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MICROPROCESSOR SYSTEM FOR DIGITAL CONTROL OF ELECTRIC DRIVES OF WORKING ELEMENTS OF GRAIN CLEANING MACHINES

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This paper addresses the development and experimental validation of a digital control system for the electric drives of grain-cleaning machine working units based on the SAKO SKI780 frequency converter, the Arduino Uno microcontroller platform and the Modbus RTU communication protocol. The proposed system is intended to improve the accuracy, flexibility and reliability of electric-drive control during grain-cleaning operations. The general architecture of the control system, the principles of interaction between its main hardware components, the control algorithm for generating and transmitting commands through the RS-485 interface, and the corresponding software implementation of the microprocessor-based control system are presented.

Particular attention is paid to ensuring stable and reliable data exchange between the microcontroller and the frequency converter, as well as to the correct formation of control commands for regulating rotational speed and other operating parameters of the electric drive. The developed software makes it possible to set the required operating modes, transmit control signals, process feedback data and coordinate the operation of individual machine units. Experimental studies confirmed the stable operation of the proposed control system and its ability to accurately reproduce specified speed modes under varying load conditions.

The obtained results demonstrate that the use of digital control makes it possible to reduce transient response time compared with conventional analog control methods, thereby improving the stability of electric-drive operation and the consistency of grain separation. The developed system also provides flexible adjustment of rotational speed and facilitates centralized control of individual working units. The proposed approach can be considered a promising solution for the automation and modernization of grain-cleaning equipment. Further development may involve the integration of sensors for monitoring grain quality, drive load and material flow, enabling adaptive control algorithms and automatic adjustment of operating parameters in response to changing technological conditions. The obtained results provide a scientific and practical basis for improving the energy efficiency, reliability and technological performance of modern grain-cleaning machines.

***Keywords**: grain separation, frequency converter, RS-485, Arduino, asynchronous electric motor, Modbus RTU, grain cleaning machine.*

Fig. 4. Ref. 20.

1. Problem formulation

Most existing grain-cleaning machines (such as the OVS-25, SM-4, and similar models) employ non-adjustable electric drives [1]. Consequently, the operating modes of the separation process are often adjusted only through the mechanical replacement of pulleys or by regulating the fan dampers, which is an inherently slow and inaccurate approach [2].

ANALYTICAL SUBSTANTIATION OF THE INFLUENCE OF PULSATION PARAMETERS AND TEAT LINER CHARACTERISTICS ON MILK FLOW INTENSITY © 2026 by Elchyn ALIIEV, Yevhenii NOSENKO is licensed under CC BY 4.0
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With the rapid development of automated technological processes in both industry and agriculture, increasing demands are being placed on the accuracy, energy efficiency, and reliability of electric drive systems [3]. Frequency converters are widely used for controlling induction motors because they provide smooth speed regulation, reduce energy consumption, and improve the operational performance of industrial equipment [4].

The transition to independent control of screen vibration frequency and fan rotational speed using frequency converters enables grain-cleaning machines to be adapted to the physical and mechanical properties of a particular grain batch [5].

However, conventional methods of frequency converter control based on analog signals or discrete inputs are characterized by limited accuracy and functionality [6]. Such approaches complicate the integration of electric drives into modern distributed control systems and do not provide sufficient flexibility for implementing advanced automation algorithms.

The application of digital communication interfaces, particularly RS-485 employing the Modbus RTU protocol, offers significant opportunities to improve control accuracy and communication reliability under industrial operating conditions [7]. Nevertheless, the development of an efficient, reliable, and easy-to-implement control system for frequency converters based on affordable microcontroller platforms remains insufficiently investigated.

Therefore, the development of a microprocessor-based control system for the frequency converters of grain-cleaning machine working units represents an important scientific and practical task. Such a system would enable precise adjustment of screen vibration frequency and aspiration fan speed, which is essential for adapting the separation process to the physical and mechanical characteristics of a specific batch of grain material.

2. Analysis of recent research and publications

Recent studies have devoted considerable attention to improving the efficiency and reliability of frequency converter control in electric drive systems. In particular, the authors of [8] investigated fault-tolerant vector control methods for induction motors. Their study proposed algorithms for compensating motor parameter asymmetry caused by stator winding faults, thereby significantly reducing electromagnetic torque oscillations and ensuring stable drive operation even under fault conditions. The reported results demonstrate that the reliability of frequency converter-based drive systems can be substantially improved through the enhancement of control algorithms.

Study [9, 17-20] focused on frequency control strategies for traction electric drives operating under demanding conditions. The authors demonstrated that conventional control algorithms do not always provide optimal energy performance and proposed modified control approaches capable of reducing current loading while improving drive efficiency. These findings highlight the importance of adapting frequency converter control strategies to specific operating conditions.

A modern approach to integrating frequency converters with microcontroller-based control systems was presented in [10]. The authors implemented motor control via the Modbus RTU communication protocol using an ESP32 microcontroller and developed a real-time remote monitoring system for drive parameters. Their results showed that the integration of variable-frequency control with Internet of Things (IoT) technologies enhances system flexibility while enabling efficient real-time supervision of electric drive operation.

A significant contribution to the development of high-precision control techniques was reported in [11], where field-oriented control (FOC) was investigated as part of a frequency converter system. The study demonstrated that coordinate transformation enables independent regulation of motor flux linkage and electromagnetic torque, resulting in highly accurate speed control and improved dynamic performance of the electric drive.

In [12], a comparative analysis of open-loop and closed-loop vector control systems was carried out. Simulation results showed that the closed-loop configuration provides significantly better speed stability and shorter transient response, confirming the advantages of incorporating feedback into frequency converter control systems.

The analysis of recent publications indicates that current research on frequency converter control systems is primarily aimed at improving the accuracy, energy efficiency, and operational reliability of electric drives. Nevertheless, despite the widespread adoption of vector control techniques and microcontroller-based solutions, their adaptation to the specific operating requirements of grain-cleaning machines remains

insufficiently explored. In particular, further research is required to develop high-precision digital control methods for screen vibration drives and aspiration fans in order to ensure stable grain separation performance under variable operating conditions.

3. The purpose of the article

The aim of this study is to develop and experimentally validate a microprocessor-based control system for the electric drives of grain-cleaning machine working units based on the SAKO SKI780 frequency converter and the Arduino platform. The system enables precise digital control of screen vibration frequency and aspiration fan speed through the Modbus RTU communication protocol. The study also assesses the stability and repeatability of the prescribed operating modes under experimental conditions.

4. Results and discussion

Experimental investigations were carried out using a laboratory test bench equipped with an induction motor driven by a SAKO SKI780-1D5G-1 frequency converter. The experimental procedure involved stepwise setting of the output frequency within the range of 10–50 Hz, followed by recording the actual motor speed. The experiments were performed under both no-load conditions and under a load close to the rated operating value.

The performance of the proposed control system was evaluated in terms of frequency tracking accuracy, operational stability of the electric drive, and communication reliability. The experimental results were analyzed by comparing the prescribed operating parameters with the measured values, which made it possible to determine the control error and evaluate the dynamic characteristics of the proposed system.

The control object was a SAKO SKI780-1D5G-1 frequency converter rated at 1.5 kW, intended for controlling three-phase induction motors [13]. The converter supports digital communication via the RS-485 interface using the Modbus RTU protocol and provides the following functions [14-18]:

- starting and stopping the electric motor;
- digital setting of the output frequency;
- reading operating status and diagnostic parameters.

The availability of a standard RS-485 communication interface makes this frequency converter suitable for implementation in both automated control systems and laboratory research installations.

The developed automated control system consists of the following main components:

- SAKO SKI780-1D5G-1 frequency converter;
- three-phase induction motor;
- Arduino Uno microcontroller platform;
- RS-485 communication interface converter;
- personal computer serving as the supervisory control unit.

The structural diagram of the automated electric drive control system for the grain-cleaning machine is shown in Figure 1.

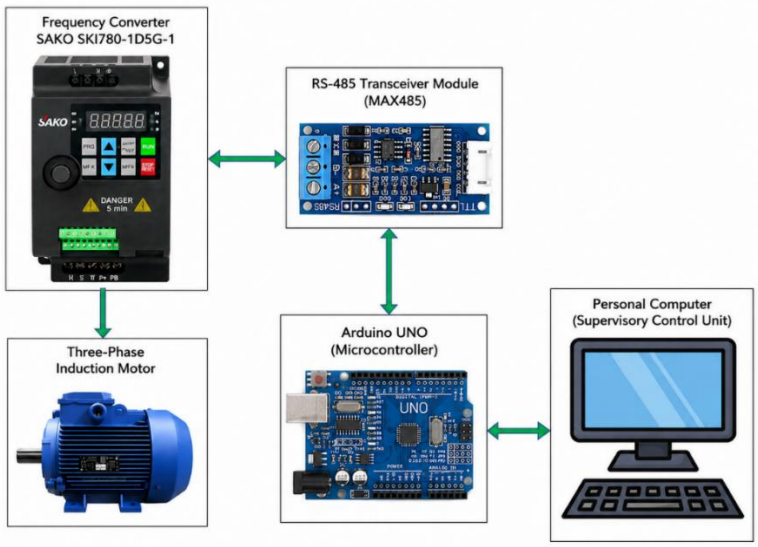

Fig. 1. Block diagram of the automated electric drive control system

The control algorithm for the frequency converter via the Modbus RTU protocol consists of the following principal stages.

1. **System initialization (Setup)**

This stage is executed once after the Arduino controller is powered on and includes:

configuration of the serial communication port by setting the baud rate (e.g., 9600 bps) and the communication frame format (8N1);

configuration of the DE/RE control pin of the RS-485 transceiver to switch between transmission and reception modes;

initialization of the operating parameters by assigning the initial frequency reference (e.g., 0 Hz) or loading predefined settings corresponding to a particular crop (wheat, rapeseed, etc.).

2. Main control loop

The main control loop continuously performs the following operations in real time:

verification of operating conditions, including detection of new frequency commands and Start/Stop control signals;

generation of a Modbus RTU request frame containing:

the frequency converter slave address;

the Modbus function code (e.g., 06 – Write Single Register);

the destination register address used for frequency or drive control;

the corresponding data value representing the required operating frequency;

calculation of the CRC-16 checksum to ensure data integrity;

transmission of the command by switching the RS-485 interface to transmission mode (DE/RE = HIGH), sending the data frame, and subsequently returning the interface to reception mode (DE/RE = LOW).

3. Response and error processing

After transmitting a command, the controller performs response verification according to the following sequence:

waiting for a reply from the frequency converter within the specified timeout period (100–200 ms);

validation of the received CRC-16 checksum to verify communication integrity;

processing of the received data. If the response is valid, the current operating status is updated. Otherwise, the command is retransmitted or a communication error message is generated in the event of a connection failure.

The flowchart of the control algorithm for the frequency converter based on the Modbus RTU protocol is presented in Figure 2.

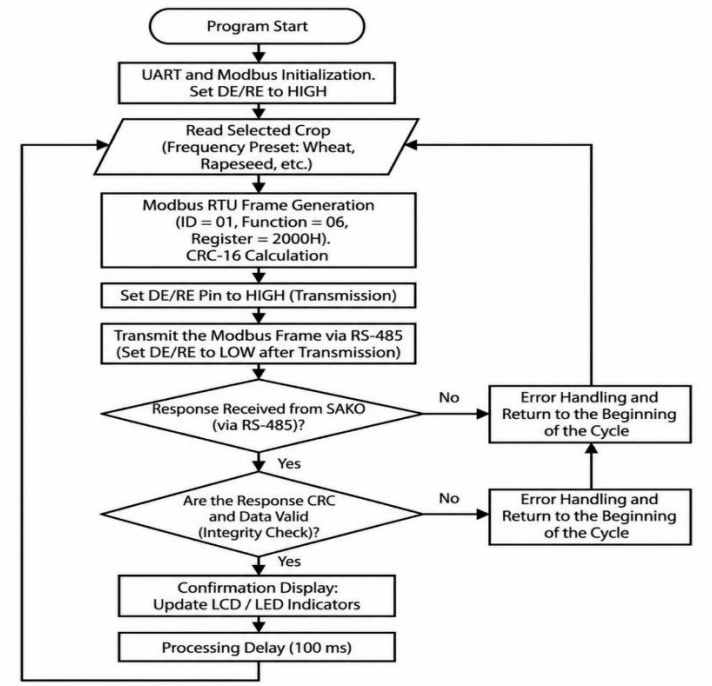

Fig. 2. Flowchart of the frequency converter control algorithm based on the Modbus RTU protocol

The main stages of software development included the following:

Communication initialization. Configuration of the serial communication parameters (9600 bps, 8 data bits, 1 stop bit, no parity) according to the frequency converter settings.

Generation of Modbus RTU frames. Software implementation of requests for writing data to the Holding Registers, including register 2000H for frequency reference and register 2001H for start, reverse, and stop commands.

Data integrity verification. Implementation of the CRC-16 cyclic redundancy check algorithm to prevent the execution of corrupted commands caused by electromagnetic interference generated by the motor power cables.

Response processing. Decoding of the status frames returned by the frequency converter to confirm successful command execution and monitor the current operating parameters of the drive, including output frequency and motor current.

Before operation, the SAKO SKI780-1D5G-1 frequency converter is configured to receive both start/stop commands and frequency references exclusively through the RS-485 communication interface. The automatic control sequence consists of the following stages:

- initialization of the Modbus RTU communication channel;
- transmission of the motor start command;
- digital assignment of the required operating frequency;
- continuous monitoring of the drive status;
- transmission of the stop command.

The digital communication architecture ensures high repeatability of the operating modes while significantly reducing the influence of electromagnetic interference on data transmission.

Experimental studies were conducted using a laboratory test bench equipped with an electric drive incorporating a SAKO SKI780-1D5G-1 frequency converter (Figure 3). The tests were performed under both no-load conditions and loading conditions close to the rated operating mode.

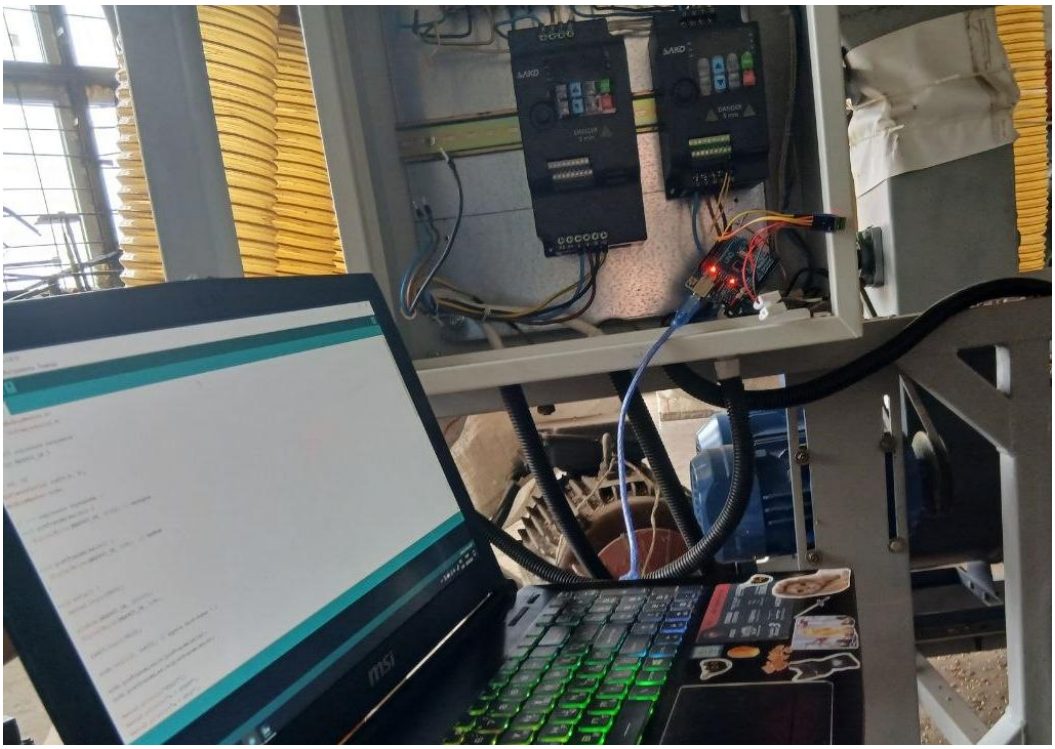

Fig. 3. General view of the experimental test bench

Based on the experimental results, the relationship between the time required for the frequency converter to reach the prescribed operating frequency under analog and digital control was obtained (Fig. 4).

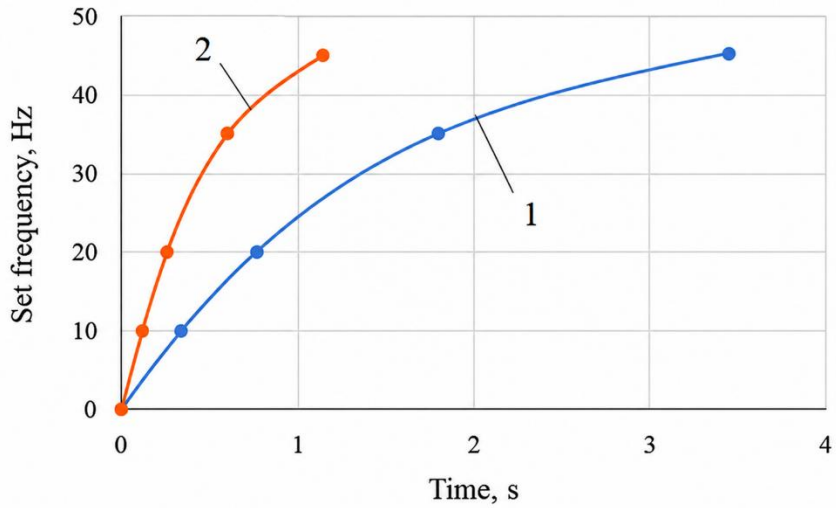

Fig. 4. Time required for the frequency converter to reach the prescribed operating frequency under analog (1) and digital (2) control

Analysis of the experimental results presented in Figure 4 revealed a substantial difference in the dynamic performance of the electric drive depending on the selected control method.

Under conventional analog control (curve 2), the drive exhibited pronounced inertia. The time required to reach the maximum technological operating frequency of 45 Hz was approximately 3.45 s. This behavior is primarily attributed to delays introduced by the analog signal filtering circuitry and the discrete analog-to-digital conversion processes within the frequency converter.

In contrast, digital control implemented via the RS-485 interface (curve 1) reduced the acceleration time to the same operating frequency to 1.15 s, representing approximately a threefold reduction in transient duration compared with the conventional analog approach.

Such a reduction in transient response is of particular importance for grain-cleaning machines operating under continuously changing technological conditions. Rapid adaptation of the screen vibration frequency and aspiration fan speed minimizes periods of unstable separator operation during transitions between processing modes.

Furthermore, the frequency response obtained under digital control is considerably smoother and more predictable than that achieved using analog control. This characteristic enables the implementation of precise automation algorithms capable of adjusting the operating parameters according to variations in grain moisture content, contamination level, and other physical properties of the processed material.

The theoretical analysis also demonstrated that reducing transient duration directly improves the technological efficiency of the grain-cleaning process. For a grain-cleaning machine with a processing capacity of 650 kg h^{-1}, the additional amount of material processed during a single transition is approximately 0.04 kg when accelerating to 10 Hz, increasing to approximately 0.20 kg when reaching 45 Hz.

Consequently, depending on the selected operating frequency, the expected technological benefit of the proposed digital control system ranges from 0.04 to 0.20 kg of additional processed material during each transient process. These results confirm the practical effectiveness of the proposed approach and demonstrate the feasibility of applying digital control to electric drive systems of grain-cleaning machines.

5. Conclusion

The experimental results confirmed that the proposed digital control system based on the Modbus RTU communication protocol reduces the duration of transient processes by approximately three times compared with conventional analog control. In particular, the time required to reach the operating frequency of 45 Hz decreased from 3.45 s to 1.15 s.

The rapid response of the electric drive achieved through digital parameter transmission ensures stable screen vibration and a uniform airflow within the aspiration system. Consequently, unstable grain separation zones arising during operating mode transitions are significantly reduced, thereby improving the quality and purity of the cleaned grain.

The proposed control architecture is flexible and readily scalable, making it suitable for integration into automated smart grain-cleaning systems. Furthermore, the Arduino- and Modbus RTU-based platform

provides a reliable foundation for future implementation of closed-loop control using sensors for monitoring grain separation quality.

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МІКРОПРОЦЕСОРНА СИСТЕМА ЦИФРОВОГО КЕРУВАННЯ ЕЛЕКТРОПРИВОДАМИ РОБОЧИХ ОРГАНІВ ЗЕРНООЧИСНИХ МАШИН

У статті розглянуто розробку та експериментальну апробацію цифрової системи керування електроприводами робочих органів зерноочисних машин на основі перетворювача частоти SAKO SKI780, мікроконтролерної платформи Arduino Uno та протоколу зв'язку Modbus RTU. Запропонована система спрямована на підвищення точності, гнучкості та надійності керування електроприводами під час виконання технологічних операцій очищення і сепарації зернового матеріалу. Представлено структурну архітектуру системи, принципи взаємодії її основних апаратних компонентів, алгоритм формування та передавання керуючих команд через інтерфейс RS-485, а також програмну реалізацію мікропроцесорної системи керування.

Особливу увагу приділено забезпеченню стабільного та надійного обміну даними між мікроконтролером і перетворювачем частоти, а також формуванню керуючих сигналів для регулювання частоти обертання та інших робочих параметрів електроприводу. Розроблене програмне забезпечення дає змогу задавати необхідні режими роботи, передавати команди керування, обробляти інформацію зворотного зв'язку та координувати функціонування окремих робочих органів машини. Експериментальні дослідження підтвердили стабільність роботи системи та її здатність точно відтворювати задані режими за різних умов навантаження.

Встановлено, що застосування цифрового керування дає змогу скоротити тривалість перехідних процесів порівняно з традиційними аналоговими методами, що позитивно впливає на стабільність електроприводу та якість сепарації зерна. Розроблена система забезпечує гнучке регулювання швидкості обертання та можливість централізованого керування окремими робочими органами. Подальший розвиток системи передбачає інтеграцію датчиків якості зерна, навантаження електроприводів і потоку матеріалу для реалізації адаптивних алгоритмів керування. Отримані результати створюють основу для підвищення енергоефективності, надійності та технологічної ефективності зерноочисних машин.

Ключові слова: *сепарація зерна, частотний перетворювач, RS-485, Arduino, асинхронний електропривод, Modbus RTU, зерноочисна машина.*

Рис. 4. Літ. 20.

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