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Andrii Novytskyi *

PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-7789-8531

Oleksandr Bannyi

PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-0505-166X

Yurii Novytskyi

Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-1115-1747

Maxim Antal

Master's Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0009-6928-2388

A study of mixer-feeder equipment operational reliability

Abstract. Modern livestock development trends in the agricultural production structure include the use of feed mixers and distribution equipment. However, a stream of malfunctions and failures is reported for mixer-feeders due to factors that are specific to agricultural enterprises in Ukraine, which reduce the operational reliability of feed mixers and distributors. The study aims to evaluate the quantitative indicators of the in-service reliability of mixer-feeders and develop methods to improve them. The reliability test plan [NMT] was used, which implies a certain number of research objects (*N*), objects undergoing repair in case of performance loss (*M*), and tests terminated when the operating time (*T*) is reached. Initial information was collected and processed, and empirical data on the time between failures of KUHN PROFILE 12.2 DS and PROFILE 14.2 DS mixer-feeders in Ukraine were analysed. The analysis established that the faulty condition of mixers-feeders in the initial operation period is caused by the second complexity group failures. Failures related to the loss of the grinding and mixing mechanism, which limits the average time between failures of the feed mixture and distribution equipment, were identified among the second complexity malfunction group. A statistical analysis of the mixer-feeder failure occurrence was carried out. The failure probability of the grinding-mixing mechanism of the feed mixer was determined to be within the normal distribution law. The main parameters of the given theoretical distribution law were determined by calculation results. The calculations determined that the average time between failures is 3152.0 motor-hours; the standard deviation is 902.6 motor-hours; and the coefficient of variation is 0.40. An average time between failures of the study objects was proved to be consistent with the normal distribution law following Kolmogorov's agreement criterion. Calculations determined that the average reliability index value, according to the normal distribution law, is within the confidence intervals: 1964.2 motor-hours – lower confidence limit; 4339.8 motor-hours – upper confidence limit. The obtained results may be used to improve the mixer-feeder operational reliability

Keywords: mixer-feeder; grinding-mixing mechanism; reliability indicators; time between failures; operation

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*Corresponding author

INTRODUCTION

One of the main branches of agriculture is livestock farming. Preparation and distribution of feed is one of the most important tasks in livestock production. At all stages of the task, efforts should be focused on reducing feed consumption, improving its physical and mechanical properties, enhancing its quality and ensuring that it meets zootechnical requirements. Y. Chen *et al.* (2017) suggest using a nutrient-balanced diet based on the physiological needs of ruminants, including cattle, goats and sheep, at different stages of growth. The rationale for these diets by animal nutrition experts includes roughage, chopped to appropriate lengths, concentrates and various additives that are fully mixed in specific proportions. S. Morrone *et al.* (2022) noted that the use of balanced ration technologies is an effective methodology for cattle and sheep farming, and the implementation of the transition from traditional to modern feeding. The justification of feeding technologies and the development of appropriate feed preparation and distribution equipment are key to its effective application.

In many countries with developed livestock production, research has been conducted on the technological processes of preparing feed mixtures, improving existing ones and developing modern feed preparation machines (Astanakulov *et al.*, 2020). Studies of the operating characteristics of feed preparation and distribution equipment have shown that, along with the increased load on each feed mixer, many factors cause a significant dispersion of technical and economic use indicators (Khmelovskyi *et al.*, 2020), machine reliability parameters (Ruzhylo *et al.*, 2022), and the durability of working bodies. In this regard, one of the most important criteria for the quality of the operation of feed preparation and distribution equipment is its reliability. The scientific and technical literature emphasises the importance of using feed preparation and distribution equipment on cattle farms (Lo *et al.*, 2019).

O. Voinalovych *et al.* (2019) presented a methodology for assessing the residual life of tractors and their units. The metrics covered in the paper reflect the results of the long-term operation of objects based on the data of flaw detection. The presented methodology is based on the use of Markov random processes in the study of a complex man-machine-environment system. To implement the model, the values of failure intensities and recovery intensities are required, which are calculated based on the use of the values of time between failure and recovery recorded during operation. The methodological approaches implemented in the article can be used to study the operational reliability of trailed and self-propelled vehicles for feed preparation and distribution.

The presented problematic issues of ensuring reliability need to be studied and implemented based on the analysis of guidelines for the use of feed preparation and distribution equipment. Foreign and Ukrainian feed mixers have recommended operating instructions, but they often differ in the range of such mechanical parameters of feed mixtures as the sequence of loading feed components; mixing time; and feeding speed. Z. Ruzhylo *et al.* (2022) argued that most guidelines for the use of feed preparation and distribution equipment lack information on the level of machine reliability, limit state criteria, and recommendations for maintaining performance. Alongside stationary feed preparation machines and trailed feed dispensers, cattle farms in Ukraine use self-propelled foreign-made feed preparation and distribution equipment. The analysis shows that some manufacturers of these machines do not provide consumers with values of qualitative and quantitative reliability indicators. An important component of the assessment of the operational reliability of feed mixers that requires detailed study is the study of the impact of the human operator as a component of the complex technical system "Man-Machine-Environment" (Novitskyi *et al.*, 2016).

I.L. Rogovskii *et al.* (2022) presented a methodology for determining the patterns of change in the technical condition of Slavutych KZTs-9F combine harvesters (self-propelled combine harvester, Ukraine) during operation. The research paper presents the results of operational studies of combined harvesters' performance and identifies mechanisms and systems that limit reliability. A list of working bodies and parts whose technical condition requires constant monitoring and, if necessary, restoration in case of loss of performance is substantiated. T. Yezekyan *et al.* (2020) reflected the technical parameters of grain harvesters and forage harvesters and developed reference models for determining technical and economic parameters. The authors put forward a variant of linear models, which are reference models for determining the size of equipment and key parameters, and are the basis for development or modernisation. The proposed solution made it possible to justify the choice of machine design and ensure the rational use of economic and environmental resources. The use of modelling will provide a forecasting capability for determining the technical and economic parameters of machines.

To ensure the serviceability or operability of feed mixers, it is necessary to perform a set of maintenance and repair measures. Therefore, researching assessing and ensuring the operational reliability of feed mixers is a rather urgent problem. The study aims to evaluate the quantitative indicators of the reliability of feed mixers in operation and develop measures to improve it.

LITERATURE REVIEW

The tendency is towards the widespread use of feed mixers with horizontal and vertical grinding-mixing designs. In most countries with developed livestock production on cattle farms, considerable attention has been focused on the development of stationary or trailed vertical single-screw and horizontal twin-screw feed mixers-feed dispensers of feed mixtures (Li *et al.*, 2017; Norton *et al.*, 2019; Yezekyan *et al.*, 2020). T. Fuyang *et al.* (2020) argued that the hopper of these devices can be either horizontal trapezoidal or vertical in the shape of a cut cone. Mixer-feeders may also include auxiliary mechanical equipment in their design, including mills for loading and chopping feed or grabs only for loading it and weighing devices for weighing components. T. Yezekyan *et al.* (2020) noted that the design of milling drums of farm combines makes it possible to load and grind silage, haylage from storage, hay in rolls, concentrated feed in film sleeves, etc. It should be noted that, according to P. Ma *et al.* (2020), the working bodies of feed mixers mounted on horizontal augers provide better feed chopping quality than vertical augers. At the same time, machines with vertical grinding and mixing mechanisms are characterised by a higher level of reliability and efficiency. In recent years, research has mainly focused on improving the design of stationary and trailed feed mixers.

Because the livestock industry in many countries of Europe and Asia is developing effective, scientific and practical research on the processes of preparation, transportation, distribution and dosing of feed mixtures by self-propelled and trailed vehicles, stationary equipment is becoming crucial in the technologies of feeding cattle and poultry. U. Moallem *et al.* (2020) noted that mixed diets are used on livestock farms in Israel and the United States. The quality of the overall mixed diet depends on the level and cost of feed, the appropriate diet formulation, and the specifics of preparation. Through practical research, the authors of the scientific article determine the impact on the quality of the feed mixture of the parameters of the equipment used for mixing and dispensing, the professionalism of the operator, control systems, and the sequence of loading of feed components. The issues of testing feed preparation machines need to be clarified.

L. Li *et. al.* (2017) noted that in China, for the most part, stationary or trailed vertical single-screw and horizontal twin-screw mixers are used for feed preparation. Separate studies have been conducted on silage loaders and belt conveyors. At the same time, practical issues of processing information on the efficiency and reliability of these objects need to be clarified. G. Bekele (2020) presented a stationary poultry feed mixer developed, tested, and evaluated by the author. The results of experimental studies indicate that the coefficient of variation has decreased, the degree of mixing has improved, and, accordingly, the mixer shaft speed and mixing time have increased. These indicators minimise the cost of preparing the feed mixture.

S. Morrone *et al.* (2022) noted the relevance and importance of research in precision animal husbandry, which has spread around the world since its formation in 2003, using the achievements of Industry 4.0 and IoT technologies. This modern technological approach to livestock farming covers ethical, economic and logistical aspects. The authors of this paper note that the successful and sustainable development of the livestock industry requires the use of modern feeding technologies and the development of new and improvement of existing means for the preparation and distribution of feed. Among the main resources that ensure high-quality preparation and dosed distribution of feed mixtures are the following: computerisation of the technological process; and on-demand service.

P. Najafi *et al.* (2015) pointed out that the performance of a sugarcane harvester as a complex system depends on the reliability of its component subsystems or mechanisms. When calculating reliability, the authors considered the possible impact of the environment, the effectiveness of maintenance, the specifics of the work process, and the experience of farmers. Therefore, to identify bottlenecks in the harvester system and search for components or subsystems, an analysis of mechanisms with low reliability is necessary. G. Jia *et al.* (2017) proposed a general stochastic formula for analysing the life cycle of wearing engineering systems. The authors note that parametric and emergency failures of an engineering system can be caused by operating conditions, extreme loads, or the influence of environmental conditions. These methodological approaches can be used to restore the parameters of technical mixer-feeders. C. Leangsuksun *et al.* (2022) pointed out that there is a gap between the design process and the modelling of the research objects, which can be compensated by using analytical methods for reliability assessment and assurance. At the same time, additional theoretical and experimental studies are needed to make it possible to realise the property of using these methods and methodologies for forming the reliability of feed mixers at certain stages of the life cycle.

MATERIALS AND METHODS

The study was carried out at the National University of Life and Environmental Sciences of Ukraine (NULES). The objects of the study were mixer-feeders PROFILE 12.2 DS and PROFILE 14.2 DS (Auduro S.A. plant, KUHN Group, France) of KUNH Ukraine LLC (Operator's manual..., 2018; Operator's manual. Mixer feeder wagon. PROFILE. 2DS, 2019) (Fig. 1a) and the grinding-mixing mechanism (Fig. 1b).

a)

b)

Figure 1. PROFILE 14.2 DS feed mixer (a) and chopping and mixing mechanism (b)
Source: compiled by the authors

The reliability of 25 PROFILE 12.2-14.2 feed mixers, which were operated in agricultural enterprises of Ukraine during 2015-2022, was monitored during the research. During the test, PROFILE feed mixers were distributed by region as follows: Khmelnytsky – 9 machines; Zhytomyr – 3 machines; Cherkasy – 3 machines, Vinnytsia – 6 machines; Volyn – 1 machine; Chernihiv – 2 machines; Poltava – 1 machine.

Failures of the PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers are distributed by subsystems of the feed mixer: chopping and mixing mechanism; feed mixture unloading mechanism; running system; frame; and control system. The test mode at the site was set as operational. The reliability test plan [NMT] (DSTU 3004-95..., 1995) was adopted, which provides for the presence of a certain number of research objects *N,* objects are restored in case of loss of efficiency *M*, tests are terminated when the corresponding operating time *T.* That is, for the presented test plan [NMT], the initial parameters are: number of observation objects *N*, pieces; property of objects to be restored in case of loss of efficiency *M*; duration of observations *T*, motor-hours. To determine the minimum number of observations, the initial data that indicates the accuracy of the research results is set. The initial data include the confidence probability, which is assumed to be $\gamma = 0.9$, and the maximum relative error $\delta = 0.15$. The distribution of failures of feeder mixers according to a priori data follows the law of normal distribution (DSTU 3004-95..., 1995). Using reference tables, the minimum number of objects to be set up for testing was determined to be $N_{min} = 21$ (DSTU 3004-95..., 1995). $N = 25$ feed mixers were accepted. The established duration or time of observation is 4880 motor-hours. This value was determined under the assumption that the distribution of failures follows a normal distribution law, with $\gamma = 0.9$ and $\delta = 15$.

The methodology included checking the correspondence between the theoretical law and the empirical distribution of the time between failures of the mixer-feeder according to the agreement criterion λ by O.M. Kolmogorov (Chornovil *et al.*, 2010) The number of objects required for reliability testing was calculated using the following formula by M.I. Chornovil *et al.* (2010):

$$n = \frac{\sigma^2 t_\beta^2}{\Delta^2}, \tag{1}$$

where n – required number of parts for inspection, pieces; σ^2 – statistical variance, motor hour.; t_β^2 – a tabular coefficient that depends on the accepted confidence level, β; Δ^2 – the magnitude of the permissible error (when studying the wear failures of parts, assume $\Delta = 0.8$ of the interval value).

The results obtained on the occurrence of failures of the PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers were taken from the reporting regulatory and technical documentation of the official dealer of KUHN equipment in different regions of Ukraine. Statistical analysis methods and experimental data processing techniques were used to obtain the following indicators: mean time between failures; standard deviation; coefficient of variation; theoretical distribution law; and scattering intervals.

RESULTS AND DISCUSSION

Based on the results of the analysis of regulatory and technical documentation, failures were recorded for 25 machines and the time between failures was determined. The results of the failure distribution are shown in the diagram (Fig. 2). Analysis of the diagram shows that most of the failures relate to the grinding and mixing mechanism: wear and damage to the knives; loss of efficiency of the working auger with knives; wear of the hopper body; oil leakage from the gearbox; short circuit of electrical equipment. Failures were distributed as follows: auger, auger with knives – 48%; hopper – 44%; other reasons – 8%.

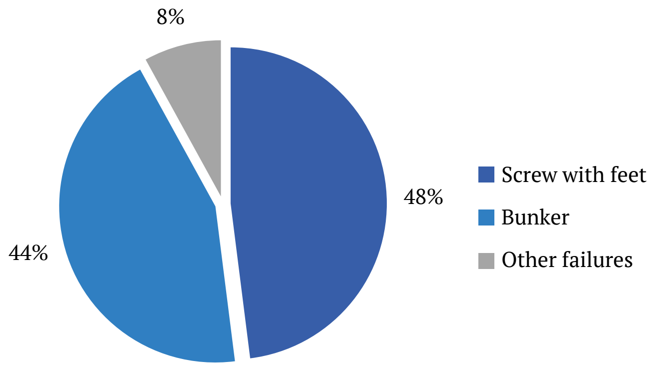

Figure 2. Failure distribution of PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers
Source: compiled by the authors

Failures that limit the reliability of feed mixers were identified. For systematisation, finding ways to analyse and eliminate them, the failures were divided into complexity groups. The analysis of the diagram (Fig. 2) shows that 92% of failures of PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers belong to the second group of complexity. These failures can be eliminated by replacing or repairing easily accessible components and assemblies. To eliminate these failures, it is necessary to open the internal cavities of the units without disassembling them or to perform extraordinary maintenance operations. The diagram shown in Figure 2 also confirms that the most typical failures that limit the reliability of the research objects are failures of the grinding and mixing mechanism.

Statistical data of the tests of the PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers were obtained in the course of the research. A table of statistical information was compiled to process the experimental data on the time between failures of the feed mixers. After grouping the test results by intervals, the failure rate was specified and the accumulated experimental probability was determined. The results of the empirical distribution of the time between failures of feed mixers are presented in Table 1 in the form of a statistical series of information and are graphically shown in Figure 3.

Table 1. Statistical series of time between failures of feed mixers

No. pp	Boundaries of intervals	Interval median	Occurrence rate, m_i	Probability, P_i	Accumulated probability of experimental results, ΣP_i
1	1250-1976	1613	4	0.16	0.16
2	1976-2702	2339	2	0.08	0.24
3	2702-3428	3065	7	0.28	0.52
4	3428-4154	3791	10	0.4	0.92
5	4154-4880	4517	2	0.08	1.0

Source: compiled by the authors

The histogram analysis shown in Figure 3 demonstrates that in the initial period of operation of the feed preparation and distribution equipment, which corresponds to the operating time in the range of 1250-1976 motor-hours, knife failures were recorded, and in the range of 2702-3428 motor-hours – failures of augers with knives. Failures of feed mixers, which were recorded in the range of 3428-4154 motor-hours, correspond to the loss of efficiency of the feed mixer hopper.

After processing the information, the obtained array of experimental data is characterised by the following indicators:

- average wear per failure, $\bar{t}$ = 3152.0 motor-hours;
- average square deviation, σ = 902.6 motor-hours;
- variation coefficient, υ = 0.40.

The occurrence of failures of the grinding and mixing mechanism of the PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers is subject to the law of normal distribution (DSTU 3004-95..., 1995). The correspondence between the theoretical law and the empirical distribution of the time between failures of the mixer-feeder was checked by Kolmogorov's criterion of agreement λ. Since $P(\lambda)$ = 0.9972 is greater than the accepted significance level for the law of normal distribution, the accepted condition of the possibility of matching the Weibull-Gnedenko law with the empirical distribution of operating time is rejected (DSTU 3004-95..., 1995).

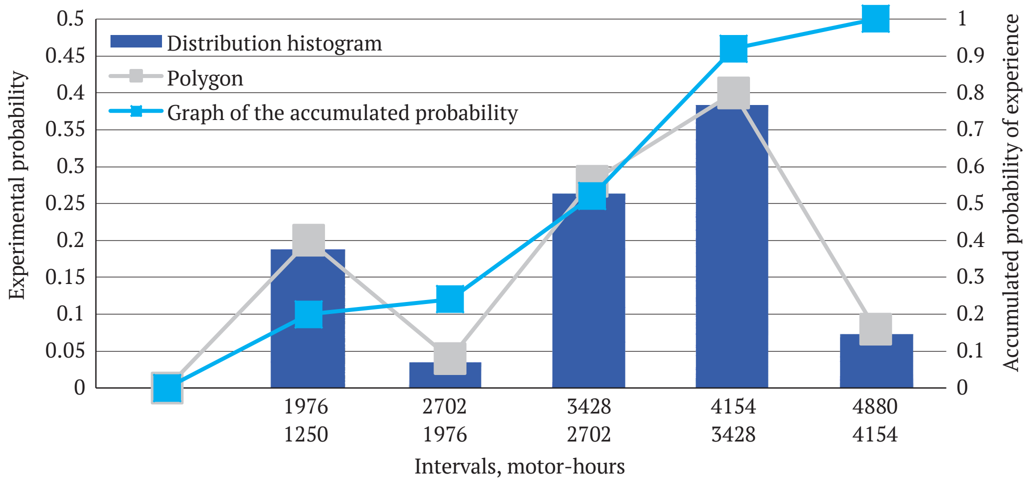

Figure 3. Histogram of distribution, distribution polygon, the graph of the accumulated experimental probability of time between failures of PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers

Source: compiled by the authors

The boundaries of confidence intervals and the size of the scattering interval of the mean time between failures of PROFILE feed mixers for the normal distribution law were calculated using the formulas (DSTU 3004-95..., 1995; Chornovil *et al.*, 2023). The results of these values were respectively:

1. t^l_{90} = 1964.2 motor-hours – lower acceptable limit;
2. t^u_{90} = 4339.8 motor-hours – upper acceptable limit;
3. I_{90} = 2375.6 motor-hours – interval value.

The number of objects required for the tests was calculated. The results of the calculations showed that 9 objects were sufficient for the research according to the test plan

[NMT]. The operational reliability of 25 feed mixers was investigated.

The reliability of the chopping and mixing mechanism (Fig. 4) is limited by the knives, auger sets with knives and the hopper body. The PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers are equipped with two A5336551 augers (Auduro S.A., KUHN Group, France). Each auger is fitted with a corresponding number of knives, according to the design of the PROFILE 12.2 DS or PROFILE 14.2 DS. The knives of the chopping and mixing mechanism can be installed in two ways (Fig. 4). The small knife A5362450 (Auduro S.A., KUHN Group, France), shown in Figure 4a, contains 7 teeth and is installed on the lower turns, and the large knife A5303620 (Auduro S.A., KUHN Group, France), shown in Figure 4b, contains 9 teeth and is fixed on the upper turns of the grinding and mixing mechanism screw. The number of knives mounted on one screw is 6 for small ones and 2 for large ones.

a)

b)


Figure 4. Knives of the PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers in operation and assessment of their technical condition

Note: a – small blade A5362450; b – large blade A5303620

Source: compiled by the authors

Based on this, to prevent the occurrence of mixer-feeder failures during operation, it is necessary to provide for the possibility or include in the list of maintenance activities for the elements of the grinding and mixing mechanism the operation of assessing the technical condition and restoring the hopper's performance at 3000-3100 motor-hours. The inclusion of this operation in the complex maintenance and repair works will increase the availability of the mixer-feeder, reduce the downtime of the vehicle and reduce the cost of restoring performance in case of failure of the grinding and mixing mechanism.

From the analysis of theoretical materials and the results of experimental studies of the operational reliability of feed preparation and distribution equipment, it can be concluded that most authors conducted a scientific search to establish the design parameters and functional and operational parameters of feed mixers. V. Loveikin *et al.* (2022) note that the process of preparing a feed mixture by a feed preparation device is carried out in a single-stream way by a cone-shaped screw working body. The functioning of the device is carried out due to the simultaneous movement and operation of the screw mechanism of grinding and mixing. In this case, dynamic forces arise that lead to the movement of the feed preparation device in the transverse and longitudinal directions, relative to its axis and wear of the elements of the specified mechanism and the chassis. The authors of the article substantiate a rational design of the grinding-mixing mechanism in the form of a two-stroke conical screw. These proposals for changes in the design of the mechanism will intensify the technological process of feed preparation by a mobile feed preparation unit, and improve the balance of the mechanism and the durability of tyres. It would also be advisable to clarify how changes in design parameters will affect the quantitative and qualitative indicators of the reliability of the grinding and mixing mechanism and the durability of the working bodies.

The tendency towards the widespread use of feed mixers with horizontal and vertical grinding-mixing designs is evident. In most countries with developed livestock production on cattle farms, considerable attention is focused on the development of stationary or trailed vertical single-screw and horizontal twin-screw feed mixers-feed dispensers of feed mixtures (Norton *et al.*, 2019). The hopper of these machines can be either horizontal trapezoidal or vertical in the form of a cut cone. Mixer-feeders may also include auxiliary mechanical equipment in their design, including cutters for loading and chopping feed or grabs only for loading it and weighing devices for weighing components. T. Yezekyan *et al.* (2020) found that the design of milling drums of farm combines makes it possible to load and grind silage, haylage from storage, hay in rolls, concentrated feed in film sleeves, etc. It should be noted that the working bodies of feed mixers mounted on horizontal augers provide better feed-chopping quality than vertical augers (Ma *et al.*, 2020). At the same time, machines with vertical grinding and mixing mechanisms are characterised by a higher level of reliability and efficiency of use.

The following combine harvesters have been tested in livestock production in Western European countries and China: Sam 5 490/95 by Seko (Italy), Solomix 2 12VL3 by TRIOLIET (Netherlands), Roto-mix 354-12 by Roto-mix (USA), and 12 St by De Laval (Sweden). However, the scientific and technical literature still lacks information on the performance characteristics of the presented equipment, and research on the technological processes of loading feed components, mixing, transporting and distributing both farm combines and trailed vehicles.

Due to the increase in the volume of foreign agricultural machinery, there is an urgent need to ensure its efficient use in Ukrainian farms, to study the impact of technical and operational parameters of agricultural machinery on the efficiency of its operation, to assess its operational reliability (Najafi *et al.*, 2015), and to use a systematic approach to ensure its performance (Leangsuksun *et al.*, 2022). Strategies for repairing and restoring the operability of machines to increase the reliability and functionality of a complex technical system during operation are proposed in an article by G. Jia *et al.* (2017).

In this aspect of research, the materials provided in the test report of the German testing organisation DLG (DLG Test Report 6418, 2016) for the Siloking Self Line 4.0 Premium 2215 self-propelled mixer-dispenser (Germany) are worthy of attention. This manual opens up the prospects for its use not only to ensure its operational efficiency but also to formulate and develop test plans for similar feed preparation and distribution equipment.

The absence of uniform technical requirements and recommendations for the use of feed mixers leads to a decrease in the quality of mixing feed components and the uniformity of feed distribution to animals. This problem is partially reflected in some scientific articles. However, these studies do not fully reflect the reliability indicators and recommendations for their improvement for feed mixers, including KUHN (France), Seko (Italy), Roto-mix (USA), Trioliet (Netherlands), Siloking and Strautmann (Germany), Delaval (Sweden), which are used in Ukraine. This is because these products are used in different regions, on livestock farms with different livestock, for the preparation of feed mixtures for different groups of livestock and different rations.

V. Khmelovskyi *et al.* (2020) substantiate that for the preparation and distribution of feed mixtures for 51-400 cattle heads, mobile feed preparation equipment should be used with the mixture being fed to feed tables. The paper presents a study of the process of self-cleaning of screw turns at different rotational speeds. The analytical studies and several experiments made it possible to determine the optimal angle of inclination of the turns and the speed of rotation of the screw, which should be at least 25 min^{-1}. The importance of the results for improving the functioning of the grinding-mixing mechanism is confirmed by the possibility of intensifying the process of the feed mixture descent from the screw turns. At the same time, it would be interesting to conduct research aimed at establishing the relationship between these recommendations on the modes of use of the feed preparation agent and its reliability in operation.

The results of studies of feed mixers and self-propelled feed mixers presented in a paper by D. Wang *et al.* (2017) can be useful for the optimal design and optimisation of machines for the preparation and distribution of feed. The researchers presented a justification for the parameters of the auger with the angle of the coils, and the design of the hopper body and determined their impact on the effective preparation of the mixture. The article recommends maintaining the speed of rotation of the auger of the grinding and mixing mechanism close to 32.5 min^{-1}, which will make it possible to prepare a high-quality feed mixture in 4.7 minutes. At the same time, operators need to know how these changes in the design and operation of the grinding and mixing mechanism will affect the performance and reliability of feed mixers. T. Fuyang *et al.* (2020) recommend improving the design and technological parameters of self-propelled feed mixers using the methodology and results of optimising the vertical auger of the grinding and mixing mechanism. The authors of the research paper note that to ensure the quality of preparation and uniformity of the dosed feed mixture, the screw rotation speed should be 22...26 min^{-1}. The recommended time for mixing feed components with self-propelled mixers should be within 6...8 minutes.

S. Postelga *et al.* (2021) presented the results of a comprehensive evaluation of the Siloking SelfLine 4.0 Premium 2215 self-propelled mixer-distributor (Germany) in the process of using it in operation. According to the results of the research, the author found that during the mixing of 5 types of feed, a high-quality homogeneous feed mixture was obtained, with a moisture content of 59.5%, bulk density of 405 kg/m^3, and an average particle size of 17.4 mm. The tests confirmed the effectiveness of the self-propelled mixer-feeder, which ensured 94.3% uniformity of feed mixing and 95.5% uniformity of feed distribution. The test results show that the mixer-dispenser satisfactorily and efficiently performs the technological process of preparing and distributing the feed mixture. However, as the analysis of the test results of Siloking SelfLine 4.0 Premium 2215 (Germany) shows, the article does not sufficiently reflect the reliability of the mixer-dispenser in operation.

V. Bulgakov *et al.* (2017) presented theoretical studies of the parameters of auger working bodies of agricultural machinery and equipment. The authors investigated the movement of a material particle along the working body of an agricultural machine in the form of a vertical auger limited by a coaxial fixed cylinder and proposed for use in the development and improvement of mixer-feeders the dependencies of changes in the speed of transport of a material particle under the influence of the coefficient of friction of the particle on the surface of the auger and the surface of the limiting vertical cylinder. V.M. Baranovsky *et al.* (2018) presented the results of a study of technological operations for transporting agricultural production materials in closed fixed buildings. The study of the operations of transporting these materials by screw conveyors described in the article was not only highly appreciated and efficient but also confirmed the possibility of using them in the design of loading and unloading mechanisms for agricultural machinery. The research results obtained in the articles can be used to substantiate the design parameters and ensure the operational reliability of feed preparation and distribution equipment.

The human factor as a component of the complex technical system "man-machine-environment" is of particular importance in ensuring the operability of machines and equipment. H.-W. Lo *et al.* (2019) and R.M. Amaya-Toral *et al.* (2022) pointed out that increasing the operational reliability of machines and reducing the possible risks of failures during the production process also depends on the reliability of the human operator. It is also necessary to take advantage of the experience of using analytical methods and methods of expert assessment of specialists in calculating and ensuring the reliability of technical systems "man-machine-environment". The results of scientific work have confirmed the possibility of using analytical methods and test results to ensure the reliability of not only feed preparation and distribution equipment but also service and repair and technological equipment.

During the study of the operational reliability of feed mixers, it was found that some failures were caused by the lack of information in the regulatory documentation on the criteria for the limited state of the working bodies of the grinding and mixing mechanism, including knives and auger elements. The practice of using PROFILE 12.2 DS and PROFILE 14.2 DS has established that one of the first causes of failures of the grinding and mixing mechanism is a deviation from the frequency of assessment of the technical condition of working bodies and parts. Other reasons for mechanism failures are a decrease in the reliability of the human-operator system and insufficient control over the parameters of the technical condition of the mixer-feeder as a complex technical system. Most of the analysed articles are aimed at the design improvement of units and machines in general to ensure efficient operation and reliability. At the same time, the analysed sources do not reflect the level of reliability of mixer feeders both at the stage of manufacture and during operation. The methodology proposed in the article and the results obtained confirm the possibility of assessing and calculating quantitative reliability indicators during the operation of machines for the preparation and distribution of feed.

CONCLUSIONS

Based on the research results, information was obtained on the time between failures of 25 feed mixers under operating conditions. The obtained data set of time between failures of the PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers are characterised by the following indicators: average time between failures, $t = 3152.0$ motor-hours; standard deviation, $\sigma = 902.6$ motor-hours; coefficient of variation, $\upsilon = 0.40$; theoretical law of distribution – the law of normal distribution. The correspondence between the theoretical law and the empirical distribution of the time between failures of the mixer-feeder according to Kolmogorov's criterion of agreement was established. The calculations have established that the values of the mean time between failures of the objects of study, which are consistent with the law of normal distribution, are within the confidence intervals: $t^u_{90} = 1964.2$ motor-hours – lower acceptable limit; $t^l_{90} = 433.8$ motor-hours – upper acceptable limit.

According to the KUHN recommended frequency of scheduled maintenance and repairs of the PROFILE 12.2 DS and PROFILE 14.2 DS feed mixers, it was found that in the initial period of operation of the machine, which corresponds to an operating time of 1250-1976 hours, knife failures were recorded, and in the range of 2702-3428 hours – failures of augers with knives. Failures of feed mixers, which were recorded within the operating time between failures of 3428-4154 motor-hours, are associated with the loss of efficiency of the hopper. It is proposed to include in the complex of works on maintenance and repair of the operation an assessment of the technical condition and restoration of the hopper's operability, which will ensure an increase in the availability of the mixer-feeder.

Further research will consider analytical methods for assessing the reliability of the grinding-mixing mechanism of feed mixers as complex technical systems "man-machine-environment" and develop measures to reduce the likelihood of failures depending on the influence of the human factor. Another promising area for further research is the formation of feedback from machine manufacturers and technical service representatives on the development and implementation of a programme to ensure the reliability of feed preparation and distribution equipment at the stage of operation.

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CONFLICT OF INTEREST

None.

REFERENCES

[1] Amaya-Toral, R.M., Piña-Monarrez, M.R., Reyes-Martínez, R.M., de la Riva-Rodríguez, J., Poblano-Ojinaga, E.R., Sánchez-Leal, J., & Arredondo-Soto, K.C. (2022). Human-machine systems reliability: A series-parallel approach for evaluation and improvement in the field of machine tools. *Applied Sciences*, 12(3), article number 1681. doi: 10.3390/app12031681.

[2] Astanakulov, K.D., Gapparov, Sh., Karshiev, F., Makhsumkhonova, A., & Khudaynazarov, D. (2020). Study on preparation and distribution of forage by chopping coarse feed. In *IOP Conference Series: Earth and environmental science 1st international conference on energetics, civil and agricultural engineering* (vol. 614, article number 012158). Tashkent: IOP.

[3] Baranovsky, V.M., Hevko, R.B., Dzyura, V.O., Klendii, O.M., Klendii, M.B., & Romanovsky, R.M. (2018). Justification of rational parameters of a pneumoconveyor screw feeder. *INMATEH: Agricultural Engineering,* 54(1), 15-24.
[4] Bekele, G. (2020). Development of livestock feed mixer. *International Journal of Scientific and Research Publications*, 10(10), 481-486. doi: 10.29322/IJSRP.10.10.2020.p10665.
[5] Bulgakov, V., Holovach, I., Bandura, V., & Ivanovs, S. (2017). A theoretical research of the grain milling technological process for roller mills with two degrees of freedom. *INMATEH. Agricultural Engineering,* 52(2), 99-106.
[6] Chen, Y., Tian, F., Yan, Y., Song, Z., Li, F., & Zhang, Z. (2017). Research progress of domestic and foreign TMR feeding technologies and mixers. *Journal of Chinese Agricultural Mechanization*, 38(12), 19-29.
[7] Chornovil, M.I. (Ed.). (2010). *Reliability of agricultural machinery*. Kropyvnytskyi: CODE.
[8] DLG Test Report 6418. (2016). *Self propelled vertical feed mixer wagon SILOKING SelfLine 4.0 Premium 2215-19*. Retrieved from https://cdn2.hubspot.net/hubfs/4411355/Verkkosivut/Siloking/Tekniset%20tiedot/Siloking%20SelfLine%20DLG-test.pdf.
[9] DSTU 3004-95. (1995). *Reliability of equipment. Methods of estimating reliability indicators based on experimental data*. Kyiv: State Standard of Ukraine.
[10] Fuyang, T., Yuhua, C., Zhanhua, S., & Yinfa, Y. (2020). Finite element simulation and performance test of loading and mixing characteristics of self-propelled total mixed ration mixer. *Journal of Engineering,* 12, 1-15. doi: 10.1155/2020/6875816.
[11] Jia, G., Tabandeh, A., & Gardoni, P. (2017). Life-cycle analysis of engineering systems: Modeling deterioration, instantaneous reliability, and resilience. In *Risk and reliability analysis: Theory and applications* (pp. 465-494). Cham: Springer International Publishing.
[12] Khmelovskyi, V., Otchenashko, V., Voloshyn, S., & Pinchevska, O. (2020). Providing processes of preparation and distribution of feed for cattle on animal husbandry farms. In *Engineering for rural development* (pp. 778-783). Jelgava, Latvia.
[13] Leangsuksun, C., Song, H., & Shen, L. (2003). Reliability modeling using UML. In *Proceedings of the international conference on software engineering research and practice* (pp. 259-262). Las Vegas, USA.
[14] Li, L., Wang, D., & Jiang, Z. (2017). Comparison of detection methods for mixing uniformity of rotary total mixed rations mixer. *Journal of Gansu Agricultural University*, 52(3), 136-139.
[15] Lo, H.-W., Liou, J.J.H., Huang, C.-N., & Chuang, Y.-C. (2019). A novel failure mode and effect analysis model for machine tool risk analysis. *Reliability Engineering and System Safety,* 183, 173-183. doi: 10.1016/j.ress.2018.11.018.
[16] Loveikin, V., Khmelovskyi, V., Lukach, V., & Achkevych, V. (2022). Improving efficiency of mobile combined feed mixer. In *Engineering for rural development* (pp. 853-859). Jelgava, Latvia.
[17] Ma, P., Li, L., Wen, B., Xue, Y., Kan, Z., & Li, J. (2020). Design and parameter optimization of spiral-dragon type straw chopping test rig. *International Journal of Agricultural and Biological Engineering*, 13(1), 47-56.
[18] Moallem, U., & Lifshitz, L. (2020). Accuracy and homogeneity of total mixed rations processed through trailer mixer or self-propelled mixer, and effects on the yields of high-yielding dairy cows. December 2020. *Animal Feed Science and Technology,* 270, article 114708. doi: 10.1016/j.anifeedsci.2020.114708.
[19] Morrone, S., Dimauro, C., Gambella, F., & Cappai, M.G. (2022). Industry 4.0 and precision livestock farming (PLF): An up to date overview across animal productions. *Sensors*, 22(12), article number 4319. doi: 10.3390/s22124319.
[20] Najafi, P., Asoodar, M.A., Marzban, A., & Hormozi, M.A. (2015). Reliability analysis of agricultural machinery: A case study of sugarcane chopper harvester. *AgricEngInt: CIGR Journal*, 17(1), 158-165. doi: 10.22616/ERDev2019.18.N387.
[21] Norton, T., Chen, C., Larsen, M.L.V., & Berckmans, D. (2019). Review: Precision livestock farming: Building "digital representations" to bring the animals closer to the farmer. *Animal,* 13(12), 3009-3017. doi: 10.1017/S175173111900199X.
[22] Novitskyi, A.V., & Banniy, A.A. (2016). Logic and probabilistic modeling of reliability of complex agricultural machinery. *MOTROL. Commission of Motorization and Energetics in Agriculture*, 18(3), 191-199.
[23] Operator's manual. Mixer feeder wagon. PROFILE 12.2-13.2 DS. (2019). Retrieved from. https://nubip.edu.ua/sites/default/files/u132/an112bgb_a_profiie_12.2-13.2.pdf.
[24] Operator's manual. Mixer feeder wagon. PROFILE. 2DS. (2018). Retrieved from https://nubip.edu.ua/sites/default/files/u132/an101bgb_a.pdf.
[25] Postelga, S. (2021). Self-propelled mixer-distributor siloking selfline 4.0 premium 2215 testing. *Agricultural Machinery and Equipment: Forecasting, Design, Testing*, 28(42), 150-161.
[26] Rogovskii, I.L., Titova, L.L., Voinash, S.A., Troyanovskaya, I.P., & Sokolova, V.A. (2021). Change of technical condition and productivity of grain harvesters depending on term of operation. *Earth and Environmental Science*, 720, article number 012110. doi: 10.1088/1755-1315/720/1/012110.
[27] Ruzhylo, Z., Novitskii, A., Milko, D., Bulgakov, V., Beloev, I., & Rucins, A. (2022). Mathematical model for reliability assessment of device for preparation and distribution of animal feed as "Man-Machine". In *Engineering for rural development* (pp. 911-917). Jelgava, Latvia.

[28] Voinalovych, O., Hnatiuk, O., Rogovskii, I., & Pokutnii, O. (2019). Probability of traumatic situations in mechanized processes in agriculture using mathematical apparatus of Markov chain method. In *Engineering for rural development* (pp. 563-569). Jelgava, Latvia. doi: 10.22616/ERDev2019.18.N245.
[29] Wang, D., Li, C., Li, L., Li, B., Wang, G., & Lin, Y. (2017). Mechanism analysis and parameter optimization of blade-type feed mixer. *Transactions of the Chinese Society for Agricultural Machinery*, 48(12), 98-104. doi: 10.6041/j.issn.1000-1298.2017.12.011.
[30] Yezekyan, T., Marinello, F., Armentano, G., Trestini, S., & Sartori, L. (2020). Modelling of harvesting machines' technical parameters and prices. *Agriculture*, 10(6), article number 194. doi: 10.3390/agriculture10060194.

Андрій Валентинович Новицький
Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-7789-8531
Олександр Олександрович Банний
Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-0505-166X
Юрій Андрійович Новицький
Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-1115-1747
Максим Васильович Антал
Студент магістратури
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0009-6928-2388

Дослідження експлуатаційної надійності засобів для приготування і роздавання кормів

Анотація. Тенденції розвитку сучасного тваринництва в структурі аграрного виробництва передбачають використання засобів для приготування і роздавання кормів. Але завдяки факторам, які характерні аграрним підприємствам України, для змішувачів-кормороздавачів відмічається поява потоку несправностей і відмов, які знижують показники експлуатаційної надійності засобів для приготування і роздавання кормів. Метою даної статті була оцінка кількісних показників надійності змішувачів-кормороздавачів в умовах експлуатації та розробка заходів щодо її підвищення. Для цього було використано план випробувань на надійність [NMT], який передбачає наявність певної кількості об'єктів дослідження (*N*), об'єкти при втраті працездатності відновлюються (*M*), випробування припиняються при досягненні відповідного напрацювання (*T*). Виконано збирання, обробку вихідної інформації та аналіз емпіричних даних наробітку на відмову змішувачів-кормороздавачів PROFILE 12.2 DS та PROFILE 14.2 DS компанії KUHN в Україні. Під час аналізу було встановлено, що в початковий період експлуатації змішувачів-кормороздавачів, їх несправний стан викликаний відмовами другої групи складності. Серед відмов другої групи складності була виділена несправність, що пов'язана з втратою працездатності механізму подрібнення-змішування, який лімітує середнє напрацювання на відмову засобу для приготування і роздавання кормів. Проведено статистичний аналіз виникнення зазначених відмов змішувачів-кормороздавачів. Встановлено, що ймовірності виникнення відмови механізму подрібнення-змішування засобу для приготування і роздавання кормів підпорядкований закону нормального розподілу. За результатами проведених розрахунків визначені основні параметри представленого теоретичного закону розподілу. Розрахунками встановлено, що середнє напрацювання на відмову становить 3152,0 мото-год.; середнє квадратичне відхилення – 902,6 мото-год.; коефіцієнт варіації – 0,40. Доведено, що середнє напрацювання на відмову об'єктів дослідження узгоджується із законом нормального розподілу за критерієм згоди Колмогорова. Розрахунками встановлено, що середнє значення показника надійності згідно закону нормального розподілу знаходитися в довірних інтервалах: 1964,2 мото-год. – нижня довірна межа; 4339,8 мото-год. – верхня довірна межа. Отримані результати дали можливість підвищити експлуатаційну надійність змішувачів-кормороздавачів

Ключові слова: змішувач-кормороздавач; механізм подрібнення-змішування; показники надійності; напрацювання на відмову; експлуатація