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Designs and parameters of asynchronous electric motors for agricultural needs

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The purpose of this study is to analyse the design features of asynchronous electric motors used in the agro-industrial sector in the processing of oilseeds. The paper is aimed at identifying optimal technical solutions to ensure high energy efficiency, reliability, and durability of units in difficult operating conditions. The methodology of the study is based on a theoretical analysis of literature sources and a comparative analysis of the design parameters of engines of different power. In experimental studies, thermal conditions are measured, and the influence of variable load conditions on the technical characteristics of electric motors is evaluated. The results obtained indicate a substantial influence of the rotor geometry, winding insulation class, and housing design on the performance of the units. It is determined that medium-power engines equipped with efficient cooling and protection systems against aggressive environments demonstrate stable operation under short-term overloads. Analysis of heat sink and wear resistance indicators allows determining the optimal design parameters that help reduce energy losses and increase the reliability of units.

Keywords
Drive mechanisms, technological processes, energy consumption, thermal mode, working load, cooling system, dynamic conditions

The agro-industrial complex plays a leading role in the economy of many countries, as it provides the population with food and raw materials for further processing. In turn, modern agriculture cannot be imagined without reliable and efficient electromechanical equipment that provides mechanisation and automation of various technological processes. Among such technical solutions, asynchronous electric motors occupy a special place due to the combination of simplicity of design, energy efficiency, and durability. They are the basic drive for most agricultural machines and mechanisms operating in dynamic and sometimes extreme conditions of high humidity and dust.

Considerable attention is paid to the problem of ensuring the energy efficiency of agricultural equipment in the paper of Bazaluk et al. (2021), where the energy assessment of sorghum cultivation in the southern regions of Ukraine was reviewed. The authors stress that optimisation of electric drives in agriculture helps to reduce energy costs and increase the overall productivity of agricultural enterprises.

The relevance of the subject is due to the fact that the agricultural sector requires high-performance, reliable, and at the same time unpretentious in maintenance solutions. Frequent starts and stops, voltage drops, variable workload – all this puts increased requirements on engines (Tropina et al. 2014). With the growing demand for processed products, especially oilseeds, the need to optimise the design of electric motors becomes even more evident. Processing plants and farms engaged in oil

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production operate in intensive modes, often continuously, which further increases the requirements for the reliability and energy efficiency of drive systems.

Asynchronous electric motors in such an environment have proven their superiority in a number of parameters. Firstly, they have a simple design that requires minimal maintenance. Secondly, short-circuited rotor motors provide reliable start-up even with partial or periodically variable loading, which is typical for screw presses, conveyors, and other equipment used in oilseed processing processes. Thirdly, the ability to work under conditions of short-term overloads and withstand voltage fluctuations contributes to a more stable technological cycle. Ultimately, the relatively low cost and availability of spare parts make these machines particularly attractive for the agricultural sector.

The efficiency of asynchronous motors in agriculture also depends on their durability and resistance to mechanical wear. In a study by Hopner and Wilhelm (2021) consider the service life of insulation of low-voltage electric motors. The authors note that insulation materials are substantially exposed to moisture and dust, which is typical for the operating environment of oil presses and conveyors.

Thereby, the specifics of processing oilseeds, in particular, in screw presses of oil-separating machines, impose additional requirements on the engine design. Constant contact with solid cake residues, high humidity, and the presence of dust can lead to premature wear of moving parts, disrupt the normal thermal regime, and reduce the overall efficiency of work. Therefore, in the context of agro-industrial use, it is important not only to study asynchronous motors in general but also to analyse their design features in depth, in particular, the selection of winding materials, insulation technologies, and cooling systems.

A substantial contribution to the study of the design features of electric drives for agricultural machinery was made by Abhilash et al. (2021). The paper considers an approach to evaluating the reliability of induction motors based on the analysis of possible failures, which is relevant in the context of intensive use of engines in agriculture.

Optimisation of these elements allows increasing the oil yield, reducing energy consumption, and ensuring uninterrupted operation of the equipment even under enhanced operating conditions. This question is raised in the study by Wong et al. (2021), where the authors optimise the design of a permanent magnet synchronous motor (PMSM) to improve the efficiency of electric drives in agriculture.

In addition, an important aspect of the operation of electric motors in agricultural machinery is the control of their condition and the ability to prevent malfunctions. Dekhandji et al. (2019) investigated the application of predictive maintenance for three-phase asynchronous motors. The use of fault diagnosis and analysis methods can substantially improve the reliability of equipment and prevent critical breakdowns, which is especially important for enterprises with continuous production.

This work is mainly theoretical in nature and is devoted to a comprehensive analysis of the design features of asynchronous electric motors used in agriculture, with an emphasis on the specifics of their operation during the processing of oilseeds. The study examines the main parameters that determine the reliability and performance of engines, as well as the conditions under which they operate most efficiently. Special attention is paid to the design of the motor of the screw press of an oil-separating machine operating in a particularly difficult environment of intense loads and continuous operation.

Materials and methods

The main objects of research were three-phase asynchronous electric motors of various capacities, ranging from 3 kW to 37 kW, which are widely used in agricultural technological processes. The paper analyses three-phase asynchronous motors, the power of which varies from 3 to 37 kW. They are conventionally divided into three groups: 5 low-power engines (up to 5 kW), 5 medium-power engines (from 5 to 30 kW), and 5 high-power units (over 30 kW). This allows for the consideration of manufacturing tolerances and, accordingly, the evaluation of the expected vibration range for each motor type. The study focuses on a comparative analysis of general design characteristics, particularly the housing type, winding insulation class, and rotor design. Regarding the design of the rotor, the analysis is conducted both for units with concentric and those equipped with rod rotors, since these parameters directly affect the efficiency and performance of engines in difficult conditions of the agro-industrial environment, in particular, when processing oilseeds.

The analysis is based on general technical characteristics typical of asynchronous motors of various manufacturers that supply equipment for the agro-industry. In the study, motors were selected that differed in several fundamental parameters: the type of housing (aluminium, cast iron, and steel), the insulation class of windings (F, H), and the design of the rotor, in particular, the presence of a short-circuited rotor with different groove geometries. For the most accurate reproduction of real operating conditions, specialised experimental stands were created that allowed simulating both variable and continuous loads. In addition, the influence of such factors as temperature changes, the presence of dust, cake residues, and humidity levels, which are characteristic features of the environment at processing enterprises of the agro-industrial complex, was carefully monitored and analysed in the laboratory. This provided for evaluating the performance characteristics of engines in real production conditions and determine the optimal parameters of their operation. A detailed comparative analysis of their parameters was conducted to determine the optimal design solutions for three-phase asynchronous electric motors. Special attention was paid to the geometry of the rotor and the size of the radial clearance. For these measurements, standard instruments were used, in particular, dipsticks, indicator heads, and factory technical documentation, which enabled the confirmation of the rated characteristics of the engines.

The next important aspect of the analysis was the type and class of insulation of the windings. The study included microscopic analysis of insulation materials, determination of their heat resistance using the thermal ageing method, and verification of compliance with international standards of International Electrotechnical Commission (IEC 2022a). This allowed assessing the durability of insulation systems under various operating conditions. In addition, the hull material and its weight and size characteristics were analysed. Overall dimensions were measured, thermal conductivity and mechanical stability of the structure were evaluated, considering specific operating conditions, in particular, continuous operation in a dusty environment. This helped determine the optimal design solutions that ensure the efficiency of engines in agricultural and industrial conditions. All the results obtained were systematised in comparative tables, which became the basis for justifying the most appropriate choice of the design of electric motors depending on their power and operating conditions.

The analysis of the thermal modes of three-phase asynchronous electric motors was conducted using modern measuring technologies, which allowed obtaining accurate and representative data on the heating of their main structural elements. K-type thermocouples and infrared pyrometers were used to control the temperature, which were fixed at key monitoring points – on the windings and motor housing. Additionally, non-contact temperature sensors were used, which provided continuous tracking of the heating of the rotor and bearing units. For each engine under study, different load modes were set – 50% , 70% , and 90% of the rated power, which provided for simulating the real operating conditions of screw presses. After reaching the stationary thermal regime, key parameters were recorded: the temperature of the windings in accordance with the IEC 60034-1 method (International Electrotechnical Commission; 2022b), the temperature of the bearings, as well as the efficiency factor, which was determined using standard electrical measuring devices, including power meters and a mechanical brake stand.

The obtained experimental data were subjected to statistical processing, which included calculating the average values, variances, and constructing the “temperature-load” and “efficiency-load” dependencies. This enabled the identification of patterns of changes in the thermal parameters of engines depending on the load, which is an important factor for improving the efficiency of their operation in the conditions of agro-industrial technological processes. A set of analysis methods was used to identify the factors that cause accelerated wear of three-phase asynchronous electric motors in an environment of high dust and humidity. One of the key approaches was visual and microscopic analysis of moving components, in particular, bearings and seals, after their operation in bench and production conditions. The degree of mechanical wear and the main problem areas of the structure were assessed in this way.

The housing and fasteners were tested using special salt solutions in accordance with the methodology State Standard (GOST) 9.308-85 (1985) with appropriate adjustments to assess the resistance to corrosion processes. The study determined materials that show increased resistance to aggressive environments and high humidity. Special attention was paid to vibration monitoring according to the International Organisation for Standardisation (2014) (ISO) 10816 methodology. Measuring changes in the amplitude and frequency of vibrations helped assess the degree of wear of bearing units and identify the presence of unbalance of the rotor, which can lead to additional loads and reduce the engine life.

Based on the obtained data, practical recommendations were developed to improve the wear resistance of electric motors. In addition, the expediency of using high-tech insulation materials with improved water-repellent properties, which increases the service life of windings, was justified. It is proposed to implement a system for continuous or periodic monitoring of temperature and vibration indicators, which allows detecting potential malfunctions at an early stage and preventing emergencies.

Results

Comparative analysis of design parameters of engines of different power

In the initial stage of the study, a detailed comparison of the design parameters of asynchronous motors of various capacities, which are most often used in agriculture, was conducted. The main purpose of the analysis was to determine the influence of rotor geometry, winding insulation class, housing materials, and weight and size indicators on the performance of motors in difficult operating conditions.

One of the key parameters that affects the efficiency of engines is the rotor geometry and the size of the air gap. The analysis showed that in low- and medium-power engines, this gap is usually 0.2–0.6 mm. This configuration reduces magnetic losses and increases the overall energy efficiency of the unit. However, for engines with a power of more than 30 kW, the air gap can be increased to 0.8 mm, which compensates for possible mechanical deformations, especially in conditions of frequent starts and braking, which are typical for agricultural technological processes.

An important aspect of motor durability is the type of windings and their insulation class. Low-power motors are usually equipped with Class F insulation, which meets most standard operating requirements. However, for medium- and high-power engines, Class H is increasingly used, which can withstand increased temperature loads. In addition, it was established that the rod winding is more resistant to mechanical influences compared to the concentric one, but its use increases the cost of motor production.

The body design and materials used also play a substantial role in ensuring the reliability and efficiency of the engine. For mobile agricultural installations, where weight restrictions are a critical factor, engines with aluminium housings are most often used (Voloshina et al. 2019). They are lighter and more convenient for installation and maintenance. In stationary installations, particularly, in screw presses and conveyor systems, engines with steel or cast-iron housings are preferred since they provide better rigidity and thermal conductivity, which is critical for continuous operation under conditions of increased mechanical and thermal loads.

The last but no less important parameter is the weight and size characteristics of the engine, which determine its ease of installation and maintenance. For medium-capacity screw presses, the optimal ratio is the length of the stator to its diameter in the range of 1.2–1.4. This design approach contributes to uniform heat dissipation, which, in turn, reduces the likelihood of local overheating of the windings and, accordingly, increases the reliability and operational life of the motor.

The analysis of the design parameters of asynchronous motors used in agriculture clarified the optimal configurations for various operating conditions. Considering the features of the rotor geometry, insulation class, housing materials, and weight and size characteristics makes it possible to improve the operating parameters of engines, increase their energy efficiency and durability in difficult production conditions (Panchenko et al. 2021). The systematised comparative analysis data is presented in Table 1. They confirm that the optimal design characteristics of engines must be consistent with the modes and specifics of the technological process, as well as with the level of load in real operating conditions.

Table 1: Comparative design characteristics of asynchronous motors of various capacities

Characteristics	**Low power (< 5 kW)**	**Medium power (5–30 kW)**	**High power (> 30 kW)**
Radial clearance in mm	0.2–0.4	0.4–0.6	0.6–0.8
Stator length/Diameter ratio	1.0–1.2	1.2–1.4	1.3–1.5
Housing type	Aluminium	Cast iron/Steel	Cast iron/Steel
Insulation class	F	F or H	H
Preferred type of windings	Concentric	Concentric or rod	Rod

Source: compiled by the authors based on Hopner and Wilhelm (2021), Abhilash et al. (2021)

According to the data obtained, medium-power engines are most often used in the processing of oilseeds because they meet the requirements for reliability, the ability to withstand short-term overloads, and maintain proper energy efficiency in continuous mode. The reliability and durability of asynchronous electric motors are vital factors in agro-industrial production, where the equipment is operated in conditions of high humidity, dust, and mechanical loads. Tests were conducted in accordance with GOST 9.308-85 standards (1985) and ISO 10816 (International Organisation for Standardisation 2014) to assess the performance of electric motors. The study allowed determining the influence of corrosion processes and the level of vibration load on the performance of electric motors in real operating conditions. Asynchronous motor housings used in the agro-industrial sector are subject to substantial corrosion effects, especially in oilseed processing facilities (Kozakevych 2016). In such conditions, high humidity and aggressive impurities in the air is present, which helps to accelerate corrosion processes. Tests were conducted under conditions that simulate the actual operating environment to determine the resistance of electric motors to corrosion.

There are substantial differences in the corrosion resistance of motor housing materials. In particular, during experiments in salt mist (5% NaCl solution) for 168 hours, aluminium housings showed an average corrosion rate of 0.02 mm/year, while cast iron housings were substantially more stable, with a corrosion rate of 0.008 mm/year. This indicates that cast iron is a more durable material for electric motor housings in corrosive environments. In addition, tests in conditions of high humidity (relative humidity of more than 85%) showed that fasteners without additional anti-corrosion protection begin to corrode after 4–6 months of operation. This can negatively affect the reliability and durability of the entire electric motor, reducing its mechanical strength and increasing the risk of failure.

An important measure to increase the resistance of electric motors to corrosion is the use of protective coatings. Studies have shown that the use of zinc alloys and epoxy coatings can reduce the rate of corrosion by 2–3 times, which substantially extends the service life of equipment. This makes protective coatings an effective solution for the operation of electric motors in difficult conditions of agro-industrial production. The results obtained confirm the need to introduce anti-corrosion protection for electric motors operating in environments with high humidity and aggressive impurities. The use of anti-corrosion measures not only increases the durability of equipment but also reduces the cost of its maintenance and replacement, which is an important factor for the effective functioning of agro-industrial enterprises (Gabdullin et al. 2019).

One of the key reliability parameters of asynchronous electric motors is the level of mechanical vibrations, which directly affects their durability and stability of operation. Excessive vibration can lead to premature wear of parts, unbalance of the rotor, and failure of the entire unit. Control measurements were conducted in accordance with the international standard ISO 10816 to assess the vibration characteristics of electric motors of various capacities (International Organisation for Standardisation 2014). The research results showed that for medium-power motors (5–30 kW), the total vibration level in the frequency range of 10–1000 Hz was 2.1 mm/s, which corresponds to Class A, i.e., normal operation without the need for additional intervention. However, for engines with a power of more than 30 kW, the vibration level was recorded in the range of 3.2–3.8 mm/s. Such indicators may indicate initial signs of bearing wear or rotor unbalance, which requires increased attention from technical personnel.

Analysis of the causes of increased vibration revealed several main factors affecting its growth. One of them is the accumulation of dust in the air vents, which leads to a disruption of effective cooling and creates an additional load on the system. Another important factor is to reduce the level of lubricants in bearings, which increases friction and contributes to rapid wear of parts. In addition, loosening of fasteners and unbalancing of structural elements can cause uneven load distribution, which further increases vibration.

Increasing the vibration level by 20–30% due to contamination of the ventilation ducts and insufficient lubrication of bearings was proven to substantially shorten the service life of electric motors and lead to their premature failure. A number of preventive measures have been developed to prevent such problems. In particular, optimisation of ventilation systems allows removing dust more efficiently and improving heat dissipation, which helps to reduce the load on the engine. Additionally, it is proposed to use reinforced anti-vibration fasteners that reduce the vibration level to 1.8 mm/s, increasing the stability of the unit. Regular maintenance, including cleaning of ventilation ducts and timely replacement of lubricants in bearings, is an essential measure to maintain the proper level of reliability of electric motors (Nadykto et al. 2015).

In comparing the energy consumption of asynchronous electric motors used in agro-industrial applications, different operational modes were analysed, focusing on varying load conditions and their impact on motor efficiency. At low load conditions, around 50% of rated power, the motor operates at lower energy consumption but exhibits suboptimal efficiency. The winding temperature ranges from 60–70°C, with an efficiency of 86.5%, which is relatively low compared to higher loads. This condition occurs because the motor is not operating at its full capacity, resulting in lower overall energy use but less efficient performance. The motor works best when it is at its rated power, which is about 70% of its maximum load. The winding temperature increases to 70–80 °C, and efficiency rises to 89%, with the motor consuming energy in a balanced way. The cooling system is effective, with external fans and clean housing contributing to the motor's stable thermal regime. This condition ensures that the motor is utilising energy efficiently, resulting in minimal losses.

At high load conditions, around 90–100% of rated power, the motor consumes more energy but exhibits reduced efficiency. The winding temperature rises to 85–95 °C, with efficiency dropping to 86% . While the motor is working at its maximum capacity, the increased temperature leads to higher losses in the rotor and stator, reducing the overall efficiency. The cooling conditions become less effective due to cake and dust accumulation, which makes it more difficult for the motor to dissipate heat, exacerbating the energy inefficiency.

The comparison reveals that while low-load operation results in reduced energy consumption, it also leads to less efficient performance. The optimal load range, between 70–80% of rated power, provides the best balance of energy consumption and motor efficiency, with minimal energy losses and a stable thermal regime. On the other hand, operating at high load conditions increases energy consumption and reduces efficiency due to the higher thermal stress on the motor. Therefore, the most energy-efficient operation occurs when the motor works within the optimal load range.

Maintaining the motor within this optimal load range is crucial for maximising energy savings and improving overall performance. The findings suggest that, particularly in high-load operations, additional measures such as improved cooling systems and enhanced insulation materials could mitigate the effects of high temperatures and prevent significant efficiency losses.

Research of thermal modes and energy efficiency

The second area of the study focused on the analysis of thermal modes of operation of asynchronous motors in the processing of oilseeds. Heat load is one of the crucial factors that determine the duration of engine operation and efficiency. The specific characteristic of oil presses is their continuous working cycle with periodic changes in the load level, which drastically complicates thermal processes and requires additional temperature control (Table 2).

Table 2: Results of statistical processing

Load in %	Average temperature in°C	(Range, in °C)	Average efficiency in %	(Range, in %)
50	65	(60–70)	86.5	(85–88)
70	75	(70–80)	89.0	(88–90)
90	90	(85–95)	86.0	(85–87)

Source: compiled by the authors based on Feng et al. (2020), Dinolova et al. (2023)

At an optimal load (70%), the temperature of the windings reaches approximately 75 °C, and the efficiency is about 89% , which indicates a balanced operation of the motor. When the load is increased to 90% , the temperature increases to 90°C, while the efficiency decreases slightly to 86%. Evaluation of the temperature of the windings and core showed that during the operation of motors in the oilseed processing mode, the temperature of the windings often exceeds the nominal permissible values by 10–15°C. This phenomenon is caused by uneven feed of raw materials and the formation of cake residues, which can complicate the cooling process. This is especially critical for low-power engines, which are less resistant to overloads and quickly heat up when operating at the limit of their capabilities.

The level of engine load also substantially affects the thermal regime. The optimal load is in the range of 70–80% of the nominal value since under such conditions, a balance is provided between the performance of the press and the temperature regime of the windings. In turn, at a load of more than 90% for a long time, the motor temperature increases sharply, which leads to accelerated ageing of insulation materials, increased losses in the rotor and stator, and a general decrease in the efficiency of the unit.

The cooling system plays a major role in maintaining engine performance under heavy operating conditions. Experimental studies have shown that the use of fans with extended blades and directional air channels can increase the efficiency of heat removal by 10–15%. In medium-power engines, such measures help to stabilise the temperature regime even in difficult conditions, in particular, with high humidity or substantial dustiness of the working environment. Insufficient maintenance of the ventilation system, particularly the accumulation of cake and dirt in the vents, can substantially reduce cooling efficiency, which leads to additional overheating of the engine (Figure 1).

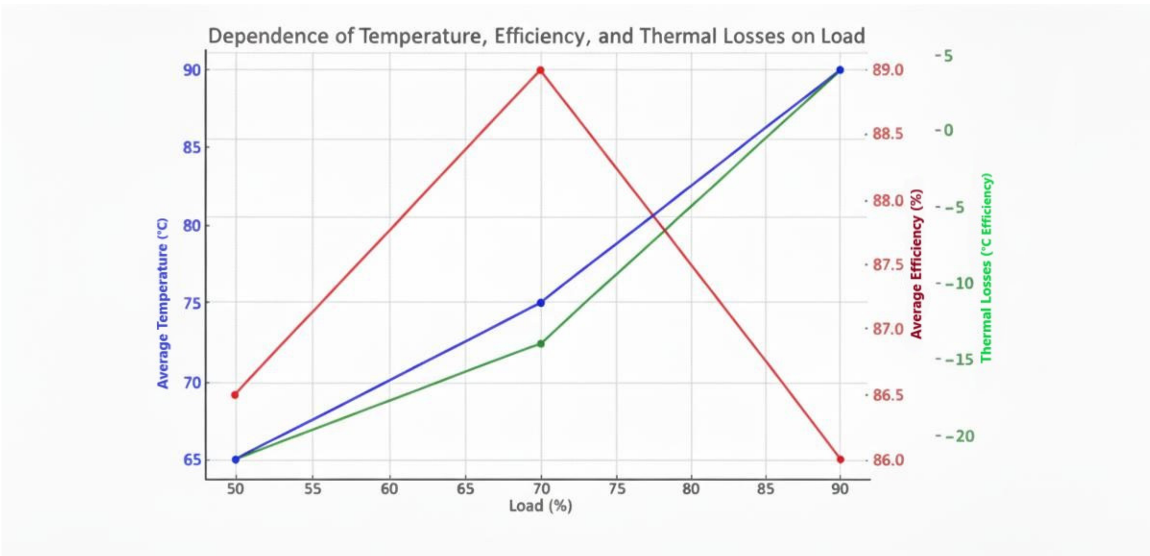

Figure 1: Dependence of temperature and efficiency on load (Source: compiled by the authors based on Feng et al. (2020), Dinolova et al. (2023))

Analysis of changes in engine efficiency has shown that the thermal regime is closely related to the overall level of energy efficiency. Contamination of the housing surface and ventilation ducts can lead to a decrease in efficiency by 1.5–2% of the declared nominal characteristics. Regular cleaning of the engine and preventive measures allow keeping the efficiency at a high level, ensuring stable operation of the unit and extending its service life. The generalised data of thermal analysis and efficiency measurement are given in Table 3.

Table 3: Thermal performance of asynchronous motors of screw presses

Working schedule	Winding temperature in °C	Exceeding the nominal value in °C	Efficiency in %	Cooling conditions
Low load (≈ 50%)	60–70	5–7	85–88	External fan, no contamination
Optimal load (70%)	70–80	8–10	88–90	External fan, clean housing
High load (90–100%)	85–95	12–15	85–87	Ventilation is difficult, cake and dust

Source: compiled by the authors based on Feng et al. (2020), Dinolova et al. (2023)

Reliable operation and achieving acceptable energy efficiency largely depend on keeping the engine clean and maintaining an optimal operating mode. In real-world conditions, this is achieved thanks to constant monitoring of the load level and an efficient ventilation system.

Impact of aggressive environments on engine durability and reliability

The third stage of the study was aimed at determining the effect of the aggressive environment that occurs during the processing of oilseeds on mechanical components and electrical insulation of asynchronous motors. Factors such as dust, solid cake residues, high humidity, and high temperature create complex operating conditions that differ from standard industrial environments. Since the equipment can operate in both intermittent and continuous mode, the negative impact of these factors only increases over time, which requires special protection measures.

One of the main problems in conditions of increased dust formation is the rapid contamination of the lubricant in the bearings. Studies have demonstrated that during 3–4 months of intensive operation in screw presses, the loss of lubrication can reach 25–30% , which leads to increased vibrations, increased noise levels, and the risk of rotor jamming (Feng et al. 2020, Dinolova et al. 2023). The lack of regular maintenance of bearings notably reduces their service life and can cause an emergency engine failure.

Another critical problem is a violation of the tightness and ventilation system of the engine. The accumulation of a layer of dust and solid residues on the housing, vents, and seals makes it difficult to remove heat, which accelerates overheating and contributes to corrosion processes. Especially dangerous is the penetration of moisture through damaged seals, as this leads to the accumulation of condensation in the internal cavities of the engine. This situation leads to the destruction of the electrical insulation of the windings, which increases the risk of short circuits and reduces the operational life of the motor (Harerimana et al. 2020).

Corrosion phenomena also influence the wear process of equipment. In case of contact with aggressive compounds (acid or alkaline components of raw materials), metal parts of the engine are subjected to accelerated corrosion (Korzhik 1992). Most affected are the fasteners, which gradually loosen, which can lead to an imbalance of the rotor and premature engine failure. Corrosion also negatively affects the stator and rotor packages, reducing engine efficiency.

Body deformations under the influence of heat and vibration are another substantial factor that reduces the reliability of engines during operation. Intense vibration loads, especially during the pressing stage of oilseeds, combined with temperature fluctuations, can cause the formation of microcracks in the housing and mechanical joints. These microcracks contribute to the penetration of dirt into the engine, which complicates cooling, accelerates wear and reduces the overall reliability of the equipment (Mohan 2024)

In agricultural processes, particularly during the processing of oilseeds, significant mechanical loads are often observed, resulting from sudden load changes, impacts, and vibrations, which can accelerate the wear of structural components, including bearings and rotors. The constant exposure to these factors may lead to premature wear, disruption of the normal functioning of the motor, and a reduction in its service life. These phenomena are especially critical in agricultural machinery, where engines operate under conditions of variable loads, frequent starts, and stops. Therefore, taking these factors into account during the design of electric motors is crucial for ensuring their durability, reducing the risk of unexpected failures, and ensuring uninterrupted operation in the challenging conditions of agricultural machinery (Han et al. 2022).

Operating conditions in the agricultural sector require the introduction of additional protective measures to ensure the durability of asynchronous motors. It is necessary to use airtight seals, regularly replace or restore lubricants, and apply an anti-corrosion coating to protect moving elements. Ignoring these recommendations can lead to a substantial reduction in engine life, increased operating costs, and reduced economic feasibility of using such equipment.

Recommendations for optimising the design and operating conditions

Based on the results obtained and the identified patterns, a set of recommendations was developed to improve the design and operating conditions of asynchronous electric motors in agriculture. The proposed measures are aimed at improving energy efficiency, increasing the service life of equipment and minimising the risks of downtime or emergencies. One of the essential areas of improvement is the optimization of the cooling system. It is recommended to use more efficient fans with an increased blade area and special guide channels, which will help improve air exchange in the winding area. For high-power motors operating in continuous mode, it is advisable to introduce combined liquid-air cooling, especially in cases where the pressing intensity causes critical heating of the windings. Water cooling is one of the most effective methods of temperature regulation for asynchronous electric motors, especially under high load conditions where air cooling may be insufficient (Suglobov et al. 2024). Due to the high thermal conductivity of water, this method allows for quick heat dissipation from critical motor parts, reducing the risk of overheating and ensuring stable operation even under intensive operating conditions. In agricultural machinery, where motors operate under constant load fluctuations and high humidity, water cooling can significantly improve performance efficiency and extend the motor's lifespan.

In addition to water cooling, there are other alternative cooling systems that can be employed to enhance the cooling efficiency of asynchronous motors. One such alternative is the use of liquid cooling fluids (e.g., liquid crystal or specialized fluids with high heat transfer properties). This method not only improves heat dissipation but also ensures additional stability of the temperature regime under varying loads. Another alternative is the use of thermoelectric materials, which can provide localized cooling for specific motor components, reducing the likelihood of overheating.

Protecting engines from aggressive environments requires the use of high-quality seals and protective covers. For units located near screw presses and conveyors, it is advisable to use special labyrinth seals, which prevents dust and cake residues from entering the bearing area (Panchenko et al. 2019). In addition, the use of removable protective covers will greatly simplify the maintenance process, allowing quickly cleaning the engine from dirt.

Another important direction is to improve the insulation of windings. The use of materials with a high heat resistance Class (F or H, and for extreme conditions – even C) protects the windings from overheating and moisture. In regions with high humidity, it is advisable to use impregnating lacquers with water-repellent properties, which reduce the risk of inter-turn short circuits and extend the service life of the engine.

Control and prevention play an important role in maintaining the stable operation of the equipment (Bulgakov et al. 2020b). The installation of a winding and bearing temperature monitoring system will enable a response in a timely manner to exceed the permissible values. This can be realised using thermal sensors built into the motor housing or non-contact infrared sensors. Performing regular maintenance at least once every 3–4 months, including cleaning the ventilation ducts, replacing or refilling lubricants, checking the tightness level, and anti-corrosion inspection, is crucial to ensure smooth operation.

Adaptation of operating modes allows minimising the load on the engine and increasing its durability (Gutarevych et al. 2020, Panas et al. 2024). It is optimal to maintain the load in the range of 70–80% of the rated power, which ensures a balance between thermal load and performance, while maintaining high efficiency. It is recommended to use frequency converters that allow implementing “soft” start modes and more accurately adjust the speed of rotation to reduce inrush currents and mechanical loads.

Separately, the possibility of upgrading the rotors to improve their wear resistance should be considered. In cases of intense contact with solid cake residues or abrasive particles, it is advisable to use rotors with a reinforced structure – made of stronger alloys or subjected to special heat treatment. It is recommended to use short-circuited rotary systems with variable groove shapes, which increases the engine’s resistance to short-term overloads to ensure high starting torques and more precise speed control.

All these measures are aimed at improving reliability, reducing energy consumption, and optimising the operation of asynchronous electric motors in agriculture. In conditions of high rates of agro-industrial production, especially during the harvesting and processing season, any failures in the operation of electric motors can lead to considerable financial and time losses. Therefore, the implementation of the recommended solutions, including an improved cooling system, the use of reliable seals, high-tech insulation materials, and modern control methods, will ensure stable operation of the equipment even in the most difficult conditions.

The results of the study confirm that asynchronous electric motors remain one of the most efficient solutions for the agro-industrial sector due to their simple design, relatively low cost, and ability to operate in variable and complex conditions. However, to maximise the use of their potential, the design features, the specifics of operation, and the level of intensity of work processes must be accounted for. A responsible approach to the selection of the engine, its timely maintenance and modernisation will both extend the service life of the equipment and contribute to improving the overall efficiency of the technological process of processing oilseeds. This, in turn, will have a positive impact on the competitiveness and profitability of agro-industrial production.

Discussion

The results of the analysis of the design features of asynchronous electric motors used in agriculture indicate a close relationship between the design parameters, operating modes, and the overall efficiency of technological processes. As part of the study, it was determined that factors such as the size of the radial clearance, the insulation class of windings, the type of housing, the geometry of the rotor, and the quality of cooling and sealing, have a decisive impact on the performance and durability of electric motors, especially in difficult conditions of processing oilseeds. Below is a systematic discussion of the main points obtained on the basis of test results and analysis of the operational characteristics of the machines under study.

Firstly, the high importance of the correct selection and design of structural parameters is confirmed. The practice of using different models of asynchronous motors shows that the same technical indicator can have different effects depending on the operating mode. For example, the radial clearance, which averages between 0.2 and 0.6 mm for low- and medium-power engines, provides an optimal balance between starting characteristics and the level of magnetic losses. Instead, for more powerful units operating in the mode of continuous substantial loads, the gap is often increased to 0.8 mm, given possible mechanical deformations of the housing and rotor during intensive use. In this context, the results presented in a study by Xie et al. (2019), where attention is paid to the design of high-start induction motors with reduced vibration levels to improve their durability, should also be considered.

Equally important is the insulation class of the windings. If class F insulation may be sufficient for low-power engines, then for medium and large engines, it is advisable to use high-temperature classes that can withstand substantial excess operating temperatures for a long time. A similar situation occurs, in particular, in screw presses operated in continuous loading cycles. In conditions of intense heating, it is equally important to analyse the cooling systems because Boglietti et al. (2019) demonstrated in their paper how optimising the cooling design of traction motors can improve heat dissipation efficiency and enhance performance. For the agricultural sector, this means the ability to operate engines longer without overheating and shortening their service life.

The type of housing is a critical factor in determining the mechanical and thermal stability of electric motors. For mobile agricultural installations, where weight and ease of installation are paramount, aluminium housings are often the best choice. However, for continuous operation with heavy loads, such as in stationary processing lines, steel or cast-iron housings are more appropriate due to their superior ability to withstand vibration loads and higher stiffness, which reduces the risk of microcracks and deformations. These design choices also impact noise and vibration levels during operation. The use of low-frequency predictive control, as described by Feng et al. (2020), can help mitigate acoustic noise in induction motors.

In modern agriculture, mobile electric motors used in autonomous and portable machines – such as electric tractors, mobile presses, ventilation systems, and transport units – are becoming increasingly important (Bekenov et al. 2020). These motors must operate under variable load conditions and require adaptive cooling systems, reliable protection against vibration and dust, and compatibility with battery or hybrid power sources. The structural requirements for mobile motors differ significantly from those of stationary asynchronous machines, underscoring the need for specific criteria for selection, energy consumption calculation, and stable performance under field conditions. Integrating the mobile segment into electric motor selection provides a more comprehensive understanding of the electromechanical needs of agro-industrial production and enhances the overall efficiency of technological processes.

The overall energy efficiency of asynchronous motors largely depends on the level of heat loss. Studies show that when working with a load in the range of 70–80% of the nominal value, the temperature of the windings remains close to the permissible values, and the efficiency remains at a fairly high level. This mode contributes to optimal energy use and does not overload the engine, which extends its overall service life. Similar conclusions are confirmed by the review of Dinolova et al. (2023), where the energy efficiency of induction electric drives is considered, and ways to reduce energy consumption due to optimal operating modes are given. However, in real conditions, when the load can reach 90% or more, the temperature of the windings increases by 10–15°C above the calculated values. This leads to increased losses in the rotor and stator, intensive ageing of insulation materials, and a rise in the probability of unscheduled machine stops.

The cooling system affects the stability of the thermal regime and directly determines the duration of inter-repair intervals (Kyurchev et al. 2023). The use of a fan with extended blades and directional air channels increases the intensity of heat dissipation by approximately 10–15% . Design improvements aimed at reducing noise can also be implemented due to additional methods similar to those proposed by Han et al. (2022) to reduce noise in the cabs of agricultural tractors. Although their research focuses mainly on sound insulation, conceptually, the approach to minimising vibrations and unwanted oscillations can also be adapted for electric motors to ensure comfortable operating conditions and long-term operation of equipment.

The aggressive environment that is formed during the processing of oilseeds is another critical challenge. High humidity, abrasive action of dust particles and cake residues, and ingress of chemical compounds from vegetable raw materials – all this leads to accelerated wear of moving parts and vulnerable engine parts (Bulgakov et al. 2020a). Among the most affected elements are bearings, which can lose a substantial proportion of lubricant over several months of operation without proper protection. This factor increases the risk of rotor jamming and emergency stops. In addition, contamination of the ventilation ducts worsens cooling and further loads the engine. In such conditions, the use of intelligent monitoring systems is especially promising, where approaches similar to those described by Mohan (2024) are used. The author offers a solution based on the Internet of Things (IoT) for intelligent management of agricultural processes, which allows tracking the state of equipment in real time and quickly responding to changes in temperature or vibrations.

Proper sealing and protective solutions help minimise the impact of aggressive environments. For example, the use of labyrinth seals or multi-stage sealing systems for bearing assemblies makes it difficult for dust and moisture to enter the internal areas of the engine. Such technical solutions can be successfully combined with the energy-efficient design approaches for autonomous sensor devices described by Harerimana et al. (2020), which refers to low-power energy collection. This opens up the possibility of creating adaptive engine health monitoring systems that do not require substantial maintenance and can be powered by minimal energy sources, such as photovoltaic cells.

Another important factor that was noted in the course of the study is vibration characteristics. Frequent start-stops, which are typical for the agricultural sector, generate increased shock loads on the shaft and bearings. The probability of interaction with solid fractions of raw materials, possible contact with working bodies or mating mechanisms, further clarifies that resistance to shock and vibration influences is one of the most important requirements for engines. The experience described by Stavinskii et al. (2019), where an axial asynchronous motor with a two-section cone-cylindrical magnetic circuit is considered, can be useful to increase the durability of structures, in particular, in large agricultural complexes. This unusual configuration allows reducing energy losses and increasing resistance to vibrations.

The conducted comparative analysis confirms that the main challenge in agriculture is to find the optimal compromise between the maximum productivity of the technological process and the need to preserve the engine resource. Depending on whether low-power systems with a limited load level or high-performance equipment with a continuous pressing cycle are in view, the emphasis is on various design solutions. For example, in the field of pumping equipment, where brushless motors are becoming increasingly important, an approach suggested by Pravin et al. (2023), who presented a new design for an energy-efficient brushless direct current (BLDC) pump for agricultural applications, deserves attention. Although their study focuses specifically on brushless motors, the very idea of optimisation in terms of reducing energy consumption and improving efficiency is also relevant for asynchronous machines.

Regarding improved control systems, the introduction of precision farming elements already involves the widespread use of IoT, unmanned aerial vehicles, augmented reality, and machine learning. Some aspects of this integrated approach are revealed in a study by Ponnusamy and Natarajan (2021), where the emphasis is on improving the efficiency of resource use in agriculture. The implementation of such technologies enables the integration of asynchronous motors into a single smart system, where load, vibration, and temperature data are collected in real time. Additionally, innovative sensor solutions described by Rayhana et al. (2021) can be used because printed sensor technologies help reduce energy consumption and quickly monitor the technical condition of equipment.

In general, agriculture is in a phase of large-scale transformation associated with the transition to more environmentally friendly and resource-efficient production methods. The concepts of "climate-friendly agriculture" include optimising energy consumption and reducing greenhouse gas emissions. Safdar et al. (2024) pay attention to this, exploring technological and environmental aspects of implementing adaptive farming methods. In such a paradigm, asynchronous motors, which are characterised by reliability and relatively low losses in a properly organised mode, can be instrumental. Thereby, research is continuing in the direction of electrification of all agricultural machinery, as evidenced by the review of Scolaro et al. (2021). The authors stress that the transition to electromechanical solutions reduces dependence on fossil fuels and emissions, which is important for the sustainable development of the industry.

At a time when many agricultural enterprises are striving for autonomy and trying to reduce energy costs, the issue of using alternative energy sources is becoming increasingly relevant. It can be either biofuels or a variety of biogas plants. The importance of switching to alternative fuels is disclosed in a paper by Goncharuk et al. (2018), where the features of the alternative motor fuel market are analysed. In parallel with this, Havrysh et al. (2019) assessed the feasibility of using sunflower husks as an energy resource for oilseeds, which illustrates the trend towards self-sufficiency of enterprises, in particular, with heat and electricity. Such approaches directly affect the operation of asynchronous motors, because the stability and quality of power supply become crucial factors for ensuring the reliable operation of equipment in the agricultural sector.

Separately, the possibility of adapting electric motors to difficult operating conditions due to the optimisation of design solutions should be mentioned. For example, Yunusov et al. (2023) reviewed a method for modelling a linear asynchronous electric drive for low-speed mechanisms in agriculture, which opens the way to improving the efficiency of a number of specific processes. In addition, the possibility of using double drives for electric tractors is revealed by Wen et al. (2022), indicating the desire to solve the problem of uniform load distribution and more flexible power consumption management.

As a result, it can be argued that asynchronous motors will continue to be the leading drive for agricultural machinery due to the combination of reliability, simplicity, and low operating costs. However, to realise their full potential, it is necessary to account for special environmental conditions, develop improved cooling and protection systems, and provide an adequate maintenance system. In this aspect, Varani et al. (2021) proposed a notable approach, having analysed the performance of electric agricultural units powered by an external generator: this format increases autonomy and simultaneously reduces fuel consumption. Thereby, increased attention is paid to thermal control, as described by Wang et al. (2021), for electric vehicle engines, it will help extend the service life and reduce losses from overheating.

Given the development of bioenergy and the transition to renewable power sources, asynchronous motors can be integrated into broader technological systems where energy is obtained from sunflower husks or biogas. For example, in a paper of Hruban et al. (2023), the prospects for generating electricity from biogas were reviewed, and Havrysh et al. (2021) analysed the life cycle when using crop residues in bioenergy. All this provides for optimising production processes, including the operation of electric motors that are powered from various sources. Under such conditions, the question of the design of asynchronous machines becomes important. Comparative analysis of axial and radial induction motors performed by Iegorov et al. (2023) confirms that each configuration has its own advantages and limitations. Therefore, the choice of a particular engine type should depend on the operating conditions, which is especially important in industrial oil production, where both high torque and the ability to work continuously are required.

The practical value of this discussion lies in the fact that it confirms that in the process of processing oilseeds, it is appropriate to use asynchronous motors, provided that their design features and the intensity of operating modes are considered. A synergistic approach, when monitoring the engine condition is conducted using IoT systems (Amin et al. 2021), and the preparation and optimisation of working environments are implemented taking into account climatic factors (Safdar et al. 2024), opens up prospects for stable and high-performance operation of equipment. In addition, attention should be paid to the development of precision farming, in which the role of unmanned aerial vehicles is becoming increasingly important. Their adaptation in the agricultural sector is demonstrated by Popescu et al. (2020), which helps quickly collect data on the state of fields and predict engine loads in different parts of the process chain in advance.

As the international community pays more and more attention to the environmental component and innovative approaches to improving the efficiency of agricultural production, asynchronous motors remain a key element of mechanisation and at the same time an object of improvement. The development of more advanced control schemes aimed at reducing losses and improving dynamic performance can be conducted, in particular, through predictive control and machine learning methods. In some publications, like one by Herman and Suranta (2019), the creation of intelligent monitoring and control systems that are easily integrated into the overall digital infrastructure of the farm (hydroponic precision farming in their example) is described, which confirms the universality of using such solutions.

Thus, asynchronous motors can function as an efficient drive-in agriculture if their structural design is optimised, reliable cooling, protection against aggressive environments, and modern methods of load diagnostics and management are implemented. Taken together, these measures will ensure the stability of production processes, reducing the risk of unexpected shutdowns and increasing overall productivity and competitiveness.

Conclusions

In the course of the study, a comprehensive analysis of the design features of asynchronous electric motors used in agriculture, in particular, in the processing of oilseeds, was conducted. The results obtained allowed formulating the following main conclusions. The efficiency of using asynchronous motors is confirmed by their high reliability, ability to work in conditions of high humidity, dust, and dynamic loads. Especially important are their energy efficiency and ease of maintenance, which make them the best choice for technological processes of the agro-industrial complex under the mentioned conditions.

Design parameters that affected service life include the choice of housing materials, winding insulation, rotor geometry, and bearing type. Examinations demonstrated that for stationary technological installations, such as screw presses, medium-power motors with a cast-iron or steel body, which have an improved heat sink, are most suitable. Operating temperatures and their impact on engine performance showed substantial differences depending on the load mode. The optimal load was in the range of 70–80% of the rated power, which ensured stable efficiency and prevented overheating of the windings. An insufficient cooling system or clogged ventilation ducts were established to result in a decrease in engine efficiency. The influence of an aggressive environment on the durability of equipment was confirmed by the analysis of corrosion processes, abrasive wear, and contamination of bearing units.

It was determined that without proper maintenance, the loss of lubricants can reach 30% in 3–4 months of operation, which increases the risk of engine failure. The need to implement security solutions and monitoring systems was evident. The use of labyrinth seals, high-tech insulation materials, improved ventilation systems, and temperature and vibration monitoring sensors were identified to extend engine life and reduce the risk of emergency shutdowns. Upgrading and improving the design of electric motors may include the introduction of frequency converters for soft start, the use of variable groove rotors to improve overload resistance and expanding integration capabilities with precision farming systems to improve overall production efficiency.

The impact of agricultural electrification and the use of alternative energy sources is becoming increasingly important. In modern conditions, the autonomous energy supply of agricultural enterprises, particularly biogas plants and renewable energy sources, plays a significant role. This creates opportunities for optimizing electric drives and improving energy efficiency in technological processes. While this study confirms that asynchronous motors remain a pivotal element in the mechanization of agricultural processes, their full potential can only be realized by considering their design features, operating modes, and timely maintenance. Further research is needed to assess the performance and adaptability of these motors in other industrial sectors, thereby fully exploring their potential beyond agriculture. Additionally, future studies could focus on developing innovative engine designs with greater adaptability to varying operating conditions and integrating these designs into digital control and diagnostic systems, further enhancing the efficiency of agro-industrial production.

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