^2 = 0.779$ ($P<0.001$).

Figure 2. Compact and convenient arrangement of the animals and equipment in the space using the milking trench enables operator to perform working operations in a comfortable body position

The time for washing the udder during milking with the use of a milking trench is most prominently allocated for the better. It is significantly ($p < 0.001$) 2.5 times smaller compared to washing in the case when the trench was not used.

In addition, the operator's work with the location of his workplace in the milking trench has a beneficial effect on his energy expenditure and fatigue (Cockburn, 2015; Hwang et al., 2010). In particular, in our studies, it was established that significantly less time was spent on performing the majority strenuous working operations in a trench compared to performing the same operations without the use of a trench (Table 3). For example, it should be noted the complete absence of working actions in the "squatting" position when the operator works in the milking trench.

In addition, the advantage of milking with the use of a milking trench is very considerable and significant when evaluating the time spent by the operator with a very bent torso (more than 40°). So, this time is almost 50 times shorter compared to the time spent in a very bent position when milking is done without using a milking trench. And working with a bent torso is one of the most difficult options (Oliveira et al., 2018).

The use of a milking trench also has the effect of reducing the time of labour operations with an inconvenient position of the arms. At the same time, the completeness and quality of execution of working operations by the operator also improves. This happens, in particular, due to less muscle load and weariness of the operator (Németh et al., 1990; Jakob et al., 2012; Jakob & Liebers, 2017).

Table 2. Time spent on working operations when milking cows is done with and without the use of a milking trench

Presence of a milking trench during milking	Measures of variability	Duration of working operations per milking 1 cow, seconds:						
		washing the udder	preparation of napkins	wiping the udder	milking of the first streams of milk	putting on milking teatcups	post milking teat spraying or dipping	cows' driving
Without the use of a milking trench (there is no milking trench)	Number of milkings (N)	185	185	185	185	185	185	185
	Mean (M)	17.36	7.52	3.95	6.02	11.01	2.75	5.46
	Standard error of the mean (SEM)	0.94	0.52	0.4	0.35	0.56	0.2	1.01
	Standard deviation (SD)	12.72	7.08	5.45	4.76	7.64	2.75	13.68
	Coefficient of variation (CV), %	73.27	94.15	137.97	79.07	69.39	100.00	250.55
With the use of a milking trench (there is a milking trench)	Number of milkings (N)	227	227	227	227	227	227	227
	Mean (M)	6.88	3.28	4.95	5	7.63	1.8	8.81
	Standard error of the mean (SEM)	0.43	0.18	0.23	0.22	0.2	0.12	0.34
	Standard deviation (SD)	6.42	2.77	3.41	3.33	3.06	1.78	5.12
	Coefficient of variation (CV), %	93.31	84.45	68.89	66.60	40.10	98.89	58.12
In general	Number of milkings (N)	412	412	412	412	412	412	412
	Mean (M)	11.58	5.19	4.5	5.46	9.15	2.23	7.31
	Standard error of the mean (SEM)	0.54	0.27	0.22	0.2	0.29	0.11	0.5
	Standard deviation (SD)	11.06	5.58	4.46	4.06	5.84	2.32	10.05
	Coefficient of variation (CV), %	95.51	107.51	99.11	74.36	63.83	104.04	137.48
Measure of effect size, η^2		0.223	0.143	0.012	0.015	0.083	0.042	0.027
Significance level, P		<0.001	<0.001	0.023	0.012	<0.001	<0.001	<0.001

If milking occurs in places where cows are kept (in stalls), when the cows are tied, and the milking trench is not used, then the close distance between the cows causes a number of negative consequences due to the difficult access of the operator to the cow's udder and to some elements of equipment.

In particular, the insufficient distance between adjacent cows for the passage of the operator (Figure 3) forces the operator to change the position of the cows in the stall to ensure the space of the workplace.

Table 3. The duration of the machine milking operator's stay in uncomfortable body positions when using and without using the milking trench, per cow (seconds)

Presence of a milking trench during milking	Measures of variability	Uncomfortable body positions: torso being in an uncomfor table position	including with a torso bent at an angle of 20–40º	including with a torso bent at an angle of 41º or more	in the "squatting" position	upper arm being in an uncom-fortable (raised) position	including with upper arm raised at an angle of <90º	including with upper arm raised at an angle of ≥90º
Without the use of a milking trench (there is no milking trench)	Number of milkings	185	185	185	185	185	185	185
	Mean	105.83	19.37	63.66	22.81	108.82	103.44	5.37
	Standard error of the mean (SEM)	5.1	3.41	3.17	2.57	5.17	5.1	0.21
	Standard deviation (SD)	69.31	46.36	43.07	34.95	70.26	69.38	2.9
	Coefficient of variation (CV), %	65.49	239.34	67.66	153.22	64.57	67.07	54.00
With the use of a milking trench (there is a milking trench)	Number of milkings	227	227	227	227	227	227	227
	Mean	29.18	27.87	1.28	0	33.06	31.03	1.99
	Standard error of the mean (SEM)	0.66	0.66	0.16	0	0.69	0.7	0.05
	Standard deviation (SD)	9.88	9.92	2.43	0	10.43	10.53	0.83
	Coefficient of variation (CV), %	33.86	35.59	189.84	-	31.55	33.93	41.71
In general	Number of milkings	412	412	412	412	412	412	412
	Mean	63.6	24.05	29.29	10.24	67.08	63.54	3.51
	Standard error of the mean (SEM)	2.98	1.58	2.09	1.28	2.99	2.92	0.13
	Standard deviation (SD)	60.51	32.16	42.41	25.99	60.77	59.3	2.64
	Coefficient of variation (CV), %	95.14	133.72	144.79	253.81	90.59	93.33	75.21
Measure of effect size, η^2		0.398	0.017	0.536	0.191	0.385	0.37	0.407
Significance level, P		<0.001	0.007	<0.001	<0.001	<0.001	<0.001	<0.001

At the same time, the machine milking operator performs additional movements and working actions that are not related to the performance of the main technological operations (Maia & Rodrigues, 2012).

As a result, the total number, duration and intensity of labour movements increases, time spent on preparatory and final milking operations increases, as well as operator's weariness (Jaejin Hwang et al., 2010). Instead, the completeness and quality of execution of working operations deteriorates.

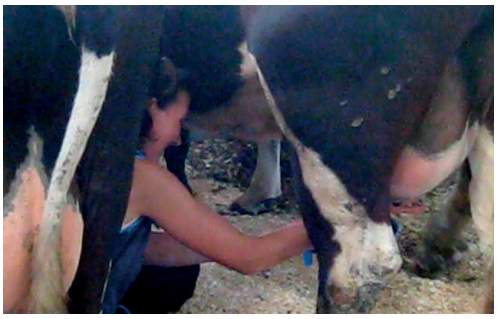

Figure 3. A small distance between cows during milking in stalls makes working operations difficult, forces the operator to make unnecessary movements to move the cows in order to ensure a comfortable working area

CONCLUSIONS

The compact placement of milking equipment elements and animals in space assists to reduce time spent on transitions between equipment elements and animals. In particular, the correlation coefficient between the length of the working area for milking and the duration of the labour operation "transition between animals and equipment" is $r = 0.330$ ($p<0.001$).

The factor of milking trench's presence / absence significantly affects the duration of most working operations in the process of milking cows. The measure of effect size of this factor on the time spent by the operator on milking 1 cow was $\eta^2 = 0.779$ ($p<0.001$).

The time when the operator stays in a position with a strongly bent torso (over 40°) during milking using a trench is almost 50 times less ($p<0.001$) compared to the corresponding time during milking without using a milking trench. In addition, when working in the trench, the machine milking operator does not perform working actions in the "squatting" position at all. If milking occurs in places where cows are kept (in stalls), then a small distance between adjacent cows makes it difficult for the operator to access the udder and to some elements of equipment, as a result of which the operator has to perform a number of additional and redundant labour action to arrange his workplace.

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