UDC 621.3.04:631.81:004.8
DOI: 10.37128/2520-6168-2025-4-17

MECHATRONIC DRIVE OF A SCRAPER CONVEYOR AS AN INTEGRATED MODULE OF POWER ENGINEERING, AUTOMATED AND INFORMATION-CONTROL SYSTEMS

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The article examines the application of mechatronic principles using scraper conveyors as an example, which are among the key mechanisms for transporting bulk materials in the agro-industrial sector and industry. The authors propose the structure of a scraper conveyor as a mechatronic module that integrates mechanical, electromechanical and electronic components, which ensures high reliability, productivity and flexibility of the system as a whole. Special attention is paid to the use of two-speed induction motors, which makes it possible to implement a staged start-up of the conveyor: first at low speed for smooth acceleration and reduction of inrush currents, and then at the rated high speed to provide the required throughput and optimize energy consumption. This approach significantly reduces overloads of the mechanisms, increases the energy efficiency and service life of the equipment, and also reduces the likelihood of emergency situations.

The paper provides a detailed analysis of functional control schemes for the conveyor drive and start-up algorithms, including adaptive solutions that take into account variable load, material type and operating conditions. The interaction between the electronic control system and the mechanical components of the conveyor is analyzed, which ensures optimal load distribution on the gearbox, traction elements and drive mechanisms, and also enables in-depth diagnostics of the equipment condition and planning of preventive maintenance. Such integration increases the productivity, reliability and durability of the scraper conveyor and contributes to the efficient use of energy resources with minimal operator involvement.

The abstract emphasizes the interdisciplinary nature of the research: the combination of knowledge in power supply, electrical technologies, automation, electronics, digital circuitry, information technologies and application software makes it possible to create a comprehensive mechatronic control system that can be implemented in modern agro-industrial and industrial production processes. The proposed solution demonstrates the possibility of integrating automated and information-controlled components into transport systems to increase their adaptability, energy efficiency and operational safety. The obtained results may be useful for engineers, researchers, developers and technical specialists involved in the design, implementation and operation of automated bulk-material conveying systems in agriculture, the agro-industrial sector and industry in general. They provide practical recommendations on the integration of mechanical, electromechanical and electronic components within a single mechatronic module, as well as on the optimization of start-up algorithms and control of conveyor drives. In addition, the research findings can be used to improve the energy efficiency, productivity and reliability of transport systems, reduce maintenance costs and extend equipment lifetime.

They are also of considerable value to university lecturers and students who study mechatronics, automated power systems, modern methods of controlling electrical equipment, as well as digital and information technologies in industry. Using the obtained results in the educational process makes it possible to develop practical competencies in the design of integrated automated systems, in the analysis of their dynamic characteristics, and in the development of algorithms for adaptive control and equipment diagnostics.

Article received 24.10.2025. Article accepted 08.12.2025. Article published 25.12.2025.

In addition, the results may be useful for research groups and scientific laboratories involved in improving transport equipment, implementing intelligent control systems, and optimizing energy consumption in production processes. The interdisciplinary approach makes it possible to combine knowledge of power supply, electrical technologies, automation, electronics, digital circuit design, information technologies and application software, which contributes to increasing the efficiency and innovation potential of industrial and agro-industrial systems.

The research results not only enhance the scientific and technical level of knowledge in the field of mechatronics and automation, but also create a practical foundation for the development of modern, integrated and highly efficient automated material transportation systems.

Key words: *two-speed conveyor, mechatronic module, functional diagram, start-up algorithm, adaptive control, electronic control system, staged start-up, integrated automated systems, energy efficiency, mechanism condition diagnostics.*

Eq. 2. Fig. 3. Ref. 15.

1. Problem formulation

Scraper conveyors are widely used for transporting bulk materials in agro-industrial and industrial processes, but conventional drive systems and first-generation control devices do not ensure optimal start-up and operation under variable loads and changing operating conditions. In practice, the transition from low to high speed in two-speed conveyor drives is often implemented by a purely time-based criterion, without considering the actual loading of the conveyor, which can cause untimely switching, increased dynamic loads in the gearbox and traction elements, and overloads (up to motor stalling). As a result, energy losses, accelerated wear, unplanned downtime and the risk of emergency situations increase.

Therefore, the engineering problem is to develop and justify a scraper conveyor drive as an integrated mechatronic module that combines mechanical components, a two-speed induction motor, and an electronic control system with adaptive start-up and operating algorithms. The solution must (I) reduce inrush currents and mechanical shock loads during start-up, (II) provide reliable switching from low to rated speed based on informative criteria (time/current/speed and other monitored parameters), (III) enable diagnostics of the technical condition of key assemblies, and (IV) improve energy efficiency, reliability and service life of the conveyor under real operating conditions.

2. Analysis of recent research and publications

Recent publications confirm the growing role of intelligent and automated power-engineering solutions in agro-industrial systems, including approaches to increasing reliability and efficiency of electric power complexes and autonomous energy supply systems for agricultural facilities. In particular, studies address hybrid and autonomous power supply architectures, as well as intelligent control concepts aimed at improving reliability and operational efficiency of energy systems in agriculture. [1–5]

A separate direction is the optimisation of electricity generation and management in combined power systems, along with comprehensive educational and methodological works that systematise approaches to electrification, automation, and energy security in the agro-industrial sector. These sources provide a methodological basis for integrating electric drives, automation and power-engineering subsystems into unified architectures. [6–9]

Mechatronics as an interdisciplinary field has expanded the practical toolkit for integrating mechanical systems with electronic, microprocessor and information-control components. Modern textbooks and studies describe principles of mechatronic system design, digital control, diagnostics, and integration of sensors and protective elements, which are directly applicable to conveyor drives. [10,11]

In the scientific literature, increasing attention is paid to parametric synthesis and substantiation of operating modes for mechatronic (and adaptronic) functional modules in conveying and dosing systems. These works emphasise the importance of modelling, parameter selection, and control algorithm design with feedback based on measured process variables–an approach aligned with adaptive conveyor drive control. [12,13]

International research also presents developments of innovative conveying equipment and analyses of how drive modes affect dynamic behaviour of scraper conveyors. Such studies support the relevance of staged start-up and advanced control to reduce dynamic loads and improve reliability, especially in short-distance and on-board scraper conveyor configurations. [14,15]

At the same time, the reviewed sources show that, despite the progress in intelligent energy systems and mechatronic design, the practical problem of implementing an integrated mechatronic module for scraper conveyors–where a two-speed induction motor, protective sensors, and an electronic control system jointly realise an adaptive start-up and operating strategy with diagnostics of key assemblies–requires further development and system-level substantiation. This determines the need for the research presented in this article. [10–15]

3. The purpose of the article

The aim of this work is to develop and substantiate the concept of a scraper conveyor as an integrated mechatronic module that combines mechanical, electromechanical and electronic components in order to increase the productivity, reliability and energy efficiency of transport systems. Special attention is paid to the implementation of two-speed induction motors and adaptive start-up algorithms for the drives, which makes it possible to optimize conveyor operation under variable loads and different operating conditions [4].

The research is focused on creating a comprehensive control architecture that ensures real-time monitoring of drive operating parameters, prediction of the technical condition of the equipment, and planning of preventive maintenance. An important task is the integration of automated and information-controlled components to enhance the adaptability, durability and operational safety of the scraper conveyor.

The aim also includes the development of practical recommendations on the integration of mechanical, electromechanical and electronic components into a single system, as well as on the optimization of start-up and drive control algorithms, which can be used both in research activities and in industrial and agro-industrial practice.

4. Results and discussion

The control systems of the first-generation scraper conveyors were capable of providing basic electrical protection of the electric drives, monitoring their operating state, and interlocking in the event of fault conditions. However, with regard to the optimization of start-up and operation of two-speed conveyors, these devices had a number of significant limitations. The main drawback of such systems was that the criterion for switching from low to high speed was solely time-based. The actual loading of the conveyor was not taken into account, which led to untimely switching to the rated speed and the occurrence of overloads in the transmissions and electric drives, up to the potential stalling of the motors. In addition, overcurrent protection of the motors was activated only after the current reached its maximum threshold level, which substantially reduced the reliability of the electrical equipment. A number of essential protections for monitoring the parameters of the drive gearboxes and electric motors were also lacking, and the indication functions of the devices were limited and provided low information content.

In this regard, the need arose to develop new control systems whose principal functions, in addition to ensuring standard protections and interlocks for the electric drives, would include providing a maximally rational and optimal start-up of the conveyor. This can be achieved by employing a dedicated switching algorithm for the drives based on both time and current magnitude, which makes it possible to reduce dynamic loads on the conveyor elements during start-up and to increase the service life of the equipment.

The study of the interaction between the mechanical, electrotechnical and electronic components of the conveyor drive belongs to a new interdisciplinary field of science–mechatronics. Mechatronics, which has been intensively developing in recent years, is based on the synergetic integration of mechanical systems with electronic and computer components. It enables the design and manufacture of qualitatively new machines, modules and systems featuring intelligent control of their functional motions. One of the key aspects of mechatronics is the integration of informational and diagnostic capabilities into the mechanical part of the controlled object, which allows the condition of assemblies to be monitored and their behaviour to be predicted in real time.

In the design of two-speed electric motors for scraper conveyors, it is advisable to employ two-level PTC-type thermal sensors: the first level providing emergency and interlocking functions, and the second level providing warning and corrective functions. This makes it possible to form a protective current-time characteristic of the motor and to prevent its start-up in an overheated state. The controlled parameters also include deviations of the drive sprocket speed from its nominal value and the current drawn by the drive motors. Information on these parameters makes it possible to assess the condition of the conveyor drive and its working element.

The application of mechatronic principles in the design of a scraper conveyor as an integrated module makes it possible to transfer a substantial share of functional tasks to an electronic control system implemented on the basis of microprocessor technology. This, in turn, enables operating modes of the conveyor to be modified without significant financial costs by means of programming, taking into account the length of the transport line, installation angle, magnitude of the material flow and the number of drives. Such an approach reduces dynamic loads in the transmission, increases the reliability and service life of the conveyor's components and mechanisms, and lowers the probability of fault conditions, which is particularly important for safe and stable operation under agro-industrial production conditions.

The start-up algorithm for the two-speed scraper conveyor is shown in Figure 1.

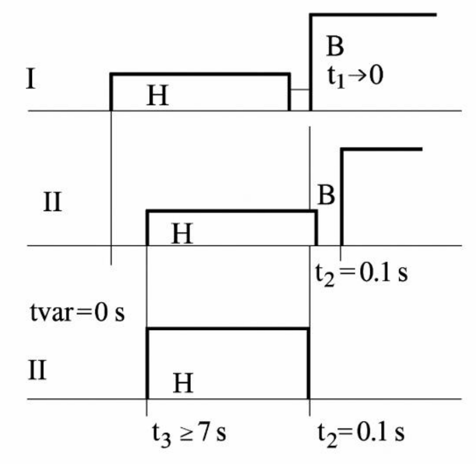

Fig. 1. Start-up algorithm for the two-speed scraper conveyor:
I – speed switching of the tail conveyor drive; II – speed switching of the head conveyor drive;
H – operation of the electric drive at low speed; B – operation of the electric drive at high speed

Let us consider the functional relationship between the control system of the mechatronic module, the other components and the feedback elements (sensors) during the start-up period of the conveyor.

The following quantities are used as information signals:

- temperature sensors of the limit level of the head (t_1H) and tail (t_1T) electric drives;
- temperature sensors of the warning level of the head (t_2H) and tail (t_2T) electric drives;
- temperature sensors of the limit value of the drive gear units of the head (*tRH*) and tail (*tRT*) drives;
- flow rate of the cooling liquid for the head (*PH*) and tail (*PT*) conveyor drives;
- current consumed by the head (*IH*) and tail (*IT*) drives;
- angular velocity of the drive (ωr);
- monitoring of the traction element performed by a sensor (*S*), whose output-signal frequency (*f*) is proportional to the conveying speed.

If we conventionally denote:

VHL – switching on the head drive at low speed;

VHH – switching on the head drive at high speed;

VTL – switching on the tail drive at low speed;

VTH – switching on the tail drive at high speed;

then the functional dependence describing the switching-on of the conveyor at low speed will have the form:

$$\begin{pmatrix} S_3 = 1 \\ t_{1\Gamma}, t_{1X} = 0 \\ t_{2\Gamma}, t_{2X} = 0 \\ t_{P\Gamma}, t_{PX} = 0 \\ P_\Gamma, P_X = 1 \\ T_1 = 0 \end{pmatrix} \Rightarrow V_{TL} = 1 \begin{pmatrix} V_{TL} = 1 \\ t_{1\Gamma}, t_{1X} = 0 \\ t_{2\Gamma}, t_{2X} = 0 \\ P_\Gamma, P_X = 1 \\ 0 < T_{X-\Gamma} \le 3 \end{pmatrix} \Rightarrow V_{HL} = 1 \quad (1)$$

The functional dependence of the conveyor transition to high speed has the form:

$$\begin{pmatrix} V_{TL} = 1 \\ V_{HL} = 1 \\ t_{1Г}, t_{1X} = 0 \\ t_{2Г}, t_{2X} = 0 \\ P_Г, P_X = 1 \\ I_Г, I_X \le 1{,}1 I_{\text{ном}} \\ \omega_Г \ge 0{,}85 \omega_{\text{ном}} \\ T_2 \ge 7c \end{pmatrix} \Rightarrow \begin{matrix} V_{TL} = 0 \\ V_{TH} = 1 \end{matrix} \begin{pmatrix} V_{HL} = 1 \\ V_{TH} = 1 \\ t_{1Г}, t_{1X} = 0 \\ t_{2Г}, t_{2X} = 0 \\ t_{PГ}, t_{PX} = 0 \\ P_Г, P_X = 1 \\ T_3 \approx 0{,}1c \end{pmatrix} \Rightarrow \begin{matrix} V_{HL} = 0 \\ V_{HH} = 1 \end{matrix} \quad (2)$$

The structural diagram of the scraper conveyor considered as a mechatronic module can be represented as shown in Fig. 2.

The structural diagram of the scraper conveyor drive as a mechatronic module demonstrates the integration of mechanical, electromechanical and electronic components into a single system that provides efficient conveyor control under various operating conditions. The main purpose of constructing such a diagram is to increase the productivity, reliability and service life of the equipment and to minimise dynamic loads that occur during start-up and shutdown of the conveyor [12].

The central element of the diagram is the control unit CU, which generates the control voltage for the head and tail drive motors. The CU processes information flows S1 and S2 coming from the control blocks CB2 of the head drive and CB1 of the tail drive, as well as the start command signal S3. On the basis of these data, the CU adjusts the operation of the electric drives, ensuring an optimal distribution of torque to the drive sprockets and minimisation of overloads in the mechanisms.

The conveyor drive motors are two-speed induction machines, which makes it possible to implement a staged start-up. At the first stage the motors operate at low speed, providing smooth acceleration of the conveyor and a reduction of inrush currents. This avoids significant impact loads on the gearboxes and mechanical components. After the system parameters have stabilised, the electronic circuitry automatically switches the motors to the rated high speed, which ensures the required capacity and energy efficiency.

The gearboxes of the head and tail drives transmit torque from the motors to the conveyor drive sprockets. Their design allows operation under variable load caused by fluctuations in the material flow or changes in material type. Integration of the gearboxes into the mechatronic module makes it possible to reduce dynamic overloads and to ensure stable drive operation regardless of conveyor length, inclination angle or number of drives.

The structural diagram includes sensors of drive operating parameters that monitor critical indicators of the electric drives and mechanisms. These include current sensors of the motors, temperature sensors of windings and bearings, rotational-speed sensors of the drive sprockets, and sensors of conveyor position or material volume. The information flows from the sensors are fed to the CU and used for adaptive real-time control of the electric drives.

The control blocks CB1 and CB2 perform local monitoring of the electric drives, controlling such parameters as current, temperature, speed and deviations from nominal values. When the permissible limits are exceeded, protection signals are generated that disconnect the motors from the supply until the fault is eliminated. This provides comprehensive protection and reduces the risk of emergency situations.

A key feature of the proposed structural diagram is the synergistic integration of all components into a single mechatronic system. [13]. The mechanical assemblies, gearboxes, electric drives and electronic control system operate as a unified entity, enabling adaptive response to changes in material flow, conveyor inclination and other operating conditions. This approach significantly reduces dynamic overloads and increases equipment life.

The diagram provides real-time monitoring and diagnostics of equipment condition, which makes it possible to plan preventive maintenance and to prevent failures. The information flows allow tracking of motor temperature, gearbox condition, current consumption and rotational speed, as well as adjusting control algorithms to ensure stable conveyor operation.

The proposed structure also allows external influences to be taken into account, such as non-uniform material flow, changes in material volume, conveyor length and inclination angle. This is achieved through the use of adaptive control algorithms that adjust motor voltage and rotational frequency, ensuring smooth conveyor operation and minimising mechanical overloads.

Practical tests have confirmed the high efficiency of the proposed system. The use of an integrated mechatronic module increases conveyor reliability, reduces energy consumption and shortens downtime in emergency situations. The adaptability of the system ensures stable operation even under variable operating conditions, which makes it suitable for use in the agro-industrial sector and in industry.

Thus, the structural diagram of the scraper conveyor drive as a mechatronic module provides a technical basis for the development of modern automated conveying systems. It ensures optimal drive control, a high level of protection and diagnostics, the ability to adapt to changing operating conditions, and a substantial increase in conveyor service life and productivity. The proposed diagram demonstrates the potential for integrating mechanical, electromechanical and electronic components into a single system to enhance the efficiency and safety of industrial and agro-industrial processes.

Integration of the electronic control system into the structural diagram of the scraper conveyor drive makes it possible to implement flexible software tuning of operating modes depending on different operating conditions. The system can take into account such parameters as transport-line length, conveyor inclination angle, material type and volume, and variations in feed rate. This allows the rotational speed of the motors, the value of the torque and the drive-switching algorithms to be adjusted so as to minimise dynamic loads on the gearboxes, traction elements and mechanical components of the conveyor. As a result, the durability and reliability of all parts of the mechanism are significantly increased, bearing and gear wear is reduced and the probability of failures during operation is decreased.

In addition, the electronic control system enables remote real-time monitoring of drive condition. The operator can obtain information on motor temperatures, current consumption, rotational speed of the drive sprockets, loads on the gearboxes and other critical parameters. If deviations from the normal operating mode occur, the system automatically generates alarm signals or blocks conveyor operation until the fault is eliminated, which improves safety and reduces the likelihood of equipment damage.

An important element of the system is the staged start-up of the drive, which makes it possible to avoid sharp impact loads on the mechanics and electric drives. At the first stage the conveyor accelerates at low speed, which reduces inrush currents and provides a smooth start. The system then automatically switches the drives to the rated high speed, maintaining the required capacity and stable operation. In combination with adaptive control algorithms that take into account variable load and the physical properties of the conveyed material, this ensures efficient, energy-saving and safe conveyor operation even under demanding conditions.

Owing to the integration of electronic control with mechanical and electromechanical components, a comprehensive mechatronic module is formed that operates as a single system. This approach not only increases reliability and productivity, but also provides flexible adjustment of operating modes in accordance with specific operating conditions. It opens up new possibilities for implementing automated conveying systems in industry and the agro-industrial sector, where adaptability, energy efficiency and operational safety are of crucial importance.

Furthermore, the use of an integrated electronic system enables preventive and predictive maintenance of the equipment. Data on the condition of motors, gearboxes and mechanical assemblies can be analysed automatically, allowing early detection of wear or overheating and the scheduling of repair work without stopping the conveyor. This not only reduces maintenance costs, but also increases the overall efficiency of the production process.

Consequently, the proposed structural diagram of the scraper conveyor drive as a mechatronic module represents a fully integrated system that effectively combines mechanics, electromechanics and electronics. It ensures a high level of reliability, stability and safety, adapts to different operating conditions, extends equipment life and reduces energy consumption. The use of such a system opens up wide prospects for the development of modern automated conveying lines in industry and the agro-industrial sector, providing efficient, safe and energy-efficient transportation of bulk materials.

For a clear representation of the operating principles and organisation of the mechatronic scraper-conveyor drive, the study presents structural diagrams illustrating the interaction of the main mechanical, electromechanical and electronic components of the system. They reflect the drive-operation logic, signal-transfer channels, staged start-up and adaptive-control algorithms, and include monitoring and protection elements that ensure stable and safe operation of the conveying equipment.

The diagrams show how the electronic control system is integrated with the drive motors, gearboxes and mechanical assemblies of the conveyor, providing optimal load distribution, remote monitoring of equipment condition and adaptive adjustment of operating modes as a function of external factors such as material flow and operating conditions.

By visually representing the relationships between the mechanical part and the control system, the diagrams make it possible to understand the operating principles of the conveyor as a single mechatronic module and highlight the role of information-controlled components in ensuring the energy efficiency, reliability and durability of the conveying equipment.

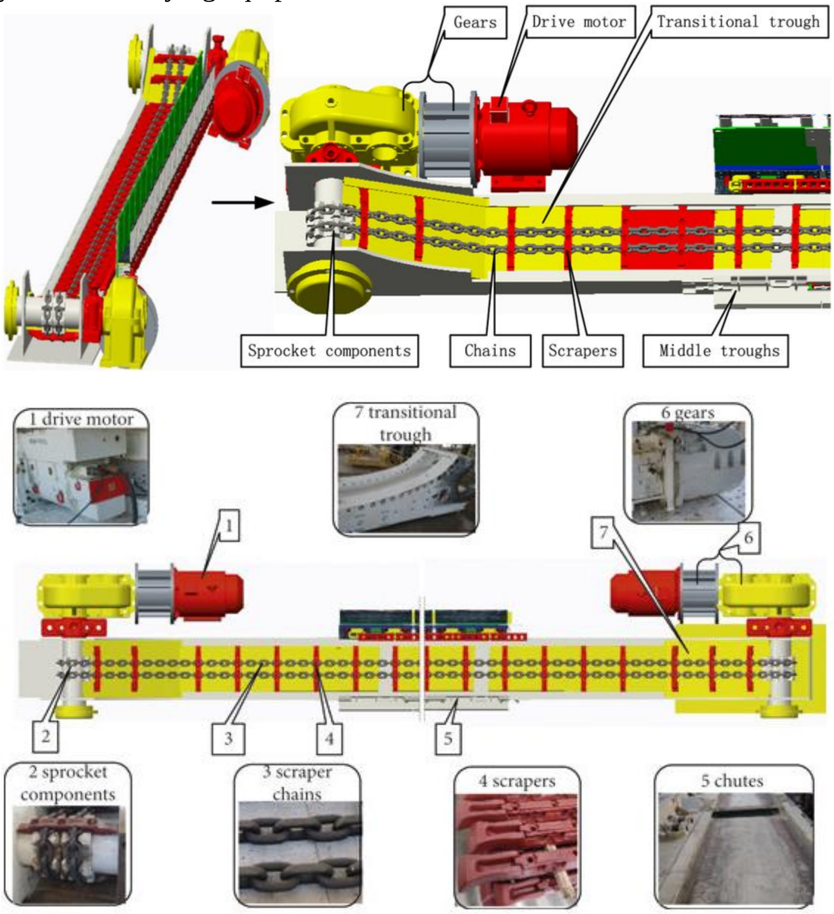

Fig. 2. Structural diagram of the scraper conveyor drive as a mechatronic module. The diagram illustrates the integration of electromechanical and electronic components, the staged start-up of the drive, signal paths from sensors, adaptive control algorithms and protective functions, and represents the operating principle of the conveyor as a unified automated and information-controlled system

Description of the diagram

1. In a typical configuration, the conveyor drive system includes an electric motor → gearbox → drive sprocket → scraper chain or belt element.
2. The drive is often complemented by a control block (current, temperature and speed sensors) and an automatic control system that provides monitoring and protection.
3. When modernising the system, two-speed induction motors or variable-frequency drives are used to implement staged start-up and adaptive load control [14].
4. Sensor information channels transmit signals to a controller (microprocessor or PLC), which supplies the control voltage/frequency to the motor, adjusts the operating mode, performs diagnostics and generates control actions for the gearbox.
5. The diagram takes into account an external factor–the material flow fed to the conveyor. Monitoring and correction of these parameters make it possible to reduce overloads of the chain, gearbox and motor.
6. Protection blocks (overload prevention, temperature monitoring, emergency shutdown) are integrated into the control system and operate in real time.

How this relates to the proposed module.

- In our scheme, the central element is the control unit (CU), which receives the information flows S1, S2 and S3 (sensor signals and the start command) and generates the control voltage U for the head and tail drive motors.
- This concept clearly corresponds to the typical scheme in which a controller governs the motors on the basis of sensor signals and the start command.

- The use of two-speed motors and staged start-up is also consistently reported in the literature (see item 3 above) [14, 15].
- The transition from the classical "mechanics + motor" configuration to a "mechatronic module" is clearly manifested through the inclusion of the electronic control system, sensors and adaptive interaction with the load conditions.

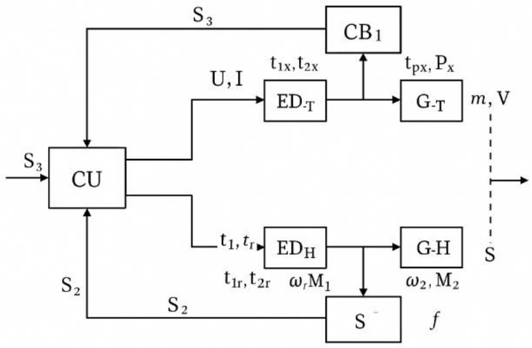

Fig. 3. Structural diagram of the scraper conveyor drive as a mechatronic module

The control unit (CU), by monitoring the information flows S1 and S2 coming from the control blocks CB2 of the head drive and CB1 of the tail drive, as well as the start command S3, generates the control voltage U supplied to the electric motors of the tail (ED_T) and head (ED_H) drives. Through the gearboxes G_T and G_H these drives create torque on the drive sprockets of the scraper conveyor. The conveyor is also affected by an external factor–the material flow, which determines changes in the incoming mass volume V. Using signals from various sensors, the CU adapts the operating modes of the conveyor to specific operating conditions, ensuring optimal torque distribution among all drives and minimising overloads.

The introduction of two-speed induction motors into the conveyor drive makes it possible to implement a staged start-up. The first stage–low speed–provides smooth acceleration of the mechanism and a reduction of inrush currents, which substantially decreases the load on the transmission and the power network. The second stage–the transition to the rated high speed–is performed after the actual load of the conveyor has been assessed and the torque parameters have stabilised, which makes it possible to achieve the required throughput and to increase the energy efficiency of the system. The information flows S1 and S2 provide continuous monitoring of the drive parameters, including motor current, rotational speed and temperature, which enables real-time detection of deviations from nominal values and adjustment of the control action.

An important function of the CU is adaptive control, which implements algorithms for adjusting the voltage and frequency of the electric drives depending on the variable material flow. When the material volume V changes, the control unit responds instantaneously by decreasing or increasing the torque on the drive sprockets so as to avoid impact loads and excessive wear of the transmission elements. This function increases the reliability and service life of the conveyor and reduces maintenance costs.

The system also provides in-depth diagnostics of the condition of the mechanisms. Using the information flows S1 and S2, the CU analyses the operating modes of the drives and identifies potential anomalies such as overcurrent, excessive heating and uneven load distribution. On the basis of these data, the system can generate warning signals and automatically adjust the operating modes, which significantly improves operational safety and prevents emergency situations.

Practical testing of the proposed solutions has confirmed the effectiveness of the integrated approach. Owing to the use of the CU as a central control element interacting with the mechanical, electromechanical and electronic components of the conveyor, it has been possible to achieve optimal load distribution between the drives, to reduce dynamic overloads on the gearboxes and to increase the overall stability of the system. In addition, the implementation of adaptive-control algorithms has ensured flexible response to changes in material flow, maintenance of the required throughput and improvement of energy efficiency [15].

Special attention has been paid to the integration of informational and diagnostic functions into the operation of the mechanical elements of the conveyor. Current, temperature and speed sensors enable continuous monitoring of the condition of the drives and assessment of gearbox performance. This creates opportunities for scheduled maintenance and prevention of premature equipment failure, which is essential for industrial production and agro-industrial complexes with high reliability requirements for conveying equipment.

Thus, the control unit CU, by monitoring information flows and adapting the operation of the scraper conveyor drives to variable operating conditions, acts as the key element of the mechatronic module. Its implementation increases conveyor productivity, reliability and service life, reduces energy consumption and creates the prerequisites for automated and safe operation of the conveying equipment.

5. Conclusion

The conducted research has confirmed the effectiveness of applying mechatronic principles to the design of the scraper conveyor drive as an integrated module. The proposed architecture makes it possible to combine mechanical, electromechanical and electronic components into a single system that ensures optimal torque distribution to the drive sprockets and minimises dynamic overloads during conveyor start-up and operation.

The use of two-speed induction motors and staged start-up reduces inrush currents, eliminates impact loads on gearboxes and mechanical units, and thus increases the energy efficiency and service life of the equipment. Adaptive control algorithms provide a flexible response to changes in material flow, conveyor inclination angle and material type, thereby enhancing the reliability and stability of the system.

Integration of the electronic control system enables remote monitoring of drive parameters, preventive and predictive maintenance, reduction of repair costs and a lower probability of emergency situations. The implementation of such a system promotes the development of highly efficient, energy-saving and safe automated conveying lines in industry and the agro-industrial sector.

The research results are of interdisciplinary significance and can be used in the educational process for training specialists in mechatronics, automation and power engineering, as well as in scientific and practical developments in the field of bulk-material conveying. The proposed concept forms the basis for further development of modern integrated control systems and enhances the innovation potential of production processes.

References

1. Stadnik, M. I., Shtuts, A. A., & Yelenych, A. P. (2025). Investigation of a method for ensuring autonomous power supply of a livestock farm based on combining basic and stochastic energy sources. *Vibratsii v tekhnitsi ta tekhnologiiakh*, *1*(116), 63–74. [in English].
2. Tokarchuk, O., Mytko, M., Tokarchuk, D., & Bahrii, V. (2024). Modern innovative technologies and materials for enhancing the efficiency of solar panels. *Engineering, Energy, Transport AIC*, *1*(124), 154–161. https://doi.org/10.37128/2520-6168-2024-1-16 [in English].
3. Stadnik, M., Shtuts, A., Kolisnyk, M., & Hryhorenko, N. (2025). Research on the implementation of intelligent systems to increase the reliability and efficiency of the operation of electric power complexes. *Engineering, Energy, Transport AIC*, *1*(128), 122–134. https://doi.org/10.37128/2520-6168-2025-1-14 [in English].
4. Stadnik, M. I., Hrytsun, A. V., & Protsenko, D. P. (2019). Method for covering the load schedule of a livestock farm in autonomous power supply based on biogas plants. *Engineering, Energy, Transport AIC*, *4*(107), 79–87. [in English].
5. Stadnik, M. I. (2018). Optimisation of the composition of generating equipment for autonomous power supply of a livestock farm using biogas. *Engineering, Energy, Transport AIC*, *2*(101), 81–88. [in English].
6. Rozen, V. P., Inshekov, Ye. M., & Kalinchyk, I. V. (2013). Optimisation of electricity generation processes in a combined power system. *Energetyka*, *1*, 20–26. [in Ukrainian].
7. Kaletnik, H. M. (2010). *Biofuel: Food, energy and economic security of Ukraine*. Khai-Tek Pres. [in Ukrainian].
8. Kaletnik, H. M., & Pryshliak, V. M. (2008). *Biofuels: Efficiency of their production and use in the agro-industrial complex of Ukraine*. Vinnytsia National Agrarian University. [in Ukrainian].
9. Martynenko, I. I., Lysenko, V. P., Tyshchenko, L. P., Bolbot, I. M., & Oliinyk, P. V. (2008). *Design of electrification and automation systems of the agro-industrial complex*. [in Ukrainian].
10. Antoshchenkov, R. V., Nanka, O. V., & Lebedev, A. T. (2020). *Mechatronic systems of automobiles and tractors*. [in Ukrainian].
11. Loveikin, V. S., Romasevych, Yu. O., & Krushelnytskyi, V. V. (2020). *Mechatronics*. [in Ukrainian].

12. Zaporozhets, O. V., & Volodin, S. O. (2024). Parametric synthesis of a mechatronic system for pneumatic conveying of bulk products. *Naukovi pratsi Natsionalnoho universytetu kharchovykh tekhnolohii*, *30*(4), 79–89. [in Ukrainian].
13. Havva, O. O., & Kryvoplias-Volodina, L. O. (2023). Substantiation of operating modes of adaptronic functional modules for weight-based dosing of liquid products. *Naukovi pratsi Natsionalnoho universytetu kharchovykh tekhnolohii*, *29*(5), 66–76. [in Ukrainian].
14. El-Kholy, M. M., & Kamel, R. M. (2021). Development and evaluation of an innovative grain cart with a pneumatic conveyor. *Heliyon*, *7*(11), e08461. https://doi.org/10.1016/j.heliyon.2021.e08461 [in English].
15. Gao, R., Zhang, H., Yang, L., Feng, Q., & Yuan, W. (2025). Research on the influence of driving mode on dynamic characteristics of on-board short-distance scraper conveyor. *International Journal of Mechatronics and Applied Mechanics*, *20*, 217–228. [in English].

МЕХАТРОННИЙ ПРИВОД СКРЕБКОВОГО КОНВЕЄРА ЯК ІНТЕГРОВАНИЙ МОДУЛЬ ЕНЕРГОТЕХНІЧНИХ, АВТОМАТИЗОВАНИХ ТА ІНФОРМАЦІЙНО-КЕРОВАНИХ СИСТЕМ

У статті розглянуто застосування принципів мехатроніки на прикладі скребкових конвеєрів, що є одним з ключових механізмів транспортування сипких матеріалів у агропромисловому комплексі та промисловості. Автори запропонували структуру скребкового конвеєра як мехатронного модуля, який інтегрує механічні, електромеханічні та електронні компоненти, що забезпечує високу надійність, продуктивність та гнучкість системи в цілому. Особлива увага приділена використанню двошвидкісних асинхронних електродвигунів, що дозволяє реалізувати поетапний запуск конвеєра – спочатку на низькій швидкості для плавного розгону і зменшення пускових струмів, а потім на робочій високій швидкості для забезпечення необхідної продуктивності та оптимізації енергоспоживання. Такий підхід суттєво зменшує перевантаження механізмів, підвищує енергоефективність і ресурс обладнання, а також знижує ймовірність аварійних ситуацій.

У роботі детально розглянуто функціональні схеми управління приводом конвеєра та алгоритми пуску, включаючи адаптивні рішення, що враховують змінне навантаження, тип матеріалу та умови експлуатації. Проаналізовано взаємодію між електронною системою керування та механічними вузлами конвеєра, що забезпечує оптимальний розподіл навантаження на редуктор, тягові елементи та приводні механізми, а також дозволяє проводити глибоку діагностику стану обладнання та планувати профілактичне обслуговування. Така інтеграція підвищує продуктивність, надійність і довговічність скребкового конвеєра та сприяє ефективному використанню енергетичних ресурсів при мінімальній участі оператора.

В анотації підкреслено міждисциплінарний характер дослідження: поєднання знань з електропостачання, електротехнологій, автоматизації, електроніки, цифрової схемотехніки, інформаційних технологій і прикладного програмного забезпечення дозволяє створити комплексну мехатронну систему керування, яка може бути впроваджена у сучасні агропромислові та промислові виробничі процеси. Запропоноване рішення демонструє можливість інтеграції автоматизованих і інформаційно-керованих компонентів у транспортні системи для підвищення їх адаптивності, енергетичної ефективності та безпеки роботи. Отримані результати можуть бути корисними для інженерів, науковців, розробників та технічних фахівців, які займаються проєктуванням, впровадженням і експлуатацією автоматизованих систем транспортування сипких матеріалів у сільському господарстві, агропромисловому комплексі та промисловості загалом. Вони надають практичні рекомендації щодо інтеграції механічних, електромеханічних та електронних компонентів у складі єдиного мехатронного модуля, а також щодо оптимізації алгоритмів запуску та управління приводами конвеєрів. Крім того, результати дослідження можуть бути використані для підвищення енергоефективності, продуктивності та надійності транспортних систем, зниження витрат на технічне обслуговування та збільшення ресурсу обладнання.

Вони також становлять значну цінність для викладачів і студентів вищих навчальних закладів, які вивчають мехатроніку, автоматизовані енергетичні системи, сучасні методи управління електротехнічним обладнанням, цифрові та інформаційні технології у промисловості. Використання отриманих даних у навчальному процесі дозволяє формувати практичні компетенції у проєктуванні інтегрованих автоматизованих систем, аналізі їх динамічних характеристик, розробці алгоритмів адаптивного керування та діагностики обладнання.

Крім того, результати можуть бути корисними для дослідницьких груп і наукових лабораторій, які займаються удосконаленням транспортного обладнання, впровадженням *інтелектуальних систем керування та оптимізацією енергоспоживання у виробничих процесах. Використання міждисциплінарного підходу дозволяє поєднувати знання з електропостачання, електротехнологій, автоматизації, електроніки, цифрової схемотехніки, інформаційних технологій і прикладного програмного забезпечення, що сприяє підвищенню ефективності та інноваційного потенціалу промислових і агропромислових систем.*

Результати дослідження не лише підвищують науково-технічний рівень знань у сфері мехатроніки та автоматизації, а й створюють практичну базу для розвитку сучасних, інтегрованих і високоефективних автоматизованих систем транспортування матеріалів.

***Ключові слова**: двошвидкісний конвеєр, мехатронний модуль, функціональна схема, алгоритм запуску, адаптивне керування, електронна система управління, поетапний запуск, інтегровані автоматизовані системи, енергоефективність, діагностика стану механізмів.*

Ф. 2. Рис. 3. Літ. 15.

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