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## Examination of maintainability indicators of feed preparation and distribution products

**Abstract.** New scientific and practical approaches in the livestock industry use Industry 4.0 and IoT technologies, in particular, feed mixers, for efficient transportation and dosing of feed, but the reliability problems of these mechanisms require research to determine the parts and assemblies that limit their performance and calculate their maintainability. The purpose of this study was to establish the design, production, and operation failures of feed mixer mechanisms, the causes of their occurrence, and the time to eliminate them. For this purpose, an examination of feed mixers was conducted according to the reliability test plan [NMT]. The test plan provided for the presence of  $N$  objects, which were restored in case of working capacity loss by  $M$ , and experiments are stopped when the operating time  $T$  was reached. The initial information was collected and processed, and empirical data were analysed to eliminate failures of the PROFILE 12.2 DS and PROFILE 14.2 DS feed dispensers. The tests established that during the warranty period of operation of feed dispensers, their faulty condition is caused by failures of the second group of complexity. Failures related to the restoration of the working capacity of the subsystem for grinding and mixing, which affects the maintainability of the feed dispenser mixer, are identified. A

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statistical analysis of the occurrence of these failures was conducted. The main parameters of the theoretical distribution law were determined. In particular, the maintainability indicators of feed dispensers were established: the average recovery time of working capacity,  $\bar{t} = 24.0$  hours; mean square deviation,  $\sigma = 12.93$  hours; coefficient of variation,  $\nu = 0.49$ ; the theoretical distribution law – the law of normal distribution. It was confirmed that the average recovery time of feed dispensers according to the Kolmogorov consent criterion was in good agreement with the law of normal distribution. Calculations established that the average time for restoring the operability of research objects was in confidence intervals: 6.98 hours – lower confidence limit; 41.02 hours – upper confidence limit; 34.04 hours – the size of the interval. The results can be implemented to improve the efficiency of maintenance and repair of equipment on livestock farms and optimise spare parts stocks

**Keywords:** feed dispenser mixer, operational reliability, time to failure, recovery time, grinding-mixing mechanism

## INTRODUCTION

The study on maintainability indicators is necessary to ensure continuous operation of the enterprise, reduce maintenance costs, minimise downtime, increase the efficiency of production processes, extend the service life of equipment, optimise spare parts stocks, improve the design of new models, develop recommendations for operation and improve labour safety. This allows timely detection and elimination of potential failures, preventing their transformation into serious breakdowns, and contributes to more accurate planning of repair and preventive measures, ensuring stable and efficient operation of livestock farms.

The relevance of research in the field of precision animal husbandry, which has spread to Europe, Asia, and America since its formation in 2003, is noted. New technological approaches in the livestock industry take advantage of advances in Industry 4.0 and IoT technologies, covering economic, technological, logistical, and social aspects (Norton *et al.*, 2019). Authors U. Moallem & L. Lifshitz (2020) note that for the sustainable and effective development of animal husbandry, it is advisable to use modern feeding technologies, justify highly efficient and improve the available means for loading, grinding, mixing, transporting, distributing, and dosing feed mixtures. The quality level and volume of livestock products largely depend on the duration of the feeding process.

The diversity of cattle species and their age groups, the difference in their conditions of keeping and differences in livestock, require designers and machine builders of agricultural machinery to produce efficient, high-performance, and reliable machines (Novitsky *et al.*, 2023). Along with substantiating the main parameters of the horizontal coarse feed grinding mechanism, K. Astanakov *et al.* (2020) manufactured and conducted experimental studies on a small-sized feed dispenser with a vertical screw, including testing the performance of the technological process and determining optimal parameters. P. Ma *et al.* (2020) conducted an examination of the design and technological characteristics of the grinding mechanism – a mixer with a horizontal screw. The main tests in this paper were: multiplicity of technological operation; number of fixed blades; grinding speed; number of working bodies; angle of inclination of the mixer body components.

Among the main scientific and practical searches that form a highly productive provision of feed preparation, the

following should be mentioned: computerisation of the technological process; technical service of machines and equipment; ensuring maintainability; training and advanced training of personnel.

Agricultural engineering plants produce trailed and self-propelled mixers-feed dispensers, which, depending on the design, can provide a set of measures for feed preparation and distribution of mixtures. Researchers S. Morone *et al.* (2022) state that at all stages of mixers-feed dispensers use, according to their functional purpose, attention should be focused on ensuring zootechnical requirements, reducing the consumption of feed components, improving the nutritional value of feed mixtures, improving their quality indicators.

During the operation of mixers, it is necessary to ensure a high level of maintainability indicators. Failure of any mechanism leads to a disruption of the entire complex of technological operations that feed mixers provide according to their structure and purpose. This can lead to a decrease in the level of operability of funds both during running-in, warranty service, and during the period of operation.

As noted by F. Tian *et al.* (2020), it is especially important in the operation of complex agricultural machinery to ensure and maintain the reliability parameters that were laid down at the stages of design, construction, production, and commissioning. The most important period is the initial period of use of agricultural machinery – the period of running-in. Violation of the rules of operation and maintenance of machines during the warranty period can reduce the reliability of the machine and lead to malfunctions and failures. It is necessary to perform maintenance and repair work to prevent failures and ensure the operability of machinery and equipment for animal husbandry. Based on the above, conducting research on calculating and ensuring the maintainability of feed dispensers is an important and urgent task.

The purpose of this study was to determine the design, production, and operational failures of feed mixer mechanisms, the causes of their occurrence, and the time to eliminate them.

## LITERATURE REVIEW

The organisation of the technological process of feed preparation is a promising direction for reducing costs in the livestock industry, as noted by V. Khmelovskiy *et*

al. (2020). The search for ways to reduce the energy intensity of this process is inextricably linked with the technology of preparing feed for feeding, the size of the livestock farm, and the choice of technological means for preparation and distribution.

Authors D. Wang *et al.* (2017) justified the parameters of the screw with the angle of installation of turns, improved the design of the hopper body, and determined their impact on the quality preparation of the feed mixture. They recommend ensuring the speed of rotation of the screw of the grinding and mixing subsystem close to  $32.5 \text{ minutes}^{-1}$ . The preparation time of a high-quality feed mixture is 4.7 minutes. However, it is important for operators to be able to assess the impact of these changes in the design of the auger, hopper, and operating modes of the grinding-mixing mechanism on the efficiency of use and reliability indicators of feed preparation and distribution products. Consumers are interested in the probability of parametric failures when using feed dispensers when grinding various feeds.

V. Baranovsky *et al.* (2018) proposed materials of analytical justifications for the transportation of agricultural products in fixed screw conveyor housings. These results of investigations of materials transportation operations by screw conveyors confirmed the possibility of their use in the design of mechanisms for loading and unloading agricultural machines, increasing their reliability indicators. Due to the increase in the volume of foreign means for feeding on livestock farms in Ukraine, it is timely to assess their maintainability since machine-building enterprises do not provide consumers with values of reliability indicators of the presented machines. This problem is reflected in separate papers by F. Tian *et al.* (2020), but these studies do not provide quantitative and qualitative indicators of maintainability and a set of measures to improve them for profile feed dispensers in Ukraine.

S. Morrone *et al.* (2022) note that animal husbandry can be highly efficient only due to a high-quality technological process of feeding, the use of computerisation, and the efficient technical service of feed preparation machines on demand. Therewith, as the analysis of the reliability of these tools shows, the complexity of their design, the tension and the short duration of their use in animal feeding technologies require the implementation of effective measures to ensure maintainability indicators.

As noted by M. Dumenko *et al.* (2012), maintainability indicators provide for determining the average time spent on ensuring operability, evaluating the values of criteria for the maximum condition of blades, rational methods for restoring parts, methods for ensuring the effectiveness of maintenance and repair in the conditions of the existing repair base or at different levels of the potential of the maintenance base.

According to D. Domushchi *et al.* (2019), recorded downtime of multi-operating machines, in particular, combine harvesters, reaches from 25 to 75% of the total time of their use during the day. The reason for substantial

time spent on restoring the working capacity of research objects, as a rule, can be: a lack of spare parts; insufficiently developed structure of technical service, and insufficient qualification of personnel who provide technical supervision and repair of equipment. For prompt access to spare parts that are necessary to ensure the operability of combine harvesters, the authors of the article propose to introduce the following system of storage of parts: spare parts necessary to eliminate failures of the first group of complexity, are to be stored on the combine itself or at a mobile maintenance point; eliminate failures of the second group of complexity – in the warehouse of an agricultural enterprise or in the warehouse of a department; for the third group of complexity – in the warehouse of a regional service centre.

In connection with the above, there is a need to form a list of parts and components that often lose their functionality, and the quantity that must be reserved at different storage levels: directly on the mixer-feed dispenser; in the warehouse of an agricultural firm; in the dealer's mobile maintenance point; in the warehouse of the dealer's service centre. It is also necessary to determine the list of works that operators need to perform during the function of feed dispensers. Solving these tasks will help to reduce the time spent for organisational reasons when eliminating the consequences of failures, achieve the highest operational efficiency, and ensure the productivity of funds at the lowest cost of material and labour resources under various conditions for performing feeding operations.

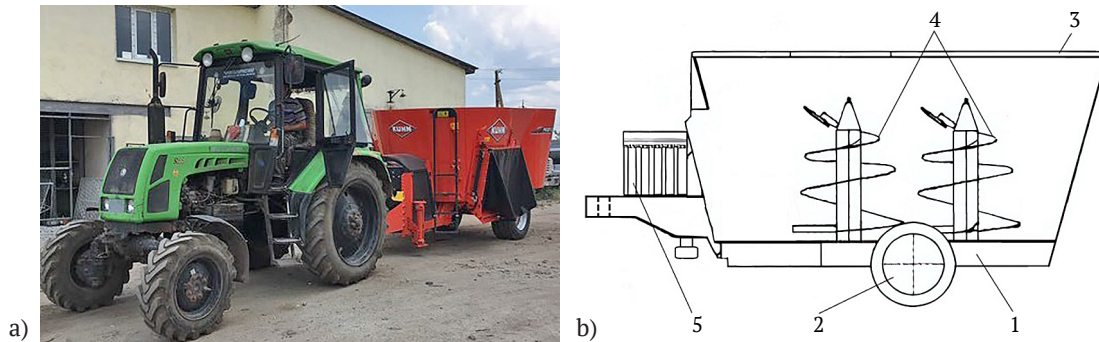
In separate scientific publications and conference materials, the issues of justifying the optimal idle time of feed mixers due to the elimination of the consequences of failures are considered. In particular, Z. Ruzhylo *et al.* (2022) review the load on one vehicle and substantial production factors that affect the reliability of equipment and the timeliness of their elimination. It is important to consider individual components of a complex technical system, record the time of time between failures of the "machine" and the time of performing functions by the "human operator", and calculate the intensity of transitions. Substantial production factors include timely restoration and maintenance of the working capacity of the "human operator" through the use of "failure harbingers" and improving their skills.

In general, the examination of the causes and consequences of equipment failures for animal husbandry is conducted to make informed and effective decisions regarding the mode of operation and maintenance of machines. Thereby, it reduces the probability of failures and the complexity of eliminating their consequences, which may lead to the disruption of zootechnical requirements, postponement or non-fulfilment of the technological process of feed preparation and distribution. Based on the results of the analysis of special literature and guidelines for use, it was determined that long-term downtime of feed dispensers is associated with untimely recovery of working capacity.

## MATERIALS AND METHODS

The study was conducted at the National University of Life and Environmental Sciences of Ukraine. The results of analytical searches and tests presented in the study are a continuation of findings by A. Novitsky *et al.* (2023), Z. Ruzhylo *et al.* (2022). They are aimed at ensuring the

reliability of mixer dispensers during operation and during the restoration of operability through maintenance and repair. The objects were mixers-feed dispensers PROFILE 12.2 DS and PROFILE 14.2 DS (Novitsky *et al.*, 2023) (Fig. 1a). The diagram of the research object is shown in Figure 1b.



**Figure 1.** Feed dispenser mixer PROFILE 14.2 DS

**Note:** a – under operating conditions; b – diagram of the mixer-feed dispenser; 1 – frame; 2 - Running system; 3 – hopper; 4 – grinding-mixing mechanism; 5 – mechanism for unloading the feed mixture

**Source:** compiled by the authors

Time-based observations were made on the use, maintenance, and repair of means for preparing and distributing feed in the period from 2015 to 2022 to collect statistical information on maintainability indicators in agricultural enterprises. The study involved 25 feed dispenser mixers “PROFILE 12.2-14.2” (Operator’s manual..., 2018; Operator’s manual. Mixer feeder wagon. PROFILE. 2DS, 2019). The tests were conducted on livestock farms in seven regions of Ukraine. In each of the presented regions, the following number of mixer distributors was tested: Khmelnytskyi – 9; Vinnytsia – 6; Zhytomyr – 3; Cherkasy – 3; Chernihiv – 2; Volyn – 1; Poltava – 1.

Timekeeping data was entered in the summary form. Failures were classified into difficulty groups. Failures that could be eliminated by adjusting, replacing, or repairing parts included in the spare parts kit, without disassembling components and assemblies, were divided into the first group. Malfunctions and defects that were eliminated by adjusting, rearranging, or repairing parts that are not included in the spare parts kit, with the disassembly of components and assemblies, as well as with the use of mobile maintenance points or mobile repair shops, were included in the second group of complexity. Failures that require dismantling components and assemblies from the frame of the feed dispenser mixer or completely replacing one of them were assigned to the third group of complexity. Failure of the working body or parts of the mixer-dispenser that caused complete or partial loss of performance of other parts were registered as one. Thus, the complexity group was determined by the greatest complexity of restoring one of the failed parts.

During the testing of feed dispensers, failures were recorded, and maintainability indicators were established.

Failures of the presented research objects were distributed across the subsystems shown in Figure 1b.

The mixer dispenser is equipped with A5336551 screws (KUHN, France). Each of the screws of the grinding-mixing mechanism is equipped with the appropriate number of blades (Audureau S.A. plant, KUHN Group, France), according to the design of the profile mixer-dispenser. Blades on the auger are installed in two versions according to the manufacturer’s recommendations: the small blade A5362450 has 7 teeth and is fixed on the lower ones, and the large knife A5303620 includes 9 teeth and is placed on the upper turns of the auger of the subsystem for grinding and mixing feed mixture.

The test mode of means for the preparation and distribution of feed is established as operational at the place of production. The plan for testing feed mixers for maintainability [NMT] has been adopted. The [NMT] plan considers the availability of an appropriate number of test objects  $N$ , which are restored in case of working capacity loss are restored by  $M$ . The test plan stipulates that experiments are suspended when the appropriate time  $T$  is reached, which is spent on restoring performance. Based on the above, for the described test plan [NMT], the initial parameters are as follows: the number of feed mixers  $N$ , pieces; the property of the presented means to be restored in the corresponding average time  $T$ , hours. The initial data were set, which indicated the accuracy of the obtained results to establish the minimum volume of observations It included confidence probability and marginal relative error, which were  $\gamma=0.9$  and  $\delta=0.1$ , respectively. According to a priori data, it was determined that the distribution of values for restoring the operability of feed mixers corresponds to the law of normal distribution.

Using reference information (DSTU 3004-95, 1995), the minimum number of objects under the presented tests was calculated  $N_{min} = 21$ ,  $N = 25$  feed dispensers were taken. The distribution of the average recovery time of working capacity is in good agreement with the law of normal distribution, according to  $\gamma = 0.9$  and  $\delta = 0.1$ .

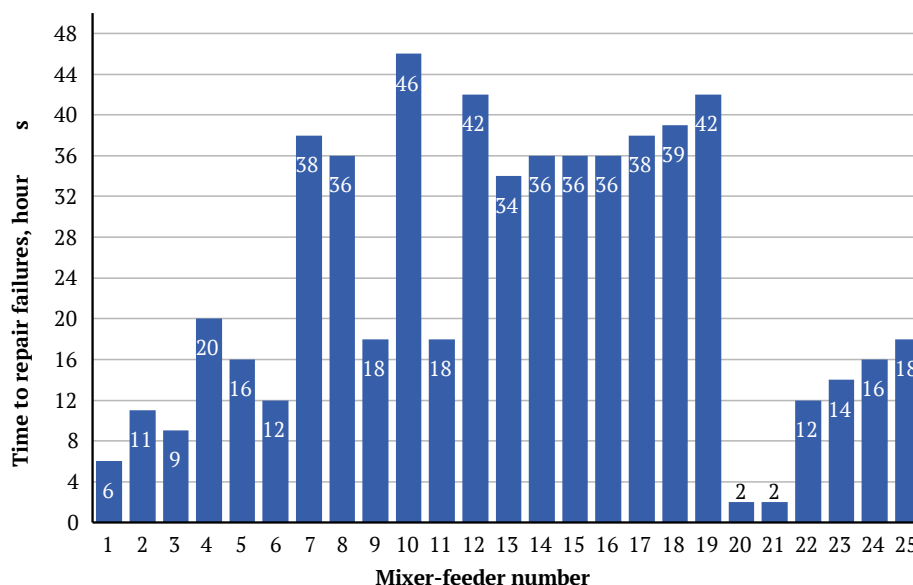
Statistical processing of experimental data was conducted as follows: according to the obtained empirical data, a statistical series of information was formed; an empirical distribution was constructed; distribution parameters were calculated; a hypothesis was formed about the type of distribution law of the random variable that was examined; according to the accepted theoretical law, the empirical curve was aligned; according to the consent criteria, an empirical and theoretical distribution was compared; in accordance with the results, a decision was made to accept or deny the proposed hypothesis.

The method of processing experimental data provides for the calculation of the following maintainability indicators: average recovery time of working capacity; mean square deviation of the indicator; coefficient of variation; theoretical distribution law; scattering intervals of empirical values of the average recovery time of working capacity.

## RESULTS AND DISCUSSION

The strategy for the development of the agro-industrial complex of Ukraine encourages the purchase of a substantial amount of new national and foreign equipment, including feed mixers. The design schemes of feed dispensers are diverse. According to the method of aggregation, they are divided into self-propelled and trailed. Trailed ones were more popular in small farms (Ruzhylo et al., 2022), and at large livestock enterprises – self-propelled (Tian et al., 2020). Most of them consist of a single-axis or two-axis chassis, on which a hopper with mixing working bodies, a transverse unloading conveyor, and an unloading system are fixed. The working bodies of these machines are driven from the tractor's PTO shaft. The mixing working bodies of the presented tools are augers with blades, which are located inside the hopper and are installed in accordance with the horizontal and vertical schemes. The number of mixing working bodies can vary from one to four.

The obtained time values for transferring PROFILR trailed vehicles to working or serviceable condition are taken from the timekeeping data of the official dealer – KUHN in Ukraine. According to the results of the conducted studies, the time for restoring the operability of 25 feed dispensers was recorded, which is shown in Figure 2.



**Figure 3.** Recovery time for feed preparation and distribution tools PROFILE 12.2 DS and PROFILE 14.2 DS

**Source:** compiled by the authors

An analysis of the results shows that the minimum recovery time was 2 hours for research objects No. 20 and No. 21. The maximum recovery time is 46 hours for object No. 10 and 42 hours for objects No. 12 and 19. Failures that limit the reliability of feed dispensers were identified. It was determined that 92% of failures of objects under study recorded during observations belonged to the second group of complexity. They were eliminated by replacing easily accessible parts and components, which required the disassembly of units or extraordinary maintenance operations.

An analysis of the maintainability indicators of mixers-distributors showed that the most characteristic failures that led to the loss of performance were failures of the working bodies of the grinding-mixing mechanism and the hopper.

During the tests, statistical data on the time of restoration of serviceability or operability of feed dispensers were obtained, which reflect the values of maintainability indicators. A table of statistical information was formed (Table 1) to process the obtained data and calculate the value of the indicator of the recovery time of the presented tool.

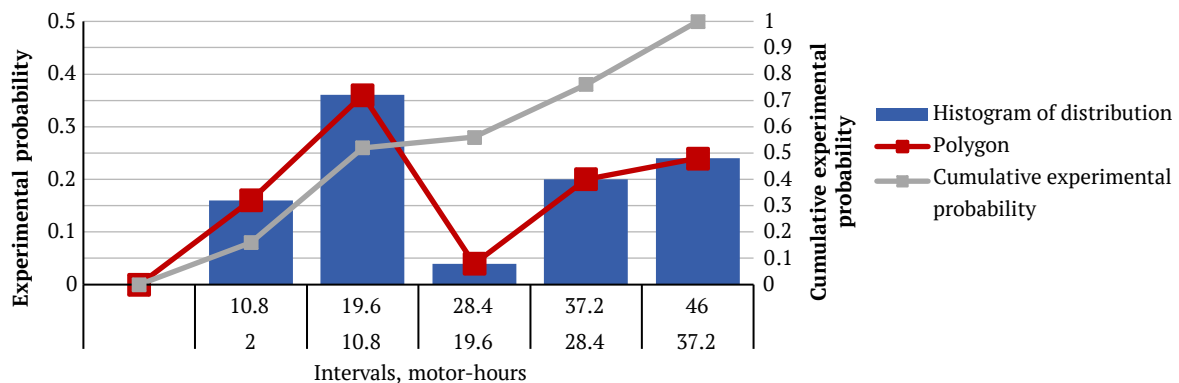
**Table 1.** Statistical time series for eliminating failures of feed dispensers

No.	Borders intervals	Mid-interval	Frequency, $m_i$	Experimental probability, $P_i$	Accumulated experimental probability, $\Sigma P_i$
1	2.0-10.8	6.4	4	0.16	0.16
2	10.8-19.6	15.2	9	0.36	0.52
3	19.6-28.4	24.0	1	0.04	0.56
4	28.4-37.2	32.8	5	0.2	0.74
5	37.2-46.0	41.6	6	0.24	1.0

**Source:** compiled by the authors

After grouping the values of the recovery time indicators by intervals, the failure rate, experimental probability, and accumulated experimental probability were determined. The obtained values of the empirical distribution of time for restoring the operability of feed preparation and distribution facilities are given as a statistical series of information (Table 1) and graphically (Fig. 3). Histogram analysis (Fig. 3) allows noting that the graph is characterised by five specific time periods in accordance with the failures that were eliminated. The lowest probabilities of events, 0.16 and 0.04, are characteristic of the first and third intervals, which correspond to the failure

elimination time intervals of 2.0-10.8 hours and 19.6-28.4 hours. The second and fifth intervals, which correspond to the failure elimination time intervals, are characterised by the highest probability, 0.36 and 0.24 10.8-19.6 hours and 37.2-46.0 hours. Time to eliminate failures, fixed within the limits of 10,8-19,6 hours, corresponds to the work that consists in replacing the auger with blades or blades of the subsystem of grinding and mixing feed dispensers, the service life of which has reached more than 3 years. Time to eliminate failures within the limits of 37.2-46.0 hours was recorded for feed dispensers for which the warranty period of 1 year has expired.



**Figure 3.** Graphical representation of empirical distributions of the maintainability indicator of feed dispensers under operating conditions

**Source:** compiled by the authors

After processing the values of the time to restore the operability of feed mixers, it was established that the resulting array of empirical data is characterised by the following indicators:

- average recovery time,  $\bar{t}=24.0$  hours;
- mean square deviation of the recovery time,  $\sigma=12.93$  hours;
- coefficient of variation of a random value,  $\nu=0,49$ .

It is assumed that the time that must be spent on eliminating failures of feed dispensers according to DSTU 3004-95 (1995) is consistent with the theoretical law of normal distribution. Verification of the correspondence of the time values for restoring working capacity within the theoretical distribution law and the empirical distribution for the mechanism of grinding and mixing

research objects was performed according to the consent criterion  $\lambda$  of O.M. Kolmogorov.

Since the resulting value  $P(\lambda)=0.9972$  is more than the accepted level of significance for the normal distribution law, then the considered condition on the compliance of theoretical and experimental data with the time of recovery of the working capacity of the Weibull-Gnedenko law is rejected (DSTU 3004-95, 1995). The limits of confidence intervals and the value of the scattering interval of the average value of elimination of failures of feed distribution mixers according to the adopted theoretical distribution law are calculated according to the corresponding analytical dependencies (DSTU 3004-95, 1995). The results of these values, respectively, amounted to:

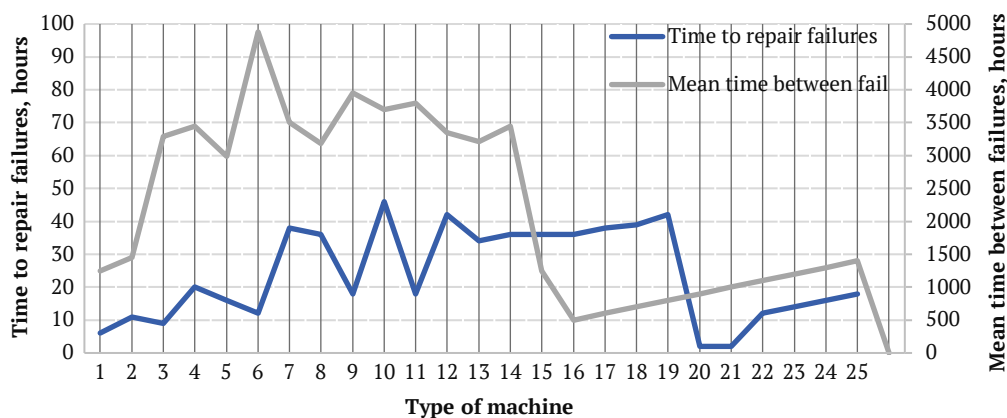
$t_{90}^H = 6.98$  hours – lower confidence limit;  
 $t_{90}^B = 41.02$  hours – upper confidence limit;  
 $I_{90} = 34.04$  hours – the size of the interval.

Previous studies by A. Novitskiy *et al.* (2023) established that the reliability of the feed mixer is limited by the grinding and mixing subsystem. The maintainability of the machines forms an indicator of the time to restore their operability, including the replacement of blades, sets of screws with blades, and restoration of the hopper body.

According to the guidelines for use, the PROFILE feed dispenser mixer, which is presented in the studies, contains two vertical augers in its design. The number of blades attached to one screw, respectively, is 6 small, and 2 large. It is this complete set of blades that must be available among spare parts at the appropriate storage levels to ensure the maintainability of the feed dispenser mixer:

level I – directly on a livestock farm or warehouse of an agricultural firm; Level II – mobile service point of the KUHN group of companies; level III – warehouse of the KUHN group of companies.

Figure 4 shows the time to failure and time to eliminate failures of 25 profile feed preparation and distribution products. For most feed dispensers, a correspondence is recorded between the maximum time to failure and the maximum time to restore operability. For mixers-distributors No. 6-14 within the time limit for failure of 3000-5000 hours, an increase in the time to restore working capacity was recorded within the maximum values – from 38 to 46 hours. For objects No. 15-19 which have a failure time of 500-1500 hours, there was a slight increase in the time to restore workability, which is 38-42 hours. The specified time is required to restore the working capacity of the hopper or screws with the replacement of blades.



**Figure 4.** Value of time to failure and time to eliminate failures of feed dispensers

**Source:** compiled by the authors

From the analysis of the above results of the time to failure examination and the values of the time to restore the operability of mixers-feed dispensers and to increase their reliability during operation, it is necessary to include in the list of maintenance works of the grinding-mixing subsystem information about the list of parts and working bodies that must be at different storage levels. Such an addition will allow increasing the value of the readiness coefficient of the product for preparing and distributing feed, reducing downtime and time spent on restoring working capacity.

For the highly efficient use of feed mixers, it is advisable to analyse the actual level of reliability indicators, including reliability, durability, maintainability, and safety (DSTU 3004-95, 1995). Such experimental studies allow identifying general dependences of changes in reliability indicators in different periods of the service life of objects under study. This is especially important during the warranty period for identifying structural and technological defects and malfunctions of feed dispensers, justifying recommendations for improving their maintainability.

Based on this, a thorough assessment of reliability is necessary to identify system bottlenecks and search for subsystems or components with a low maintainability

value. The implementation of a given project productivity and efficiency can be evaluated on the example of complex technical systems that are used in industrial engineering facilities. Of particular interest is not only the readiness of complex technical systems – agricultural machinery and equipment – to work at any given time or their reliability over a certain period but also an indicator of how quickly this system can return to operation after each failure. These issues were thoroughly analysed in the papers of a number of researchers who not only received the value of time to failure in operating conditions, set the time to restore performance but also investigated the issues of ensuring the reliability of mechanisms of various machines, in particular:

- ⓘ threshers (Sharma *et al.*, 2022);
- ⓘ motor cultivators (Katsitadze *et al.* 2021),
- ⓘ combines (Najafi *et al.*, 2015);
- ⓘ machine-tractor units (Rogovskii *et al.*, 2021);
- ⓘ transport and technological machinery (Aulin *et al.*, 2024).

The scientific-methodological approaches proposed in these studies have every reason to be used to determine the maintainability of feed dispensers and evaluate and ensure their reliability indicators.

In the study by J. Katsitadse *et al.* (2021), the results of evaluating the operational reliability of tillers, which represent a substantial group of machines and equipment used in agricultural production, are reflected. The presented methodology for calculating reliability indicators confirms the importance of forming a method for ensuring the reliability of machines, including maintainability.

From the experience of using and examining the results of experimental data on the reliability of feed mixers during operation and literature sources, it can be concluded that most researchers conducted a scientific search to determine and form the structural, technological, functional, and operational parameters of self-propelled and trailed vehicles for the preparation and distribution of feed. The materials reflected in the publications of recent years are important when discussing the results of the presented findings on self-propelled and trailed mixers for feed preparation.

F. Tian *et al.* (2020) offer a number of theoretical recommendations for improving the structure, technical, and functional characteristics of self-propelled equipment for mixing and distributing feed mixtures. Based on the results of experiments, the authors propose to optimise the operation of the loading mechanism and the grinding-mixing mechanism by combining shear, diffusion, and convective motion in the equipment hopper.

S. Şeflek & H. Haciseferoğullari (2018) investigated the maintainability of the planetary transmission mechanism of the vertical screw drive of the feed mixer R6 and indicated characteristic damage to parts. According to the test results, most of the failures were caused by cracks, fractures, and corrosion on the gears and auger. St37 steel was chosen to increase the service life of the vertical auger. However, the materials presented in the study do not contain values of reliability indicators for serial and experimental working bodies and parts of the feed mixer. There is not enough information about the level of maintainability of the feed mixer. Therewith, the practice of using the equipment of the PROFILE model range showed that two cases were recorded when uneven wear of the turns of the screw and blades led to uneven operation of the drive elements and loss of performance of the grinding-mixing mechanism.

V. Khmelovskiy *et al.* (2020) considered the use of mobile feed preparation equipment with feed mixture feeding to feed tables in livestock farms. considered the use of mobile feed preparation equipment with feed mixture feeding to feed tables in livestock farms. An important design and technological characteristic of the tool is the self-cleaning property of the screw, which ensures safety and maintainability indicators, especially in the autumn-winter period of its use. It is advisable to establish the relationship between the authors' recommendations for improving the structure and quantitative indicators of maintainability and safety in further studies on the reliability of mixer dispensers.

S. Postelga *et al.* (2021) presented the methodology and test results of a self-propelled mixer dispenser from the German company Siloking, SelfLine 4.0 Premium 2215. The materials presented in the study were obtained by the

author in the process of performing the technological operation of preparing and distributing the feed mixture by self-propelled transport-technological machines. In the process of testing and testing the mixer-dispenser, the effectiveness of its use for feed preparation of cattle and ensuring the uniformity of feed mixing of 94.3% and the uniformity of distribution – 95.5%, were confirmed. The study does not contain the results of evaluating the reliability indicators of a self-propelled mixer-dispenser, which ensured efficient preparation and distribution of feed mixture according to the materials declared by the author.

O. Dereza *et al.* (2021) analysed the specific features of using vertical and horizontal feed mixers of all types in the agricultural sector of Ukraine and formed the main reasons that limit their widespread introduction into the livestock industry. Among the most substantial problems, as the authors note, are: the lack of a comprehensive approach to the introduction of modern achievements in feeding technologies; justification of the action of a human operator in solving problems of safety of equipment and ensuring operability; the implementation of a complex of works on timely maintenance of feed mixers; reconstruction of farms of old buildings for the implementation of modern technologies for the production of feed mixtures. One of the reasons for the poor quality of maintenance and repair of feed mixers is the lack of information about maintainability indicators and the main components that form this property. These conclusions confirm the importance and relevance of the presented findings.

Several researchers in their studies presented theoretical examinations of the parameters of aggregates of agricultural machinery and equipment. V. Bulgakov *et al.* (2023) presented a methodology for the examination of such an operational indicator of agricultural machine and tractor units as smooth running, which affects the traction and dynamic performance of their work, productivity, agrotechnical quality of operation, durability, and economy. The method of mathematical modelling and experimental determination of vertical vibrations of the unit declared by the authors of the study can be used to examine the dynamics of movement of other agricultural machinery and equipment, including self-propelled and trailed transport-technical machines.

Analysing the results of tests for the maintainability of feed mixers PROFILE 12.2 DS and PROFILE 14.2 DS and studies that implement separate scientific and practical approaches to the formation of reliability of machines and equipment for animal husbandry as complex technical systems “man – machine – environment”, special importance in ensuring the operability of machines is assigned to the human factor.

In many papers, along with the design, production, and improvement of individual mechanisms of these tools, the influence of the “human-operator” component on the reliability of the “man – machine – environment” technological system is evaluated. H.-W. Lo *et al.* (2019), R. Amaya-Toral *et al.* (2022) noted that the improvement of

reliability and maintainability indicators in the operation of machinery and equipment, reducing the possible risks of failures during the production process largely depends on the influence of the human factor of the “human operator” component. J. Vegricht *et al.* (2007) determined that the energy consumption and capacity of a machine for loading feed from storage depends on the experience and professional qualities of operators, a detailed examination of the technical condition of the working bodies of mechanisms.

The experience of using analytical approaches and methods of expert assessment of personnel can be used in justifying and ensuring the reliability of technological and technical systems. The obtained values and the practice of maintaining the serviceability and operability of machines confirmed the possibility of using analytical approaches and test results to ensure the reliability of not only feed mixers but also machines, stands, and equipment of repair and service enterprises.

During the examination of the processes of maintaining the serviceability and operability of feed dispensers under operating conditions, it was established that one of the causes of malfunctions and failures is the lack of information in the regulatory and technical documentation about maintainability indicators, criteria for the onset of the limit state of the working bodies of the feed grinding and mixing subsystem (Novitskiy *et al.*, 2023). O. Dereza *et al.* (2021) note that agricultural enterprises that have purchased European-made feed mixers often encounter cases where there is no timely supply of spare parts and qualified repairs, especially in the post-warranty period. The practice of using feed mixers has revealed that one of the main reasons for the formation of malfunctions and defects is deviations from the frequency of maintenance and assessment of the technical condition of parts. Other characteristic reasons for the appearance of malfunctions and defects are a decrease in the reliability of the “human operator” and low control over the main parameters of the technical condition of the means for feed preparation, mixing, and distribution of feed mixtures as a complex technological system.

The study presents the results of testing and processing information on the maintainability indicators of means for preparing and distributing feed under operating conditions. The presented methodological approaches can be implemented by improving the design, technical and functional parameters, justifying individual and complex reliability indicators of feed distribution mixers.

## CONCLUSIONS

Based on the results of the reliability assessments of 25 feed dispensers during operation, information was obtained about the maintainability of PROFILE 12.2 DS and PROFILE 14.2 DS, and the recovery time in case of loss of performance was established. The resulting array of data on the recovery time of feed dispensers is characterised by the following values of indicators: average recovery time of working capacity,  $\bar{t} = 24.0$  hours; mean square deviation,  $\sigma = 12.93$  hours; coefficient of variation,  $\nu = 0.49$ ; the theoretical distribution law is the law of normal distribution. The consistency between the theoretical law and the empirical distribution of the time of recovery of the tool’s operability according to the O.M. Kolmogorov criterion is confirmed. Studies have established that the value of the average recovery time of feed dispensers, according to the normal law, is in confidence intervals:  $t_{90}^H = 6.98$  hours – lower confidence limit;  $t_{90}^B = 41.02$  hours – upper confidence limit;  $I_{90} = 34.04$  hours – the size of the interval. The second and fifth intervals are characterised by the highest probability of events, 0.36 and 0.24, which correspond, respectively, to the failure elimination time intervals 10,8-19,6 hours and 37,2-46,0 hours. Specified failure elimination time was recorded within the limits of 10,8-19,6 hours, corresponding to the work that consists in replacing the auger with blades or blades of the subsystem for grinding and mixing feed dispensers, the service life of which has reached more than 3 years. The time for elimination of failures is set within the limits of 37,2-46,0 hours for feed dispensers with an expired warranty period.

In further research, analytical methods of calculation and directions of the programme for forming the reliability of feed mixers as technical systems “man – machine – environment” will be used, and measures will be developed to reduce the probability of failures depending on: the impact of the “man – operator” component, considering professional level and work experience; on the efficiency of the maintenance and repair system in the conditions of the existing repair and maintenance base or at different levels of the maintenance base potential.

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## CONFLICT OF INTEREST

None.

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## Дослідження показників ремонтопридатності засобів для приготування і роздавання кормів

**Анотація.** Нові наукові та практичні підходи в тваринницькій галузі використовують технології промисловості 4.0 та IoT, зокрема змішувачі-кормороздавачі, для ефективного транспортування та дозування кормів, однак проблеми надійності цих механізмів вимагають досліджень для визначення деталей і вузлів, що обмежують їх працездатність, та розрахунку їх ремонтопридатності. Метою цього дослідження було встановлення конструктивних, виробничих та експлуатаційних відмов механізмів змішувачів-кормороздавачів, причин їх виникнення та часу на їх усунення. Для цього було виконано дослідження змішувачів-кормороздавачів за планом випробувань на надійність [NMT]. План випробувань передбачає наявність  $N$  об'єктів, які при втраті працездатності відновлюються  $M$ , а досліди зупиняються за досягнення наробітку  $T$ . Виконано збирання та обробку вихідної інформації, аналіз емпіричних даних часу усунення відмов змішувачів-кормороздавачів PROFILE 12.2 DS та PROFILE 14.2 DS. В процесі випробувань виявлено, що в гарантійний період експлуатації змішувачів-кормороздавачів, їх несправний стан викликаний відмовами другої групи складності. Були виділені відмови, які пов'язані з відновленням працездатності підсистеми для подрібнення та змішування, який впливає на ремонтопридатність змішувача-кормороздавача. Проведено статистичний аналіз виникнення названих відмов. Визначені основні параметри теоретичного закону розподілу. Зокрема, встановлені показники ремонтопридатності змішувачів-кормороздавачів: середній час відновлення працездатності,  $\bar{t} = 24,0$  год.; середнє квадратичне відхилення,  $\sigma = 12,95$  год.; коефіцієнт варіації,  $v = 0,49$ ; теоретичний закон розподілу – закон нормального розподілу. Підтверджено, що середній час відновлення працездатності змішувачів-кормороздавачів за критерієм згоди Колмогорова добре узгоджується із законом нормального розподілу. Розрахунками встановлено, що середній час відновлення працездатності об'єктів досліджень знаходиться в довірних інтервалах: 6,98 год. – нижня довірна межа; 41,02 год. – верхня довірна межа; 34,04 год. – величина інтервалу. Результати можна реалізувати для підвищення ефективності технічного обслуговування і ремонту обладнання на тваринницьких фермах, оптимізації запасів запасних частин

**Ключові слова:** змішувач-кормороздавач; експлуатаційна надійність; напрацювання на відмову; час відновлення працездатності; механізм подрібнення-змішування