

JUSTIFICATION OF METHODS AND TECHNICAL MEANS FOR DIAGNOSING TECHNICAL PARAMETERS OF MILKING EQUIPMENT

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This study addresses the issue of technical reliability and efficiency of milking equipment, which is a crucial element of modern dairy production. It has been established that the technical condition of milking systems directly affects product quality, animal health, and overall farm productivity. Despite the existence of international standards (ISO 3918, ISO 5707, ISO 6690), the current diagnostic methods are largely outdated, highlighting the relevance of developing modern diagnostic instruments. The research reviews recent scientific advancements in monitoring the technical state of milking equipment, including the application of IoT technologies, machine learning (ML), sensor systems, and augmented reality (AR). The effectiveness of using LSTM and ARIMA models for failure prediction is demonstrated, along with the implementation of RGBD cameras, electrical conductivity, and infrared spectroscopy for improving milking quality and diagnosing animal health issues. The study presents original technical solutions: the Milking Installation Tester v.2.0 based on Arduino Mega 2560, which allows the measurement of key parameters such as pressure, pulsation, temperature, air flow, and rotational frequency; and a testing stand for evaluating the condition of teat liners, enabling assessment of tension and elongation under real operating conditions. The system supports external sensor connectivity, USB data transmission, and further processing in Excel, including hysteresis graph plotting. An adaptive maintenance approach is proposed, based on actual operating hours rather than a fixed schedule, considering the variability in component quality from different manufacturers. The study concludes that the implementation of integrated monitoring systems and technical bulletins can enhance operational efficiency. The deployment of the proposed methods and devices significantly improves the reliability of milking systems, reduces failure risks, enhances animal welfare, and increases the overall economic efficiency of dairy farms.

Keywords: milking equipment, diagnostics, technical parameters, reliability, sensors, service, technical monitoring, milking unit tester, teat cup liner, pulsations.

Fig. 8. Ref. 23.

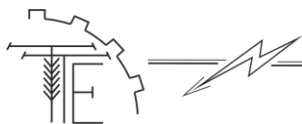
1. Problem formulation

Modern dairy production largely depends on the efficient and reliable operation of milking equipment. The quality of milking, labor productivity, as well as the health and comfort of animals directly influence the overall performance of a dairy farm. The technical condition of milking machines and systems requires constant monitoring and timely diagnostics, as even minor deviations in equipment parameters can lead to decreased milk quality, udder injuries in cows, increased operational costs, and production downtime [1].

In this context, the implementation of reliable diagnostic methods and technical tools is a critical component of the modernization of milking complexes. Timely detection of technical malfunctions helps prevent emergency situations, extend the service life of equipment, and optimize maintenance processes [2].

Despite significant advancements in milking technologies, practical operations on dairy farms still face challenges in the prompt and accurate assessment of the technical condition of milking systems. Milking equipment must comply with international technical and technological standards (ISO 3918 [3], ISO 5707 [4], ISO 6690 [5]). ISO 3918 defines the terminology used in dairy production, including terms related to milking equipment, milk processing technologies, milk classification, and equipment manufacturing methods. ISO





5707 sets the requirements for the design, safety, and functional characteristics of milking installations, while ISO 6690 outlines the standards for conducting mechanical tests to verify the performance of milking systems.

However, the obsolescence of standardized diagnostic methods and the insufficient automation of control processes often result in delayed detection of malfunctions, negatively affecting production efficiency.

Therefore, the development and justification of modern methods and technical tools for comprehensive real-time monitoring of key technical parameters of milking equipment is highly relevant. This approach will improve system reliability, reduce operating costs, and enhance animal welfare conditions.

2. Analysis of recent research and publications

Over the past decade, there has been significant progress in diagnosing the technical parameters of milking equipment, driven by the implementation of automated systems, intelligent sensors, and advanced data analysis methods. One of the key directions involves the application of in-line technologies for real-time milk analysis during the milking process. The use of near- and mid-infrared spectroscopy, optical analysis, and electrical conductivity enables effective milk quality control and timely detection of deviations associated with animal diseases or stress conditions [6].

Machine learning models, particularly deep neural networks, are increasingly being used to predict udder health and optimize automated milking processes. The use of RGBD cameras and segmentation algorithms allows for precise detection of teat positions, improving the accuracy of milking equipment alignment [7]. Additionally, models are being developed to assess the condition of teat skin, enabling earlier detection of pathologies and reducing the risk of animal injury [8].

The development of intelligent sensors, such as electrochemical sensors for detecting antibiotics in milk, integrated with machine learning algorithms, contributes to improved dairy product safety and a reduction in the volume of substandard milk entering the market [9]. Furthermore, non-contact sensors for monitoring cow body condition enable real-time health assessment of livestock [10].

Research on dynamic testing of automated milking systems helps identify risk factors that may lead to udder injuries or mastitis, such as vacuum instability or overmilking. Findings from these studies facilitate the improvement of equipment design and operational parameters [11].

For disease risk prediction—such as mastitis—data analytics based on parameters collected by automated systems (e.g., milk conductivity, temperature, and volume) are widely applied. The use of recurrent neural networks enables timely and accurate disease identification [12].

Optimization of vacuum system design through modeling helps stabilize vacuum levels, which directly affects milking quality and reduces animal trauma [13]. Video analytics based on deep learning is used to assess cow health by analyzing their behavior and body structure, ensuring early problem detection and improved herd management [14].

Energy efficiency improvement methods for vacuum systems are also being explored, enabling more stable equipment operation and lower operational costs [15]. The standardization of diagnostic methods and automation of control processes are recognized as critical, as they ensure timely detection of technical faults and help prevent failures, ultimately enhancing dairy production efficiency [16].

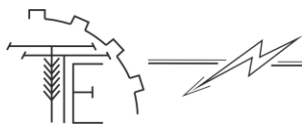
Thus, modern scientific developments in the field of milking equipment diagnostics are focused on integrating intelligent sensors, automated monitoring systems, machine learning techniques, and design modeling to increase the reliability, safety, and efficiency of milking. Nevertheless, there remains a need for further improvement of comprehensive diagnostic methods, standardization of control procedures, and development of universal technical tools capable of functioning under various types of milking equipment conditions.

3. The purpose of the article

The aim of the study is to substantiate modern methods and technical tools for diagnosing the technical parameters of milking equipment through the development and implementation of an adaptive maintenance approach based on the actual operating time of the systems, the creation of monitoring tools for assessing the technical condition of key components of milking units, as well as the development of universal diagnostic devices — the Milking Unit Tester v.2.0 and the Teat Cup Liner Testing Stand.

4. Results and discussion

The application of IoT technologies in milking equipment systems is a modern approach that enables



continuous real-time monitoring of various technological parameters, including vacuum system pressure, pulsator operation, milk flow rate, and energy consumption. For example, in [17], a monitoring system for a milking unit is described (Fig. 1), which transmits data to the Google Sheets cloud service for further analysis. The system proposed by the authors is based on a concept that involves collecting and transmitting data on the operation of individual components of the milking installation, as well as implementing feedback.

The system allows monitoring of parameters such as: the rotational speed of the vacuum pump, its energy consumption characteristics (voltage, current, frequency, power consumption); pulsator performance parameters, including maximum and minimum vacuum values, pulsation frequency, and the characteristics of pulsation phases (A, B, C, D), which correspond to the milking and recovery phases. All collected data is stored in a Google spreadsheet, enabling users to track the technical condition of the milking unit, detect deviations in the operating parameters of individual components, perform timely maintenance or repairs, and provide accumulated data for remote analysis by a service team or equipment supplier.

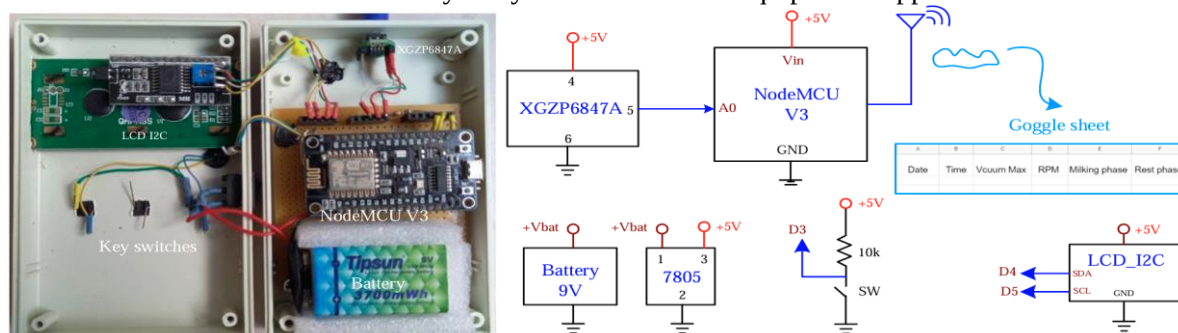


Fig. 1. Block Diagram and Prototypes of Embedded Systems for Measuring Pulsator Operating Parameters [17]

The use of machine learning (ML) algorithms in combination with IoT technologies opens new opportunities for predicting technical conditions and preventing failures in milking equipment. The application of models such as ARIMA and LSTM makes it possible to detect signs of wear and potential malfunctions before an actual failure occurs, allowing for scheduled maintenance based on predicted intervals.

In [18], the principle of operation of a system comprising four main stages is described. The first stage involves data collection from sensors installed on milking unit components. The monitored parameters include: vacuum level in the milking line, pulsation frequency and rhythm, temperature and vibrations of the vacuum pump's electric motor, milk flow, and energy consumption. The data is transmitted to a local controller or cloud storage.

At the second stage, the data is processed and anomalies are detected using machine learning algorithms such as KNN, Random Forest, Gradient Boosting, ARIMA, and LSTM. LSTM models are effective in handling time series data, while ARIMA enables accurate forecasting of parameter changes. The standard approach to anomaly detection includes identifying deviations from normal pulsation or vacuum dynamics and exceeding permissible vibration levels, which may indicate wear of bearings, seals, or blades.

The third stage focuses on failure prediction. The developed ML models can forecast decreased efficiency of the vacuum pump, the need for gasket replacement, and detect deviations in pulsation parameters that may negatively affect animal comfort. The system can also calculate the time remaining until the next maintenance of the pump or motor unit based on actual operating time and suggest preventive actions before peak milking periods.

The fourth stage involves data visualization and generation of recommendations. The user (farmer or operator) receives alerts via the control panel or mobile device about changes in the operational parameters of milking equipment, along with an overall wear indicator for key components. This system not only minimizes the risk of equipment failure but also improves operational efficiency.

In study [19], the use of augmented reality (AR) glasses with an integrated assistant is considered as a support tool for technical staff and service specialists during the diagnostics and maintenance of milking units. The main goal of the study was to evaluate the effectiveness of AR glasses (Fig. 2) in real farm conditions, specifically in terms of audio and video communication quality, battery life, marker (QR code) recognition accuracy, and voice control functionality.

The Vuzix M400 AR glasses were used as the base device. These glasses have an IP67 protection rating, making them resistant to high humidity levels (over 75%), which is typical in livestock environments.

They are equipped with a see-through system, allowing the technician to view both the real object and virtual guidance overlays within the field of vision without losing spatial orientation.

The study highlights the high potential of augmented reality technologies in the maintenance of milking equipment. AR glasses enable technical personnel to receive real-time visual instructions and reference information without diverting attention from the main task, significantly reducing diagnostic and repair time, eliminating the need for printed manuals or additional devices (e.g., tablets), and ultimately improving the efficiency of technical servicing.

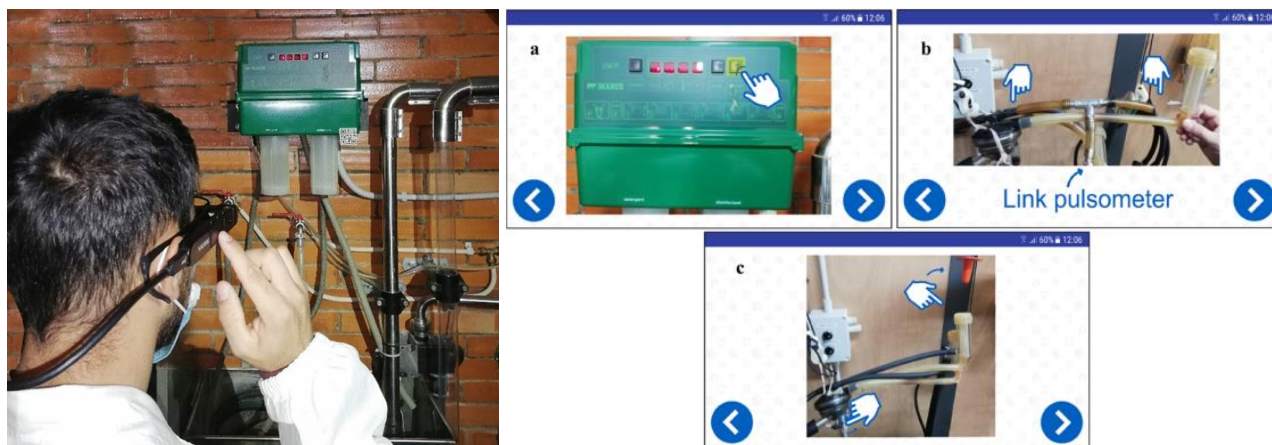


Fig. 2. Photo of AR Glasses Usage and Example of Augmented Information during Mechanical Milking Machine Testing Using the BStep Application [19]

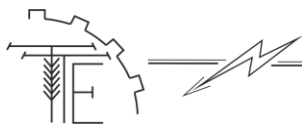
The reliability of milking equipment components subject to repair or replacement is a critical factor in ensuring uninterrupted operation of milking systems. In article [20], an approach to analyzing the reliability of key components of milking equipment based on actual failure and repair data is presented, aimed at improving overall system reliability. The study collected statistical data on types of failures, mean time between failures (MTBF), and mean time to repair (MTTR) over several years of operation. Based on this information, a descriptive analysis was performed, failure time distributions (including exponential and normal) were constructed, and the technical lifespan of components was assessed considering their suitability for continued service.

The study's results showed that the most failure-prone elements are vacuum pumps, receivers, valves, and filtration components. It was found that maintenance efficiency significantly increases when planned based on actual equipment usage rather than a calendar schedule. Thus, the study demonstrates the advantage of an adaptive maintenance planning approach, focused on real operational conditions and the technical state of components. This is particularly relevant in Ukraine, where maintenance is often carried out involving multiple independent spare parts suppliers and service organizations. Variations in component quality—depending on manufacturer and cost—lead to significant differences in the actual service life of parts.

For example, domestically produced teat cup liners, with proper care, retain their properties on average for 1.5–2 months, whereas high-quality imported analogs can function effectively for up to 6 months. At the same time, a calendar replacement schedule assuming renewal every three months may be too early for premium products and too late for budget ones. Notably, premium teat cup liners are made from softer and more elastic materials, have optimized bend geometry to prevent cracking, and provide better animal comfort.

An industry source detailing milking equipment maintenance on British dairy farms provides a comprehensive guide containing regulated measures for daily, weekly, and monthly technical checks of milking units [21]. Daily checks include monitoring vacuum levels in low-pressure (40–44 kPa) and high-pressure (44–48 kPa) systems; the characteristic hissing of the vacuum regulator is considered a normal audio marker of its operation. Pulsator function is assessed by the uniformity of sound signals, indicating proper pulsation. Airway cleanliness (particularly in collectors and pulsators) is checked since blockages reduce system efficiency.

Weekly inspections involve aligning marks on the teat cup liners by rotating them; cleaning pulsator filters to ensure stable pulsation; checking the vacuum regulator valve—hearing the hissing sound during operation which decreases when milking units are connected; monitoring teat cup liner wear with replacement norms: standard liners after 2,500 cycles or 6 months, silicone liners up to 8,000 cycles; detecting water presence in pulsator hoses as an indicator of teat cup liner damage requiring immediate replacement; and



monitoring vacuum pump oil levels to ensure continuous operation.

Monthly reviews include assessing the effective vacuum reserve; analyzing average milking duration (optimal 5–7 minutes); and monitoring teat cup liner slippage frequency (no more than 5 slips per 100 cows, more than 10 indicates need for system diagnostics).

Additionally, the guide specifies recommended professional service intervals based on equipment usage: intermediate service at 750 operating hours and overhaul at 1,500 hours. Despite its overall structured nature, it is important to note that for domestic commercial dairy farms, this guide has limited practical value since it does not cover several critical milking system components, such as the milk pipeline cleaning system, which is essential for hygiene and technical reliability.

Non-destructive diagnostics of rubber elements in milking equipment is an important component for ensuring their reliability and durability. Works [22, 23] present devices for assessing the condition of teat cup liners by measuring the teat tension on a specialized test stand. The optimal tension of the teat liner in the milking cup is 5–6 kg. When this force is applied, the elongation of the teat is measured, which depends on the physical properties and condition of the rubber. A limitation of this method is the tension time restriction (no more than 5 seconds), since prolonged loading may lead to premature material rejection.

In international practice [24], non-contact methods have been proposed for evaluating the inner surface condition of teat liners using specialized devices that allow measurements without removing the rubber elements from the milking unit. For experimental studies, a Mitutoyo SJ-210 profilometer was used, operating on the following principle: the milking machine is placed on a special table with a fixing clamp that ensures stability during measurements; the registering sensor of the tester is inserted inside the teat liner to a depth of 40–60 mm, corresponding to the standard length of the artificial teat, and contacts the inner rubber surface; on the control panel, the roughness measurement mode is activated; measurements were taken at six random points during winter and summer periods, comparing new and used teat liners (Fig. 3).

The results showed that the average roughness of old rubber in winter was 0.721 microns, while new rubber in summer demonstrated a value of 0.484 microns. Based on these data, the following conclusions can be made: first, the proposed method effectively evaluates the condition of teat liners without the need for disassembly, enabling prompt control in farm conditions; second, the duration of a single measurement cycle does not exceed a few minutes, and organizing testing only requires installation of a specialized table, which is not technically complex; third, the method is highly sensitive to changes in rubber material properties, allowing clear differentiation between new and worn rubber elements; fourth, it is recommended to implement regular measurements when replacing teat liners to realize an adaptive maintenance approach that will contribute to increased system reliability and timely defect detection.



Fig. 3. Assessment of the Inner Surface Condition of Teat Liners Using the Mitutoyo SJ-210 Profilometer [24]

Diagnostic technical tools for milking units (Fig. 4) are an important element of modern systems for monitoring the technical condition and performance of milking equipment. Their primary purpose is to provide prompt and accurate measurement of key technological parameters: vacuum pressure, pulsation frequency, air flow rate, temperature, rotor rotation speed, as well as hydrodynamic and atmospheric pressures. Such tools facilitate the detection of deviations in milking unit operation and improve the efficiency of maintenance [2, 22, 23].

The variety of devices available on the market allows selecting technical solutions tailored to the needs of farms, considering the level of automation, production scale, and budget. All the discussed diagnostic tools comply with the requirements of the international standard ISO 6690:2007, which guarantees the reliability of measurement results.



MILKOTEST MT 52
(Bepro AG)



PULSOTESTER COMFORT
(GEA WestfaliaSurge GmbH)



EXENDIS PT – V
PULSATORTESTER (Exendis B.V.)



VPR100 (DeLaval)



TEST-1 (Scientific Research
Institute «ELIRI» S.A.)



Milking Unit Tester v.1
(IMT NAAS)

Fig. 4. Diagnostic Technical Tools for Milking Units [2, 22, 23]

In summary, diagnostic technical tools for milking units encompass a wide range of functional capabilities and technical specifications. Their implementation allows for increased accuracy in assessing the technical condition of milking equipment, timely detection of malfunctions, and reduction of productivity loss risks. A promising direction involves further improvement of user interfaces, automation of data collection, and integration with digital farm management platforms.

To facilitate the diagnostics of technical parameters of milking equipment, the Milking Unit Tester v.2.0 (Fig. 5) was developed.

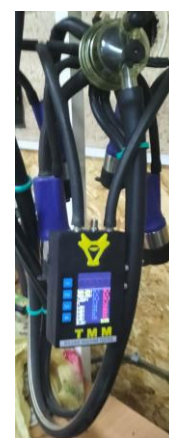
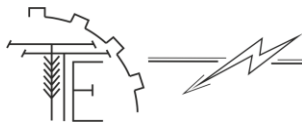


Fig. 5. General View of the Milking Unit Tester v.2.0

This modern diagnostic tool is designed for comprehensive analysis of milking equipment parameters, featuring enhanced functionality and expanded capabilities for connecting additional sensors. The device is built on the Arduino Mega 2560 hardware platform, which ensures stable operation, scalability, and flexibility in implementing control algorithms. The automated control system includes a control keypad and a 3.2" 320×480 TFT LCD graphical display, providing a user-friendly interface for mode selection, data viewing, and user interaction.

The device menu includes the following main functional sections (Fig. 6):

- “Manometer” – pressure measurement mode (displaying P , $P_{\max}$, $P_{\min}$, P_m , dP , dP_m);
- “Pulsation Mini” – basic pulsation analysis (f , n , $A+B$, $C+D$, dt);
- “Pulsation” – advanced measurement of pulsation phases in % and ms (f , n , A , B , C , D , dt);



- “Temperature” – temperature control via two channels (T , $T_{\max}$, $T_{\min}$, T_m , dT);
- “Air flow” – air flow measurement;
- “Frequency” – rotation frequency measurement (using a Hall sensor);
- “Settings” – system configuration and saving results to file.

In the basic configuration, the device is equipped with two built-in pressure sensors based on MPX5100DP sensors, enabling simultaneous pressure measurement on two channels. The design also provides the possibility of connecting external temperature sensors, an air flow sensor, and a Hall sensor for monitoring the rotation frequency of pumps or shafts.

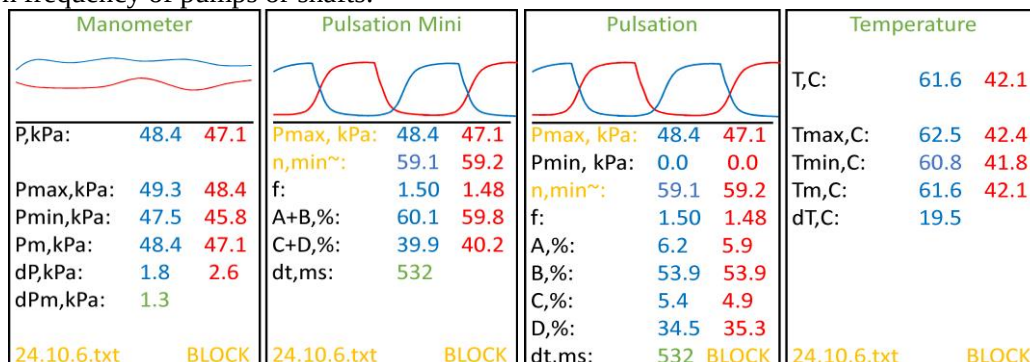


Fig. 6. View of Individual Functional Sections of the Milking Unit Tester v.2.0

All measurement results are displayed on the screen in a convenient graphical and numerical format, with the capability to save data as .txt files. The device features graph display (pulsograms, pressure graphs), calculation of average, maximum, and minimum values, as well as derived parameters such as the difference between channels, pressure fluctuation, pulsation phase ratios, and more. The keyboard lock function during measurements prevents accidental user interference and ensures the accuracy of results.

Thus, the milking unit tester v.2.0 is an effective tool for precise technical analysis of milking equipment performance. Its multifunctionality, modularity, ease of use, and ability to save results make it a valuable instrument for both scientific research and practical applications in animal husbandry.

For diagnosing the technical condition of teat rubber, a specialized testing stand has been developed (Fig. 7). It is designed to determine the tensile force of the teat rubber depending on the degree of its elongation, as well as to study the behavior of the rubber under the influence of vacuum and pulsations. The stand supports two operating modes:

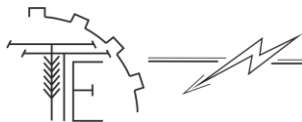
- the first – stretching with measurement of tensile force;
- the second – investigation of the material relaxation process after loading.



Fig. 7. General View of the Teat Rubber Testing Stand

The tensile force is measured in grams, and elongation is measured in millimeters. Two MPX5100DP pressure sensors are used to monitor the vacuum level, allowing vacuum measurement in kPa (Fig. 8). Testing can be performed with any type of teat rubber – both standard round and triangular – using interchangeable adapters that are pre-printed on a 3D printer.

In the stretching mode, the stand first slowly stretches the teat rubber, then gradually compresses it. The test results generate a graph showing changes in the rubber's condition throughout the stretch and



compression cycle, allowing an objective assessment of its physical and mechanical properties under conditions close to real operation.

The stand connects to a computer via a USB cable, enabling direct transfer of experimental data to Excel spreadsheets for further analysis, including the construction of hysteresis curves and calculation of the hysteresis loop area.



Fig. 8 Graph of changes in the condition of the teat rubber, green – tension, red – compression

Overall, the use of this stand enables comprehensive testing of teat rubber of various types and manufacturers – both new and those that have undergone a defined operational resource specified by the manufacturer. Comparative analysis of the results allows detection of changes in the rubber's tensile force during wear, which directly affects the quality and completeness of milking.

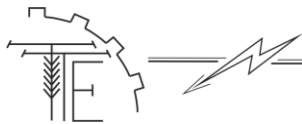
Additionally, these data can be used to predict the durability of the teat rubber and to verify the technical specifications declared by the manufacturer. Thus, the stand is an effective tool for making an informed selection of components that ensure stable performance of milking equipment.

5. Conclusion

Based on the research results, one of the key directions for improving the reliability of milking systems is the transition to adaptive maintenance based on actual equipment runtime instead of traditional calendar schedules. This approach requires taking into account the specifics of equipment from different manufacturers, collecting and analyzing technical and operational data for timely replacement of consumables and spare parts before failure occurs, thereby preventing disruptions to the technological process and avoiding harm to the animals. In this context, the development of embedded monitoring systems that provide continuous control of the technical condition of key components of the milking system is promising, allowing for rapid identification of malfunctions or their precursors. To enhance maintenance efficiency, it is also advisable to create technical bulletins containing structured information about the components of each unit (e.g., milk receiver, vacuum pump, etc.), their catalog numbers, and instructions for replacement or servicing. This will significantly simplify the identification and ordering of necessary parts, reduce repair time—especially in emergency equipment shutdowns—and contribute to improving the overall operational readiness of milking systems.

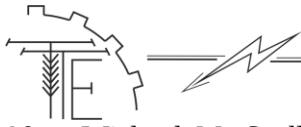
The developed milking system tester v.2.0 is a highly efficient diagnostic device designed for comprehensive analysis of the technical condition of dairy milking equipment. Its design is based on the Arduino Mega 2560 hardware platform with an integrated control keypad and graphic display, providing a user-friendly interface. The device supports measurement of key operational parameters of the milking system, including pressure, pulsations, temperature, air flow, and rotational frequency, with the possibility of expansion by connecting additional sensors. The presence of two independent measurement channels, basic and advanced analysis modes, graphical result presentation, and the ability to save data in text format enhance the device's analytical capabilities. Its stable operation, modularity, and ease of use make the tester a versatile tool for both research purposes and practical maintenance of milking equipment on farms.

The teat rubber testing stand is a device that allows determination of the teat rubber tension force depending on its elongation. Built on the Arduino Mega 2560 platform with a control keypad and graphic display, it is equipped with two MPX5100DP pressure sensors and is fully automated using a stepper motor and limit switches. The stand allows testing any type of teat rubber from any manufacturer. By testing two samples—new and used teat rubber—we obtain data that enable modification and adaptation of the teat rubber replacement schedule and allow predicting in advance the loss of working properties of the teat rubber, which directly affect the quality of milking.



References

1. Aliiev, E., Paliy, A., Paliy, A., Kis, V., Levkin, A., Kotko, Y., Levchenko, I., Shkurko, M., Svysenko, S., & Sevastianov, V. (2022). Increasing energy efficiency and enabling the process of vacuum mode stabilization during the operation of milking equipment. *Eastern-European Journal of Enterprise Technologies*, 6(1(120)), 62–69. DOI: <https://doi.org/10.15587/1729-4061.2022.267799>. [in English].
2. Shevchenko, I.A., Aliiev, E.B. (2013). *Naukovo-metodychni rekomendatsii z bahatokryteriiialnoho vyrobnychoho kontroliu doilnykh ustanovok* (I. A. Shevchenko, Ed.). Aktsent Invest-treid. [in Ukrainian].
3. International Organization for Standardization. (2007). *ISO 3918: Milking machine installations – Vocabulary*. Geneva, Switzerland. [in English].
4. International Organization for Standardization. (2007). *ISO 5707: Milking machine installations – Construction and performance*. Geneva, Switzerland. [in English].
5. International Organization for Standardization. (2007). *ISO 6690: Milking machine installations – Mechanical tests*. Geneva, Switzerland. [in English].
6. Kunes, R., Bartos, P., Iwasaka, G., Lang, A., Hankovec, T., Smutniy, L., & Kernerova, N. (2021). In-line technologies for the analysis of important milk parameters during the milking process: A review. *Agriculture*, 11(3), 239. DOI: <https://doi.org/10.3390/agriculture11030239>. [in English].
7. Borla, N., Kuster, F., Langenegger, J., Ribera, J., Honegger, M., Toffetti, G. (2021). Teat pose estimation via RGBD segmentation for automated milking. *arXiv:2105.09843*. DOI: <https://doi.org/10.48550/arXiv.2105.09843>. [in English].
8. Hao, Y., Yuan, T., Yang, Y., Gupta, A., Wieland, M., Birman, K., & Basran, P. S. (2024). AI-based teat shape and skin condition prediction for dairy management. *arXiv:2412.17142*. DOI: <https://doi.org/10.48550/arXiv.2412.17142>. [in English].
9. Aliev, T.A., Belyaev, V.E., Pomytkina, A.V., Nesterov, P.V., Shityakov, S.V., Sadovnychiy, R.V., Skorb, E.V. (2022). The development of an electrochemical sensor for antibiotics in milk based on machine learning algorithms. *arXiv:2212.04422*. <https://doi.org/10.48550/arXiv.2212.04422>. [in English].
10. Golisz, E., Kupczyk, A., Majkowska, M., Trajer, J. (2021). Simulation tests of a cow milking machine-Analysis of design parameters. *Processes*, 9(8), 1358. DOI: <https://doi.org/10.3390/pr9081358>. [in English].
11. Milanese, S., Donina, D., Chierici Guido, V., Zaghen, F., Sora, V. M., & Zecconi, A. (2024). Comparing the performance of automatic milking systems through dynamic testing also helps to identify potential risk factors for mastitis. *Animals*, 14(19), 2789. DOI: <https://doi.org/10.3390/ani14192789>. [in English].
12. Liu, N., Qi, J., An, X., & Wang, Y. (2023). A review on information technologies applicable to precision dairy farming: Focus on behavior, health monitoring, and the precise feeding of dairy cows. *Agriculture*, 13(10), 1858. DOI: <https://doi.org/10.3390/agriculture13101858>. [in English].
13. Liu, H., Reibman, A. R., & Boerman, J. P. (2020). A cow structural model for video analytics of cow health. *arXiv:2003.05903*. <https://doi.org/10.1016/j.compag.2020.105761>. [in English].
14. Aliiev, E., Paliy, A., Paliy, A., Kis, V., Levkin, A., Kotko, Y., Levchenko, I., Shkurko, M., Svysenko, S., & Sevastianov, V. (2022). Increasing energy efficiency and enabling the process of vacuum mode stabilization during the operation of milking equipment. *Eastern-European Journal of Enterprise Technologies*, 6(1(120)), 62–69. <https://doi.org/10.15587/1729-4061.2022.267799>. [in English].
15. Ongom, J., Okella, H., Ferreira, F.C., Okello, E. (2024). Association between automatic milking system parameters and intramammary infections in dairy cows at dry-off. *Frontiers in Animal Science*, 5, Article 1397144. DOI: <https://doi.org/10.3389/fanim.2024.1397144>. [in English].
16. Takaeng, C., Aurasopon, A. (2021). Monitoring system for a bucket milking machine based on IoT. *International Journal of Engineering Trends and Technology*, 69(9), 29–33. DOI: <https://doi.org/10.14445/22315381/IJETT-V69I9P204>. [in English].
17. Abdallah, M., Lee, W.J., Raghunathan, N., Mousoulis, C., Sutherland, J.W., Bagchi, S. (2021). Anomaly detection through transfer learning in agriculture and manufacturing IoT systems. *arXiv:2102.05814*. DOI: <https://doi.org/10.48550/arXiv.2102.05814>. [in English].
18. Sara, G., Todde, G., & Caria, M. (2022). Assessment of video see-through smart glasses for augmented reality to support technicians during milking machine maintenance. *Scientific Reports*, 12, Article 15729. DOI: <https://doi.org/10.1038/s41598-022-20154-2>. [in English].
19. Talkit, V., Kininge, R., Kokate, P., Narkhebe, D., Madame, S., Bewoor, A., Patil, R.B. (2022). Reliability analysis of repairable and replaceable system: Dairy product industry. *Materials Today: Proceedings*, 77(3), 573–578. DOI: <https://doi.org/10.1016/j.matpr.2022.10.074>. [in English].



20. Wieland, M., Spellman, M.E., Case, K.L., Geary, C.M., Sipka, A. (2024). Comparison of sensor-based and audible detection of milking liner slips during machine milking of dairy cows. *Sensors*, 24(5), 1361. DOI: <https://doi.org/10.3390/s24051361>. [in English].
21. Aliiev, E.B., Tislichenko, O.S., Shevchenko, I.A. (2013). *Rozrobyty systemu bahatokryterial'noho vyrobnychoho kontroliu tekhniko-tekhnolohichnykh parametriv doil'noho obladnannia ta zasobiv dlia yoho tekhnichnoho obsluhovuvannia: Final research report* (in 3 vols.), reg. no. 0111U004420. National Scientific Center "Institute of Mechanization and Electrification of Agriculture" NAAS. [in Ukrainian].
22. Aliiev, E.B.O. (2012). *Pidvyshchennia efektyvnosti ekspluatatsii vakuumnoi systemy molochno-doil'noho obladnannia* (Candidate's thesis, specialty 05.05.11). Zaporizhzhia. [in Ukrainian].
23. Bod'o, Š., Gálik, R., Gurdil, G.A.K. (2024). Inspection of rubber parts of milking equipment by non-destructive testing method. *Acta Technologica Agriculturae*, 27(4), 234–241. DOI: <https://doi.org/10.2478/ata-2024-0031>. [in English].

ОБҐРУНТУВАННЯ МЕТОДІВ І ТЕХНІЧНИХ ЗАСОБІВ ДІАГНОСТУВАННЯ ТЕХНІЧНИХ ПАРАМЕТРІВ МОЛОЧНО-ДОЇЛЬНОГО ОБЛАДНАННЯ

У роботі досліджено проблему технічної надійності та ефективності молочно-доїльного обладнання, яке є ключовим елементом сучасного молочного виробництва. Встановлено, що від технічного стану доїльних систем залежить якість продукції, здоров'я тварин і загальна продуктивність ферми. Незважаючи на наявність міжнародних стандартів (ISO 3918, ISO 5707, ISO 6690), існуючі методи діагностики здебільшого є застарілими, що обумовлює актуальність створення сучасних діагностичних приладів. У межах дослідження проаналізовано сучасні наукові розробки у сфері контролю технічного стану доїльного обладнання, включно із застосуванням IoT-технологій, машинного навчання (ML), сенсорних систем та доповненої реальності (AR). Продемонстровано ефективність використання LSTM і ARIMA для прогнозування відмов, а також застосування RGBD-камер, електропровідності та інфрачервоної спектроскопії для покращення якості доїння й діагностики захворювань у тварин. Представлено власні технічні розробки: тестер доїльних установок v.2.0 на базі Arduino Mega 2560, що дозволяє здійснювати вимірювання таких параметрів як тиск, пульсація, температура, повітряний потік і частота обертання; стенд для випробування дійкової гуми, що дозволяє визначати натяг та видовження гуми в реальних умовах експлуатації. Описано можливість підключення зовнішніх сенсорів, передачі даних через USB та подальшої обробки в Excel, включаючи побудову гістерезисних графіків. Запропоновано адаптивний підхід до сервісного обслуговування доїльних систем, що базується на фактичному напрацюванні техніки, а не календарному графіку, з урахуванням різниці у якості комплектуючих від різних виробників. Зроблено висновок про доцільність впровадження комплексних моніторингових систем і технічних бюлетенів для підвищення ефективності експлуатації. Впровадження зазначених технічних засобів і методів дозволяє значно підвищити надійність доїльного обладнання, зменшити ризики відмов, поліпшити умови утримання тварин і загальну економічну ефективність молочних господарств.

Ключові слова: молочно-доїльне обладнання, діагностика, технічні параметри, надійність, сенсори, сервіс, технічний моніторинг, тестер доїльних установок, дійкова гума, пульсації.

Рис. 8. Літ. 23.

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