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INSPECTION OF RUBBER PARTS OF MILKING EQUIPMENT BY NON-DESTRUCTIVE TESTING METHOD

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The presented study deals with determining the wear of the inner surface of teat cup liners during exploitation based on roughness. The course of wear of the teat cup liner was assessed by an innovative non-destructive method. For this purpose, a measuring stool was made, by which it is possible to measure roughness without disassembling the teat cup liner from the teat cup shell. The wear of the liners was monitored using a roughness meter at randomly selected six stands in a herringbone parlour. In the first measurement in the winter period, the teat cup liners that had been stored on the farm for three years were used. In the second summer measurement, the liners were purchased before their use. When comparing the R_a and R_z parameters from the first and second measurements in both cases, there are statistically significant differences in the measured values in favour of the second measurement ($P = 0.000 < 0.05$). The average roughness values R_a , R_z in the first measurement were 0.721 μm and 3.282 μm and in the second measurement 0.484 μm and 2.43 μm . There is a zero degree of connection between the roughness of the teat cup liners and the time of use, i.e. there is very little or no correlation. From our observations, it follows that the deteriorated quality parameters of the roughness of the liners in the first measurement were caused by using inappropriately stored liners. The new method for checking the condition of liners has proven itself in practice. The method is fast, less laborious, and results are available in a shorter time for further evaluation and drawing conclusions for the company manager.

Keywords: teat cup liner; roughness; exchange period of rubber parts

Milk as a biomatrix contains a number of basic components such as proteins, fats, carbohydrates, vitamins, and minerals (Toghdory et al., 2022; Ceballos et al., 2009). In addition, milk is rated as a high-quality food source due to its well-balanced composition of essential nutrients, and it is an easily digestible form for all adult consumers (Muehlhoff et al., 2013; Lim et al., 2020), which is considered one of its most important properties. Due to its high nutritional value, raw milk is an excellent medium for the growth of a wide range of microorganisms. There are more than 160 species of bacteria identified in raw milk (Von Neubeck et al., 2015). The teat and udder of the dairy cow are potential routes by which bacteria enter raw milk during milking (Verdier-Metz et al., 2009). These bacteria originate from various sources including the air, soil, water, udder, and teat of dairy cows as well as contaminated milking equipment (Mallet et al., 2012; Quigley et al., 2013; Pacheco-Pappenheim et al., 2021; Andreen et al., 2021; Cavallini et al., 2021; Pires et al., 2022; Heck et al., 2009; Lambertz et al., 2014). The levels of microbial contamination in raw milk are closely related to the environment, microbiological quality of water used for drinking or cleaning, animal feeding, and overall sanitation of the milking facility (Lan et al., 2017). Animal husbandry factors such as litter, air, water, feed, and cow teat along with the udder are potential sources of psychotropic bacteria (Capodifoglio et al., 2016; Mallet et al., 2012; Quigley et al., 2013). The water used on the farm must have the highest microbiological quality value to achieve high quality dairy

products (Capodifoglio et al., 2016; Nucera et al., 2016). The highly concentrated composition of animal feed significantly affects the microbial community of milk and results in a higher relative abundance of psychotropic bacteria (Zhang et al., 2014). Proper storage has a great influence on the quality of milk (O'Connell et al., 2016). Good hygiene practices for milking machines are vital to ensure the quality of raw milk and milk products made from it. Differences in cattle housing, milking strategy, and technology across farms affect the microbial quality of raw milk (Yuan et al., 2019). Most milking facilities around the world use dual-chamber teat cups to milk cows or other dairy animals. A teat cup is defined as a flexible sleeve with a nipple and a body, which may have an integrated short milk tube (ISO 3918:2007). Long-term experience with the operation of milking equipment shows that the teat cup liner was and remains a short-term and unreliable connection in the technological process of machine milking. During operation, the liner quickly loses its strength and elastic properties, becomes stiff and less elastic, and deforms and changes its shape (Paliy et al., 2021). A dairy cow is usually milked twice a day. Dairy cows with high productivity are milked three times a day. This is accompanied by a significant increase in hyperkeratosis (Cerqueira et al., 2018). The most strained and at the same time the most monitored part of the milking equipment from the point of view of hygiene is the teat cup liner (Gálik et al., 2015).

Currently, teat cup liners are produced from two basic raw materials, namely (Mein et al., 2003):

- Nitrile – a mixture of natural and synthetic rubber with fillers;
- Silicones – they are a special group of thermoplastics and belong to polymers (substances consisting of molecules of one or more types of atoms). Silicone products are widely used and are suitable for contact with food.

Currently, teat cup liners are closed under the ball in the shape of a lying figure eight or in the shape of a trefoil. Monitoring the wear of the mentioned liners is quite difficult and is exclusively limited to the recommendations of the supplier of the milking equipment. Recommendations vary according to the type of studded liners. The recommended usage time is 2500 milkings for nitrile or 10,000 milkings for silicone, unless the manufacturer specifies otherwise. According to Boast et al. (2008), liner degeneration is a progressive phenomenon, but no scientific research is available on the processes of the rate of degradation and its course, or the threshold value beyond which the action of the liner becomes unacceptable. Boast et al. (2008) recommends monitoring the area at a depth of 40–60 mm that surrounds the tip of the teat during teat cup liner closure. Its quality parameters can be monitored in several ways. Gent (2012) and Whear (2003) used the commonly used tensile test, but with the knowledge that this method is not suitable for detecting important changes in the teat cup liner that affect its quality and reliability. Boast et al. (2008) observed the surface of teat cup liners using scanning electron microscopy and X-ray spectrometry. They described the course of wear of the new liner. At the beginning, the level of roughness is high, the roughness decreases due to the influence of cleaning agents. Drbúl et al. (2014) state that even this method of measurement using a roughness gauge leaves a small mark on the surface of the object being measured. ISO 37:2024 regulates physical tests as well as methods for determining the tensile and deformation properties of

the liner. According to our knowledge, we can measure the quality or wear of the teat cup liner in several ways:

- measurement of liner hardness;
- measurement of flexibility and strength;
- quality measurement using X-ray images;
- measurement using an electron scanning microscope;
- measurement of liner roughness;
- chemical extraction;
- measuring the amount of bacteria.

Assessing the quality of teat cup liners is crucial in terms of the safety of milk as a raw material. The results from the presented article contribute to innovation in the field of determining the quality of studded teat cup liners by the method of measuring surface roughness without the need to disassemble the teat cup liner from the teat cup shell.

Material and methods

The experiment was performed in a herringbone parlour with the number of stalls 2×10 , which has been in operation for 17 years. The mentioned milking parlour was in operation on a dairy farm in western Slovakia. Milking took place three times a day (the third time only dairy cows with the highest daily productivity totalling 236 cows), while the total number of dairy cows milked daily was 307 cows. Dairy cows were divided into eight groups according to productivity. The average daily yield was 29.23 l per dairy cow. We have chosen a non-destructive method for the measurement of liner roughness. From the total number of stands, we randomly selected six stands where the roughness of the inner surfaces of teat cup liners was measured. The measurement of roughness was carried out after putting on new teat cup liners, and then roughness was measured every thirty days until the zootechnician set a date for changing the teat cup liners. Before the last change, the last measurement was taken. The first measurement took place in the winter season on the teat cup liners that had been stored on the farm for three years. The second measurement took place

in the summer season on the teat cup liners that were purchased just before their use.

Duration of milking

The milking equipment was operated by two milkers. The first milking lasted for an average of 3.7 hours, the second 3.1 hours, and the third 3.3 hours. The total milking time in one day was 10.1 hours. The average time schedule of individual actions was as following: the boarding time of dairy cows 85 s, sanitisation time 41 s, milking set deployment 60 s, milking time 300 s, expulsion time 50 s (if there was a lame dairy cow in the group, then 158 s). The basic parameters of milking were vacuum size 42 kPa, electromagnetic asynchronous pulsator 60 pulses per minute, suction and compression cycle ratio 60 : 40 on the rear quarters, and 55 : 45 on the front quarters. Nitrile teat cup liners marked Boumatic Magnum MX 400 (Fig. 1) with a nozzle diameter of 23 mm were used, with three anti-balloon ribs for better sealing of the liner and prevention of twisting. According to the manufacturer of the liner used, the time of use was 2500 milkings or six months (whichever comes the first). Black Holstein dairy cows were milked. The highest yielding cows that were milked three times a day had a basic feed composition of 56 : 44% (volume/kernel).



Fig. 1 Ribbed teat cup liner

The teat cup liner Magnum MX400 had a mark on the head and on the short milk tube so that it was correctly fitted after assembly in the nipple case. The first roughness

measurement was at a depth of 40–50 mm. One of the measurements was also in the place where the ribbing is located. Other measurements were made after rotating the teat cup liner by 90°, 180°, and 270° (Fig. 2).

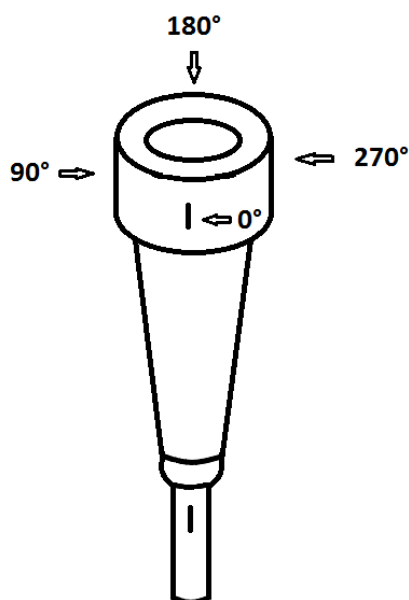


Fig. 2 Display of measurement locations

The Mitutoyo Sj 210 roughness meter was used to measure roughness. The technical data of the device: velocity: 0.25 mm·s⁻¹; return: 0.8 mm·s⁻¹; used probe for soft materials 4 mN; tip radius 10 µm; used extension 50 mm; roughness parameters R_a , R_z (R_a – the mean arithmetic deviation of the profile in the range of the basic length; R_z – the arithmetic average of the largest profile heights); evaluated length (L) – 0.8 mm; the number of sampling lengths $\times 5$; power supply via mains adapter (manufacturer: Mitutoyo, Kawasaki, Kanagawa, Japan). Solidworks version 2015 (Dassault Systems SolidWorks Corporation, Waltham, MA, USA) was used to construct the 3D model. The Excel spreadsheet program from Microsoft Office Excel (Microsoft, Redmond, USA) was used to collect data from individual measuring devices. The obtained data were evaluated using ANNOVA, Statistica CZ 7 (TIBCO, Palo Alto, USA). The measuring bench for determining the roughness of the teat cup liner is shown in Fig. 3.

To calculate the number of milkings on one stand per day and the number



Fig. 3 Measuring bench for determining the roughness of the teat cup liner

of days milked with the teat cup liner, the following equations were used:

1. The number of milkings per stand per day:

$$i_{dst} = \frac{(2 \times q_1) + q_2}{s} \quad (1)$$

where: q_1 – the average number of dairy cows milked twice a day; q_2 – the average number of dairy cows milked for the third time; s – the number of stalls in the milking parlour

2. The number of days milked with the teat cup liner:

$$i_{dsg} = \frac{i_v}{i_{dst}} \quad (2)$$

where: i_v – the total number of milkings with the teat cup liner determined by the manufacturer; i_{dst} – the number of milkings on one stand per day

Results and discussion

Measurement I

Table 1 contains the descriptive statistics from the first measurement, which, according to the methodology of the work, was carried out immediately after the teat cup liners were put into operation. Subsequently, a continuous measurement of roughness R_a and R_z was done every thirty days. The teat cup liners were in operation for six months, and the liners that had been stored on the farm for three years were used. The recommended period of use of the Boumatic SX400 liner according to the manufacturer is 2500 milkings. According to Eq. 1,

$$i_{dst} = \frac{(2 \times 307) + 236}{20} = 42.5 \text{ (the number of milkings performed per day on one stand);}$$

$$i_{dsg} = \frac{2500}{42.5} = 58.8 \text{ days (the number of days milked with one teat cup liner).}$$

Table 1 Descriptive statistics of the parameter R_a (the first measurement – winter period)

R_a I							
	1	2	3	4	5	6	7
Mean (µm)	0.765	0.653	0.649	0.626	1.05	0.953	0.694
Standard deviation	1.613	0.248	0.272	0.274	3.277	0.815	0.282
Sample variance	2.603	0.061	0.074	0.075	10.736	0.665	0.08
Minimum (µm)	0.24	0.27	0.28	0.25	0.31	0.34	0.29
Maximum (µm)	12.5	1.57	2.02	1.69	32	6.31	1.6
Count	96	96	92	92	92	92	84

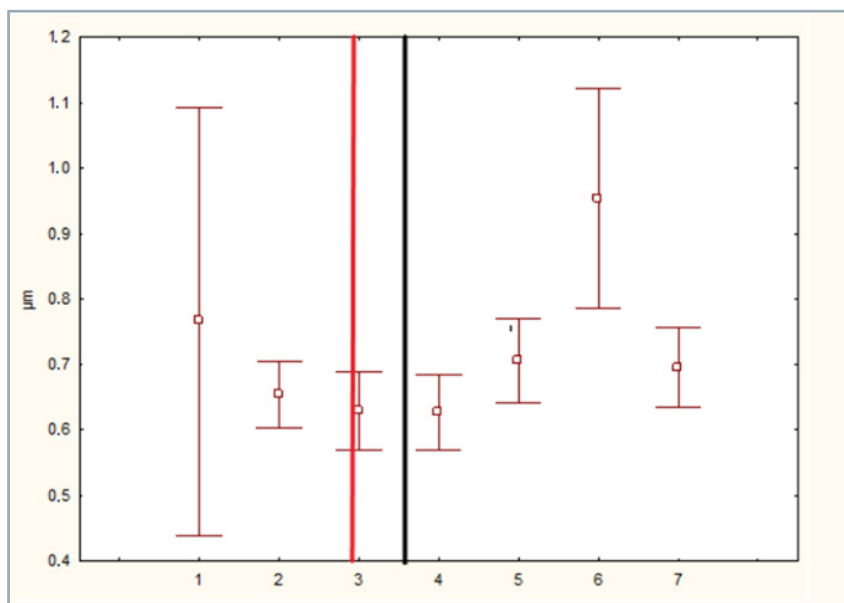


Fig. 4 Box plot of roughness R_a (μm) during the first measurement ($\alpha = 0.05$)

Table 2 Descriptive statistics of the parameter R_z (the first measurement – winter period)

	R_z						
Measurement	1	2	3	4	5	6	7
Mean (μm)	2.785	3.075	3.139	3.048	3.45	4.056	3.464
Standard deviation	1.484	1.264	1.184	1.534	1.512	2.188	1.505
Sample variance	2.203	1.597	1.401	2.354	2.285	4.79	2.264
Minimum (μm)	0.46	0.43	1.33	0.38	1.43	1.18	1.53
Maximum (μm)	14.07	8.56	7.82	9.34	11.24	17.66	8.98
Count	96	96	96	92	92	92	84

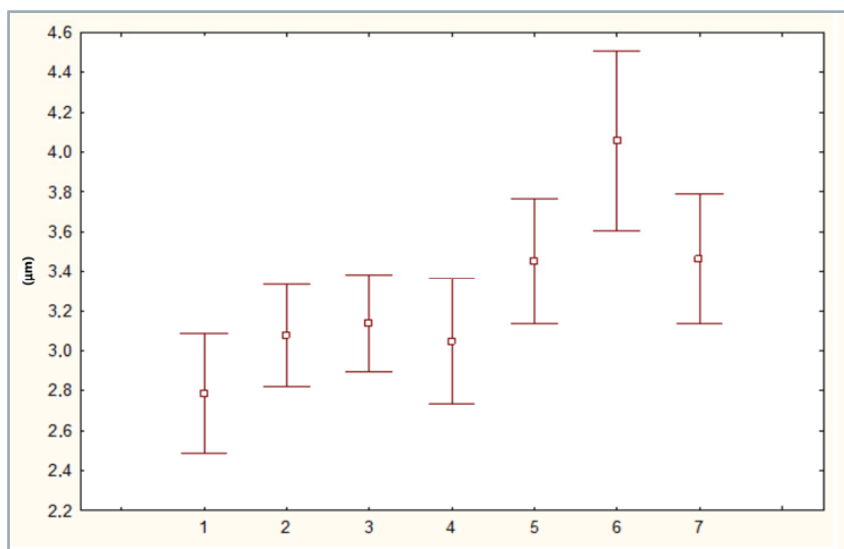


Fig. 5 Box plot of roughness R_z (μm) during the first measurement ($\alpha = 0.05$)

Based on this calculation, 2500 milkings recommended by the manufacturer with one teat cup liner can be achieved in 58.8 days.

From the measured values of R_a , it is clear that the inner surface of the new liner is rougher. With gradual use, its roughness decreases to a certain point after which it subsequently increases, which is confirmed in Fig. 4. Table 1 also shows that during the experiment, 12 of the 96 tested teat cup liners were damaged and had to be replaced. In Fig. 4, the time of use was marked. The figure shows that the monitored teat cup liners should be used for a maximum of 2500 milkings or six months of operation, whichever comes first. Statistical significance testing was at the significance level of $P < 0.05$. In Fig. 4, the recommended time of use by the manufacturer of nitrile liners is marked in red. The black colour marks the time when the first liner from our selection was damaged to such an extent that it had to be replaced.

From the evaluated data, $P = 0.243 > 0.05$; i.e. comparison shows that the difference between individual measured values is statistically insignificant. The linear equation of the straight line $y = 0.6507 + 0.017x$ tells that every 30 days the roughness of the nipple teat cup liner increases by $0.017 \mu\text{m}$. To interpret the correlation coefficient and to determine the degree of connection, the assessment according to Poláková (2011) was used. Since the value of correlation coefficient is between the values $0 \div 0.3$, $R = 0.046$, there is a zero degree of connection between the roughness of the liner and the time of use, i.e. there is very little or no correlation. As the descriptive statistics for R_z values in Table 2 shows, after less than 75 days, it was necessary to replace 4 liners. By the end of the use of the liners set by the farmer, another 8 liners were replaced.

From the measured values of R_z (Fig. 5) it follows that new teat cup liners are characterised by unevenness, which is referred to as production surface roughness. This R_z value decreases due to use and increases again after a certain time. Based on the P value = $0.000 < 0.05$, the difference between individual measured values is statistically significant. The linear equation of

the straight line $y = 2.6659 + 0.1566x$ tells that every 30 days the R_z roughness of the liner increases by 0.1566 μm . Since the value of correlation coefficient is between the values $0 \div 0.3$, $R = 0.196$, there is a zero degree of connection between the roughness of the teat cup liner and the time of use.

Measurement II

Before carrying out the second measurement, we suggested to the farmer to make some changes that could improve the quality parameters of teat cup liners. The farmer shortened the time of using the teat cup liners by 30 days. Teat cup liners purchased just before putting into operation were used.

The second major change was that new teat cup liners purchased from the dealer were fitted and tested. As can be seen from Table 3, the average values reached significantly more favourable parameters compared to the first measurement. During the entire second experiment, it was not necessary to change any liner neither in the selection set nor outside the selection set. The following values follow from Fig. 6. The P value = 0.000 < 0.05 indicates that the difference between the individual measured values is statistically significant. The linear equation of the straight line $y = 0.5442 - 0.0177x$ tells that every 30 days the R_a roughness of the liner decreases by 0.0177 μm .

Since the value of correlation coefficient was between the value $0 \div 0.3$, $R = -0.1658$, there is a zero degree of connection between the roughness of the teat cup liner and the time of use. From Table 4, it is clear that in the second measurement average roughness values R_z were lower than in the first measurement. The destruction of the teat cup liner during the experiment was not noticed.

The value $P = 0.002 < 0.05$ was subsequently calculated from the box graph (Fig. 7) of roughness R_z . Comparison shows that the difference between individual measured values is statistically significant. The linear equation of the straight line $y = 2.6571 - 0.0649x$ tells that every 30 days the R_z roughness of the teat

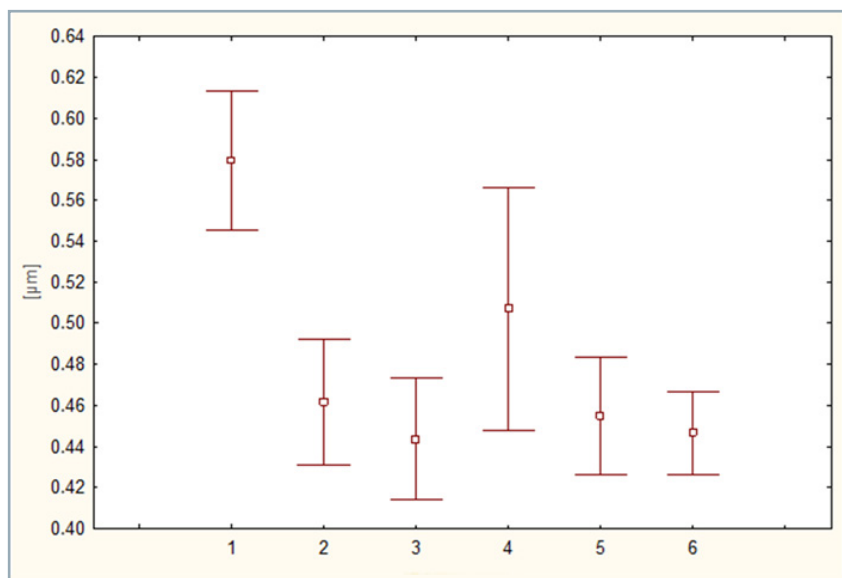


Fig. 6 Box plot of roughness R_a (μm) during the second measurement ($\alpha = 0.05$)

Table 3 Descriptive statistics of the parameter R_a (the second measurement – summer period)

R_a II						
Measurement	1	2	3	4	5	6
Mean (μm)	0.579	0.462	0.444	0.507	0.455	0.447
Standard deviation	0.167	0.151	0.146	0.293	0.141	0.099
Sample variance	0.028	0.023	0.021	0.086	0.02	0.01
Minimum (μm)	0.27	0.17	0.23	0.22	0.22	0.29
Maximum (μm)	1.02	0.91	1.16	2.11	1.11	0.78
Count	96	96	96	96	96	96

Table 4 Descriptive statistics of the parameter R_z from the second measurement (the second measurement – summer period)

R_z II						
Measurement	1	2	3	4	5	6
Mean (μm)	2.807	2.302	2.293	2.568	2.327	2.283
Standard deviation	0.805	0.7	0.833	1.387	0.68	0.523
Sample variance	0.648	0.49	0.694	1.924	0.463	0.273
Minimum (μm)	1.41	0.39	1.13	1.24	1.23	1.39
Maximum (μm)	5.32	4.34	7.36	9.74	5.62	4.47
Count	96	96	96	96	96	96

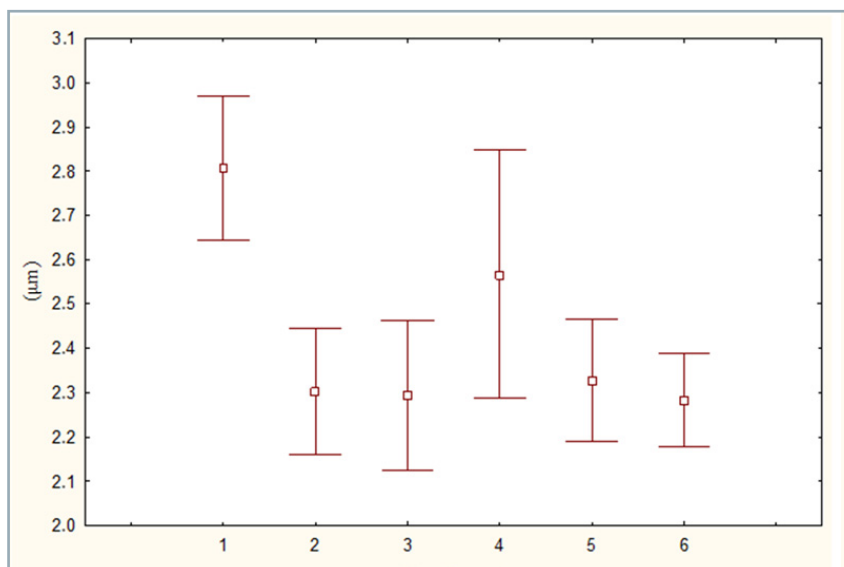


Fig. 7 Box plot of roughness R_z (μm) during the second measurement ($\alpha = 0.05$)

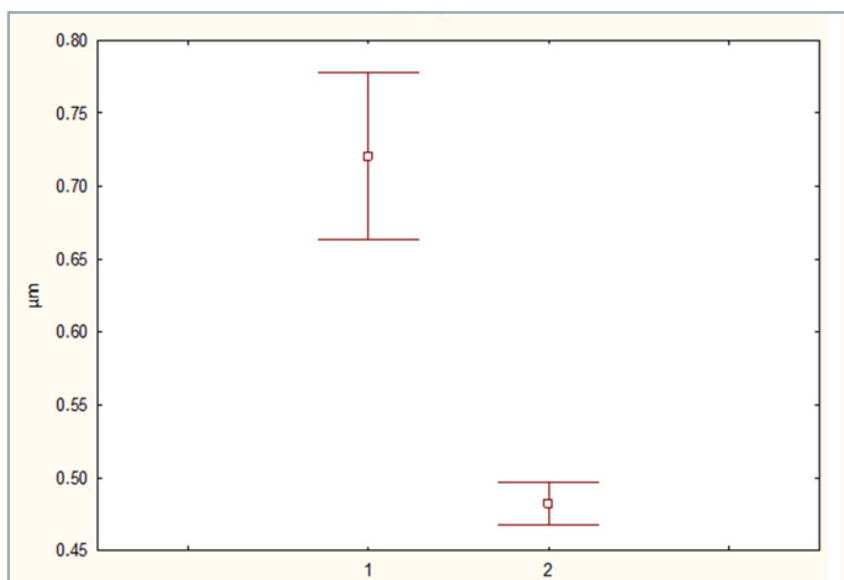


Fig. 8 Box plot of roughness R_a (μm) during the first and second measurements ($\alpha = 0.05$)

cup liner decreases by $0.0649 \mu\text{m}$. Since the value of correlation coefficient was between the value $0 \div 0.3$, $R = -0.1255$, there is a zero degree of connection between the roughness of the teat cup liner and the time of use.

There is a slight dependence between air humidity and the roughness R_a and R_z . By comparing the data from the first and second measurements of the roughness R_a (Fig. 8), it was found that in the first measurement the average measured value was $0.721 \mu\text{m}$, standard deviation 0.737 , the coefficient of variation 0.543 , the minimum measured value $0.24 \mu\text{m}$, and the maximum value $12.5 \mu\text{m}$.

In the second measurement of the roughness R_a , the following values were recorded: the average measured value $0.482 \mu\text{m}$, standard deviation 0.182 , the coefficient of variation 0.033 , the minimum measured value $0.17 \mu\text{m}$, and the maximum value $2.11 \mu\text{m}$. The P value = $0.000 < 0.05$, which means that there was a significant difference in the roughness R_a between the first and second measurement.

When comparing the data from the first and second measurement of the roughness R_z (Fig. 9), in the first measurement the average measured value was $3.282 \mu\text{m}$, standard deviation 1.592 , the coefficient of variation 2.535 ,

the minimum measured value $0.38 \mu\text{m}$, and the maximum value $17.66 \mu\text{m}$. In the second measurement of the roughness R_z (Fig. 9), the following values were recorded: the average measured value $2.43 \mu\text{m}$, standard deviation 0.883 , the coefficient of variation 0.78 , the minimum measured value $0.39 \mu\text{m}$, and the maximum value $9.74 \mu\text{m}$. The P value = $0.000 < 0.05$, which means that it does not matter whether the teat cup liner is used for 2500 milkings or six months.

In the experiment, milking was performed three times a day, which is an intensive use of the teat cup liner. It is necessary to pay attention to the correct determination of liner's time of use. A teat cup liner that bursts during operation will cause milk to reach parts where it can significantly disrupt the operation of the pulsator, up to its inoperability. Subsequent cleaning is laborious and time-consuming. Bad pulsator parameters result in deterioration of the health status of dairy cows. The reason for such a long use of teat cup liners was the fact that the milk collector did not signal to the farmer the total increased number of microorganisms in the milk. Another reason was that farmer's costs for buying teat cup liners would increase enormously if he followed the recommendation of the milking equipment seller. Both Boast et al. (2008) and Gálik et al. (2015) described the course of wear of a new teat cup liner. In the beginning, the level of roughness is high, it gradually decreases with use, and at a certain point the roughness starts to increase again. Conclusions emerge from our observations that point to the importance of proper care of teat cup liners. It is not good to store teat cup liners for a long time. Purchasing a maximum of one year's supply is recommended. The proof is the linear equation of the straight line $y = 0.6507 + 0.017x$, which tells that every thirty days the roughness of the liner increases by $0.017 \mu\text{m}$ for the total roughness R_a . When tracking the overall R_z roughness, the linear equation of the straight line $y = 2.6659 + 0.1566x$ tells that every thirty days the R_z roughness of the liner will increase by $0.1566 \mu\text{m}$. It follows from the above that cracks were getting bigger. In the second

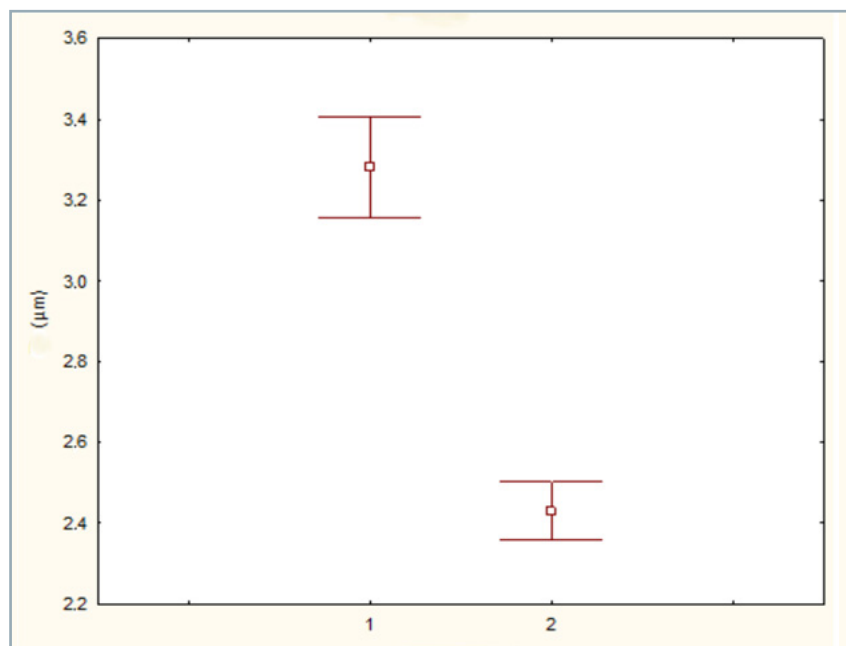


Fig. 9 Boxplot of the roughness R_z (μm) during the first and second measurement

measurement of the roughness R_a , the linear equation of the straight line was $y = 0.5442 - 0.0177x$, which tells that every thirty days the roughness R_z of the liner decreases by -0.0177 μm. For the R_z roughness value from the second measurement, the linear equation of the straight line $y = 2.6571 - 0.0649x$ indicates that every thirty days the R_z roughness of the liner decreases by -0.0649 μm. This change in the roughness R_a and R_z is caused by the abrasion of the surface of the new liner by using it to a certain point where microcracks start to form in the liner due to use. When comparing the R_a and R_z parameters from the first and second measurements, it was found that in both cases there are statistically significant differences in the measured values in favour of the second measurement ($P = 0.000 < 0.05$). When assessing the effect of temperature and humidity on the quality parameters of the liner, there was a slight negative dependence between temperature and the roughness R_a and R_z , while for humidity a slight positive dependence between humidity and the roughness R_a and R_z .

Conclusion

The presented work deals with monitoring the wear of the inner surface of teat cup liners using a roughness meter. A new measurement method was verified

without unnecessary, lengthy, and sometimes difficult disassembly of the teat cup liner from the nipple case. This method advances the area of liner's diagnostics to more exact results. With the help of preparation, it was able to measure the inner roughness of the liner at a depth of up to 60 mm in any place along the inner circumference. In this work, four places were determined, each time by turning the teat liner by 90°. For the first measurement in the winter period, teat cup liners were stored on the farm for three years. For the second measurement in the summer season, teat cup liners were purchased just before being put into operation. All previous investigations of the quality of teat cup liners were based on the principle of disassembling the liner and a destructive method, either by monitoring the modulus of elasticity, monitoring the leaching of compounds, or weight loss. The disadvantage of these methods is that during the disassembly of the liner, the liner is violently pulled out of the shell, which worsens the actual condition in which the liner was before disassembly. It follows from our knowledge that this method is suitable for monitoring the quality of the teat cup liner, but on the assumption of further long-term measurement and obtaining knowledge about the breaking point, when the initial

microcracks occur and are further developed. From the measured and evaluated data, it is clear that after installation, the new liner is smoothed to a certain point due to use, and subsequently the roughness value (R_a or R_z) begins to increase due to the formation of microcracks and the loss of the original elasticity of the liner. There is a zero degree of connection between the roughness of teat cup liners and the time of use, i.e. there is very little or no correlation. The evaluation of the achieved results shows that between the first and second measurement, there was a statistically significant difference in the roughness of both R_a and R_z ($P = 0.000 < 0.05$).

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