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AUTOMATIC WAGON LOADING CONTROL SYSTEM USING INDUSTRY 4.0 TECHNOLOGIES

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Abstract. *Purpose: the development of a system for automatic control of car loading, which will be able to combine separate nodes into one common system to ensure greater control and reliability of the process. Research methods are grapho-combinatorial. Methodology: the research is justified by a logical synthesis based on the hardware of embedded control systems, programming in the language of functional blocks of the MEK61131-3 standard. Results: the requirements for the structure of the automation system of coal loading complexes were formulated, the basic automation equipment was selected, and the control algorithms were determined. Based on the requirements for the automation system, a functional scheme and its technical implementation of the automation of coal loading complexes as a single control system were developed. The algorithm was developed and subsequently the SAC program of the local system was developed, which was able to show its performance in the "Owen Logic" environment. This made it possible to adjust and select the correct coefficients and possible calculated data. Scientific novelty: the development of a functional model of the coal loading complex and the use of wireless communications, aimed at combining fragmented local systems into one common one to ensure greater control and reliability of the process. Practical significance: the functional and structural model of the coal loading complex will allow to increase its level of automation, reliability and efficiency of operation, to eliminate the shortcomings of the technical fragmentation of the system and to prevent significant material, time and economic costs for setting up the system.*

Анотація. *Мета: розробка системи автоматичного контролю завантаження вагонів, яка зможе об'єднати окремі вузли в одну загальну систему для забезпечення більшої керованості та надійності процесу. Методи дослідження графо-комбінаторні. Методологія: дослідження обґрунтовано логічним синтезом на основі апаратних засобів вбудованих систем керування, програмування мовою функціональних блоків стандарту МЕК61131-3. Результати: сформульовано вимоги до структури системи автоматизації вугленавантажувальних комплексів, обрано базове обладнання автоматизації та визначено алгоритми керування. На підставі вимог до системи автоматизації розроблено функціональну схему та її технічну реалізацію автоматизації вугленавантажувальних комплексів як єдиної системи керування. Був розроблений алгоритм і згодом розроблена програма SAC локальної системи, яка змогла показати свою продуктивність у середовищі «Owen Logic». Це дозволило налаштувати та підібрати правильні коефіцієнти та можливі розрахункові дані. Наукова новизна: розробка функціональної моделі вугленавантажувального комплексу та використання бездротового зв'язку, спрямована на об'єднання фрагментованих локальних систем в одну загальну для забезпечення більшої керованості та надійності процесу. Практичне значення: функціонально-конструктивна модель вугленавантажувального комплексу дозволить підвищити рівень його автоматизації, надійності та ефективності роботи, усунути недоліки технічної роздробленості системи та запобігти значним матеріальним, часовим та економічним витратам на налаштування системи.*

Keywords: automatic control system, algorithm, programming, wireless communication, controller.
Ключові слова: система автоматичного керування, алгоритм, програмування, бездротовий зв'язок, контролер.

1. Introduction

In the modern world, much attention is paid to the development of the coal mining industry, but it faces the problems of improving the quality of automated processes and reducing the human presence in the technological process, the efficiency of the use of transport and technological equipment.

Shipment of coal to consumers is the final stage of mine operation. Coal loading is carried out through a coal loading point where coal is supplied from storage bunkers or from coal warehouses on the surface of the mine.

In addition to quality control, shipped coal is subject to quantitative control, which is of a commercial nature when calculating consumers with a mining enterprise.

The main type of external transport of coal from mines is railway transport.

In order to achieve an increase in the efficiency of coal loading complexes, a number of measures have been created to improve the process of loading coal into railway cars. From the obtained results, automated coal loading complexes appeared.

The mandatory presence of such installations is due to the growth of coal consumption, and therefore of coal mining sites, due to which it is necessary to increase the quality level of coal loading by fully automating the loading process.

2. Literature Analysis

An analysis of modern models of coal loading complexes [1-2] was performed, an analysis of automation in metallurgy was performed [3-4], an analysis of data transfer in automation systems was performed [5-6].

3. Object, Subject, And Methods Of Research

The facility is a coal-loading complex that can combine individual units into one common system to provide greater process control and reliability. The subject of research is an automatic control system. The conducted research was based on the general provisions of the theory of automatic control and the theory of designing computerized systems using Industry 4.0 technologies.

4. Result

Existing systems of automated control of coal loading of wagons have certain shortcomings that complicate the process of maintenance and analysis of the system. The system is divided into separate nodes that work separately and do not communicate with each other. This shortcoming does not allow full control of the loading process, which in turn leads to a decrease in productivity and an increase in crashes.

Based on a detailed analysis of the coal loading system and the conclusions drawn in the previous section, I propose to develop a SAC that can combine individual nodes into one common system to ensure greater control and reliability of the process.

The basis of the designed system is the principle of control and transmission of information of individual nodes using a cloud service with subsequent transmission of information to the dispatcher's console and control of these nodes using a programmable logic controller. Using a cloud service will allow us to transmit information wirelessly, so we can reduce the cost of resources for a wired connection. And the controller will make it possible to build a distributed control and dispatching system that can be used within the framework of one device.

Functional diagram of SAC. For the design of the modernized SAC of the coal loading complex, a functional scheme was developed, which is shown in figure 1.

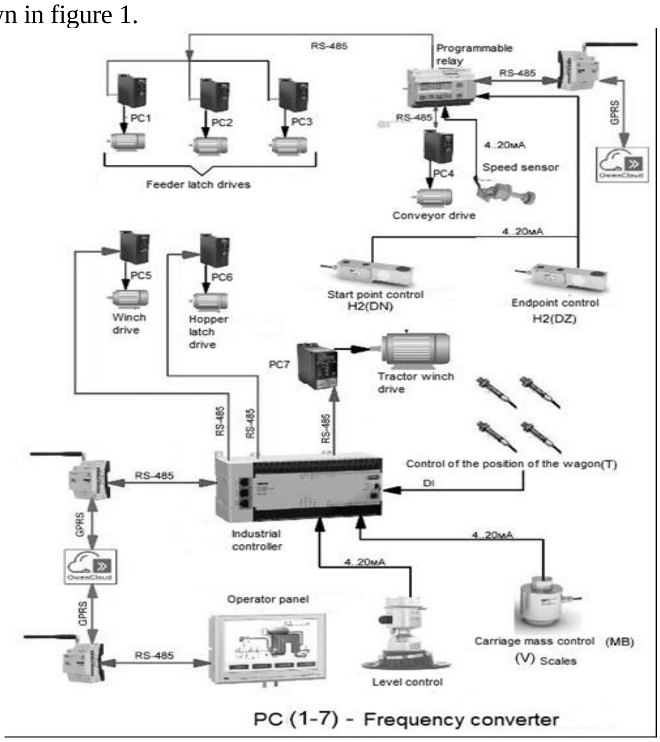


Fig. 1. Functional diagram of the modernized automatic control system

The developed SAC should ensure automatic loading of the wagon by volume and weight, uniform distribution of the coal "cap" in the wagon, reading of data from all sensors, unification of nodes of the coal loading complex into a single automated system in order to have the possibility of automatic adjustment of the loading process during the loading process.

In order to find the optimal parameters, such as the speed of the conveyor belt, the opening angle of the feeder valve and the drive speed of the tractor winch, it is necessary to know the actual values of the weight of the car and take into account the level of occupancy of the car. We measure the mass of the wagon with the help of a strain gauge built into the track scale to calculate the mass of the wagon by software. This is necessary for reporting on the weight of the cargo. A conveyor speed sensor is required to control belt slippage. The initial (DN) and final (DZ) position of the conveyor is determined by strain gauges installed on the conveyor belt. We use a level sensor to measure the level of occupancy of the car. Inductive sensors are necessary to record data about the position of the car. In this way, the data from the strain gauge in a pair with the inductive ones make it possible to adjust the speed of the winch drive. The data from the strain gauges (DN) and (DZ) together with the data on the mass and occupancy level of the car adjust the speed of the conveyor belt. The opening angle of the feeder shutter is adjusted based on the output data from the tape speed sensor, i.e. the higher the speed, the more the feeder shutter opens.

The basis of the system is a programmable logic controller. It takes over all the calculations of the data it receives from the sensors, i.e. it calculates the mass, loading level and speed. Based on the received calculations, the PLC issues tasks for all control mechanisms. The controller has frequency converters, a programmable relay and an operator panel for outputting information. For frequency converters, the frequency calculated by the controller is set. The programmable relay is a separate subsystem that also communicates with the frequency converter and receives and processes information from the sensors.

Development of SAC algorithms. The development of algorithms for the automatic control system of the coal loading complex is necessary for writing software and creating a single system based on an industrial controller. Algorithms are developed on the basis of the requirements for the automatic control system described above in the work and the created and described modernized functional scheme with all selected equipment.

The development of algorithms of the main system and the local system is expected. The main system is controlled by PLC160 controller.

The local system is based on a programmable relay and controls the feeder valves and the conveyor drive. An application will be created in the OwenLogic environment for the local system.

To begin with, it is necessary to describe how the system works as a whole in order to create block diagrams of algorithms for further development of the control system. In the functional diagram, which is presented in the previous section in Figure 1, the process begins with the operator's panel, where it is necessary to choose the control mode, manual (manual is necessary for rolling back the system) or automatic. In automatic mode, the start signal from the operator panel is output via RS485, then the signal is converted using the PM210 network gateway and then transmitted to the PLC160 industrial controller. In the next step, the PLC160 processes the signal and issues the corresponding command to the frequency converter (IF7), which controls the winch drive to start the movement of the railway stock. After the operation of the first pair of inductive terminals, which are installed behind the fixing supports, the signal is transmitted to the controller and the input to the frequency converter (IF7). The frequency converter (IF7) reduces the speed of the drive by reducing the frequency by software with the command word received from the PLC160. When the second pair of inductive sensors are activated, the signal from them and the strain gauge (MV) will be processed by the PLC and provide information to the operator's panel regarding the weight of the car and readiness for loading.

The signal from the PLC is fed to the programmable relay through the network gateway, the relay receives and processes the signal and outputs it to the frequency converter (IF4), which starts the conveyor, and later sends signals (IF1), (IF2), (IF3) that control the actuators of the feeder valves. At the same time, the programmable relay receives signals from the speed sensor of the conveyor belt and strain gauges (DN), (DZ) and, based on these data, regulates the speed of the conveyor belt and the opening of the feeder valves.

As soon as the signal from the strain gauge (DN) becomes zero, the PR200 will send a signal to the PLC160, which will start the drive of the roller winch (PC5) to form the wagon cap.

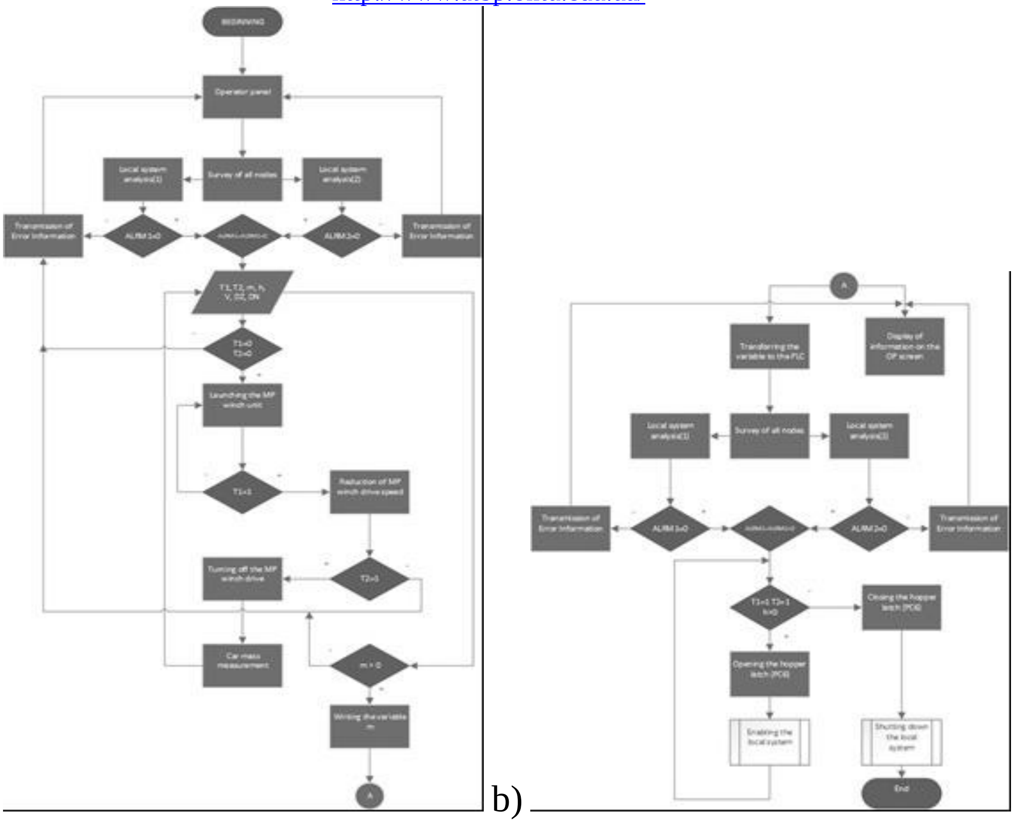
After the activation of the level sensor and the strain gauge (MV), the PLC transmits a signal to (IF6) to close the hopper valve, and to stop the supply of coal to the hopper to the programmable relay, which in turn first closes the feeder valves, and then stops the conveyor.

The signal to stop the conveyor and close the shutters is sent to the PLC, which in turn starts (PC7) the drive of the winch, which pulls up the next wagons for loading.

The block diagram shown in Figure 2 (a) describes the algorithm by which loading into railway cars is performed. The beginning of the program begins with a survey of all control nodes and analysis of local systems, which include systems controlled by PLC160 and PR200. If an error was detected, the system transmits the error code to the operator panel, where the operator then makes a decision to eliminate the error. If no errors are detected and the output signal ALM1 and ALM2 are equal to zero, the system proceeds to the next step. Next, the system records initial data from all sensors connected to the system. These are data from inductive sensors, weight data, data from a level gauge and strain gauges. Then there is a check for the absence of a car on the filling platform, this is necessary in order to avoid a collision. After the inspection, the process of adjusting the wagon under the filling hopper with the help of a maneuvering device begins. After turning off the shunting device, the weight of the wagon is measured and the next step of filling the wagon is carried out.

The next step of the algorithm is the transfer of the already defined variables to the PLC and the output of the corresponding information on the readiness of filling the railway stock on the operator panel.

Similarly to the previous step, all nodes are polled and local system data is compared. In the event that no errors are detected, the transition to the step where the received signals are compared and the hopper valve control unit is started, after which the transition to the local system follows.



a) b)

Fig. 2. Block diagram of the main program: a – the algorithm of loading into railway cars, b – the algorithm of loading into railway cars (continued)

The development of the program for the local system of the coal loading complex will take place in the OwenLogic environment. First of all, this is due to the fact that almost the entire automatic control system is built on the basis of devices from the "ARIES" company, it is also a fairly convenient tool for building a SAC.

The programming language that will be used in the environment is the language of functional blocks that meets the MEK61131-3 standard.

The system of automatic control of wagon loading uses a number of drives, namely electric motors under the control of frequency-vector converters (FVC).

To set the engine speed, the control unit calculates based on engine data and input signals.

The formula for calculating the output frequency for frequency converters that control feeder gate drives. The frequency for FVC 1 is calculated by the formula:

$$\omega_1 = ((2 \cdot \vartheta_1) \cdot P_n) \div 100 \quad (1)$$

where, ϑ_1 – speed from the first sensor; P_n – the starting case of the task; ω_1 – output frequency for FVC 1.

The frequency for FVC 2 is calculated by the formula:

$$\omega_2 = ((3 \cdot \vartheta_2) \cdot P_n) \div 100 \quad (2)$$

where, ϑ_2 – speed from the first sensor; P_n – the starting case of the task; ω_2 – output frequency for FVC 2.

The frequency for FVC 3 is calculated by the formula:

$$\omega_3 = ((4 \cdot \vartheta_3) \cdot P_n) \div 100 \quad (3)$$

where, ϑ_3 – speed from the first sensor; P_n – the starting case of the task; ω_3 – output frequency for FVC 3.

Given the output frequency and a properly configured frequency converter, we can obtain the rotational speed as a function of frequency. The rotation speed is calculated by the formula:

$$\vartheta_i = (N_m \div 100) \cdot \omega_i \quad (4)$$

where, ϑ_i – the rotation speed of the motor in rpm of the i-th converter, where “i” is from 1 to 3; N_m – nominal engine revolutions per minute; ω_i – the output frequency of the i-th converter, where "i" is from 1 to 3.

To start working in the environment, it is necessary to create a new project and select a model range of the device.

After creating a new project, you need to create variables that will be used when writing the program.

Among the input variables that come to the programmable relay from the sensors, we record the speed with the integral variable type, final (DN) and (DZ) with the Boolean variable type.

It is also necessary to add variables that will be used by the network gateway, frequency converters.

The next step is to create a frequency converter control unit. Since the program does not provide for such a functional block, we will create it ourselves.

The program turns out to be very cumbersome, so the FVC control unit (PCV) was compiled into a macro.

It is necessary to add four more FVC control blocks (PCV1-4) to the program, and create one for each task.

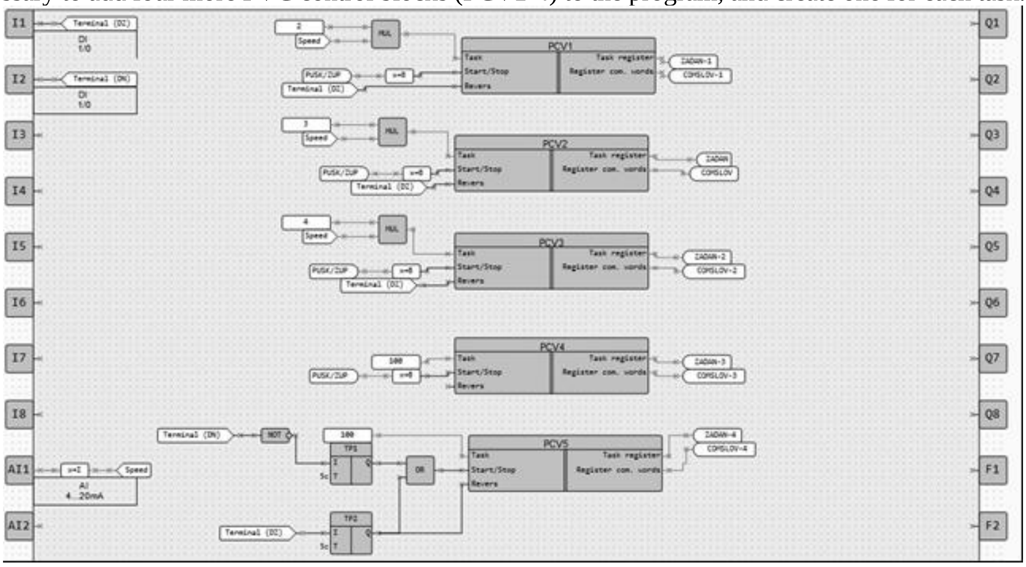


Fig. 3. Program for local system

Figure 3 shows the control program for the local system. On it, we can see the tasks for each PCV macro. For PCV(1-3) we use the following principle, when the signal from the speed sensor (AI1) arrives, we convert it into an integer and feed it to the MUL multiplication block, here we feed the multiplication factor, which depends on the angle at which the valves will open. The shutter is closed after the end (DZ) is triggered.

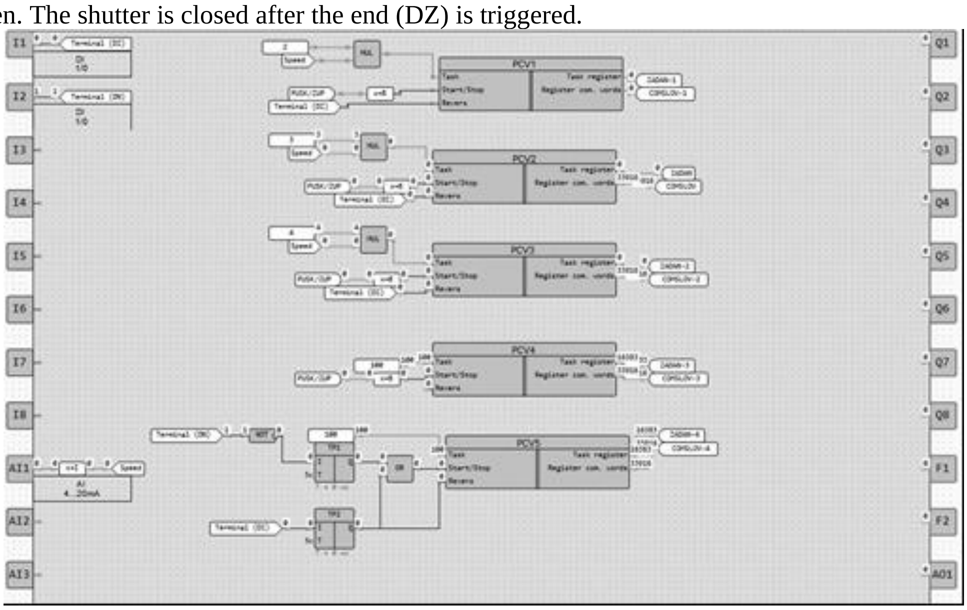


Fig. 4. Start of the program

Frequency converter number four has a constant frequency of operation and is controlled by the network variable PUSK/ZUP, PCV5 is responsible for the roller winch, which is started after disconnection of the end (DN) with a signal delay of 5 seconds. This is necessary so that the winch has time to move to the required distance.

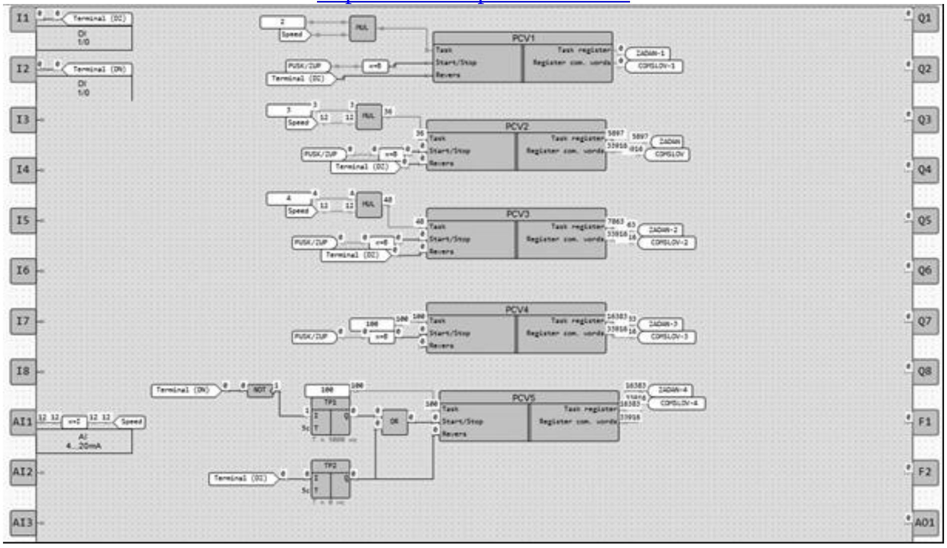


Fig. 5. Operation of the program when the signal is applied (AI1)

Figure 6 shows the debugged and simulated wagon loading program after a series of serviceability tests. The program worked stably, no errors were detected, and the obtained data satisfy the conditions of the algorithm of the entire scheme.

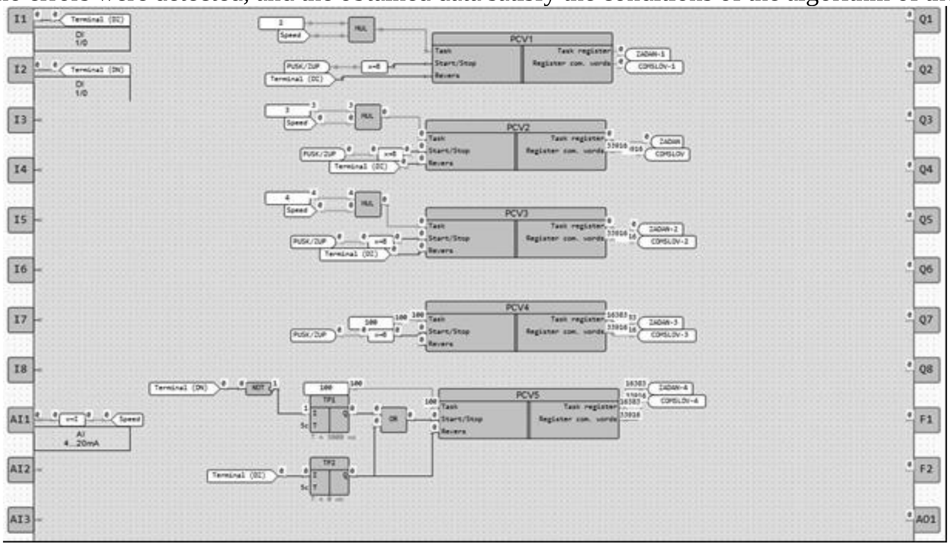


Fig. 6. The end of the program

5. Conclusions

A system of automatic control of the coal loading complex was developed and studied, which will be able to combine individual nodes into one common system to ensure greater control and reliability of the process. A modernized functional scheme of the SAC of the coal-loading complex was developed, and a set of hardware was selected for the technical implementation of the system. Algorithms for loading wagons for the local and main system under the control of a programmable relay and an industrial controller have been developed. A program based on modernized wagon loading algorithms was developed in the OwenLogic programming environment in the language of the MEK61131-3 standard.

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