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Proactive system for controlling the speed of movement of the coal cleaning combine in the conditions of the Arctic region

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Abstract. This work is devoted to the topical issue of managing complex process equipment, using the example of a coal cleaning combine used in the mining industry of the Arctic zone of the Russian Federation. The article presents an approach to the implementation of an automated system of proactive control of the speed of movement of the coal cleaning combine (CC) using two fuzzy controls. The proposed control system analyzes the current value of the engine current driving the cutting unit and predicts the readings of the gas pollution sensors in the mine. Accounting for gas readings is vital to ensure the safe operation of the tunneling machine and other equipment. Excess gas pollution can lead to explosions, casualties and damage to process equipment. Based on the analysis of these values, the developed system generates a control action on the drive motor regulator, which drives the combine. The drive motor controller is made on the basis of a proportional-integral controller. Thus, the system is a hybrid structure combining classic regulators and fuzzy regulators that generate a control signal. The presented approach allows for adaptive, proactive management, as well as improving the safety of the coal mining process and minimizing the human factor in the implementation of management. The effectiveness of the approach is demonstrated using the developed simulation model of a coal cleaning combine in the Simulink application of the MatLab software package. Analysis of the results obtained in the work allows us to conclude that it is expedient to apply this approach to other technological objects used in the mining industry of the Arctic zone of the Russian Federation and other countries

1. Relevance

Currently, there is a stable opinion that a significant amount of explored coal reserves of the Far Eastern region, part of the Arctic zone of the Russian Federation, is concentrated in the depths of the northeastern Arctic, and the raw material base is prepared for energy supply for many hundreds of years [1].

Therefore, the development of this region is an urgent national economic task.

Coal mining in difficult climatic conditions is associated with considerable difficulties. For the extraction of natural resources, it is necessary to use special equipment capable of working in the extreme conditions of the nature of northern latitudes.

The complexity of the process of coal mining in a closed way implies the presence of highly qualified personnel for maintenance of equipment and management. To optimize human resources, it is necessary to apply automation of the coal mining process. Automation will also minimize the number of management decisions, and as a result of human errors.

The main tool for underground mining is the coal cleaning combine, which is a combined mining machine that simultaneously performs operations on the destruction of coal, its crushing to pieces of transportable size and loading them on the bottomhole conveyors.

The combine is controlled by a operator. The operator carries out the process of regulating the technological parameters of the combine: the speed of movement, the position of the cutting coal auger, the work of the storage bodies. The control of speed CC and the position of the screw are necessary for the implementation of the collection of rock only within the extracted reservoir, without going beyond its boundaries.

Additional functions of the operator are: control the degree of heating of the surface of the combine, which helps to assess its mode of operation; determination of faults in machines and mechanisms by smell and sound; assessment of gas pollution in the face, based on the readings of the sensors, in order to control the speed of movement of the combine. The control algorithm is to reduce the speed of CC with increasing gas concentration (up to a stop), waiting for a decrease in gas pollution rates, due to the operation of the mine ventilation system, increasing the speed (start) CC.

Based on the complexity of the production process, we can conclude about the need for highly skilled operator-driver. Therefore, the problem of substantiating and developing new ways to control combines is important for improving the safety of miners and the productivity of coal mining processes in general.

2. Model of the electric drive system of coal cleaning combine

To study the issue of implementation and study the properties of the drive control system CC, it is necessary to develop a correct mathematical model of the joint functioning of the three components: the feed drive, the cutting drive and the cleaning face.

Conducted to date, studies show that the representation of the subsystems of actuators CC in the form of elastic elements with discrete masses is quite acceptable when solving most of the problems of dynamics [2].

Cutting drive and CC feed drive can be represented as three-mass models. In forming the models, the following assumptions were made: the deformation of elastic bonds is linear and obeys HoCCe's law; inertial properties of links are displayed by masses of inertia concentrated at the points or moments of inertia concentrated at the cross section; Elastic relations between these masses and moments of inertia are considered to be inertia-free; shafts have a specified stiffness; the mass of the shaft is concentrated on the gears; energy losses during deformation of elastic bonds are not taken into account.

Then the operation of the cutting drive CC can be described using a known system of linear inhomogeneous differential equations [3].

CC as an object of automatic control is a system of interconnected cutting and feed drives; interacting through the face. Therefore, to combine the models of the feed drive and the cutting drive into a single mathematical model, it is necessary to analyze the properties of the face when it is mechanically destroyed and the influence of these properties on the feed drive and electric cutting.

The relationship of the influence of the mechanical properties of the face on the power parameters of the electric drive cutting and feed drive for the cleaning combine УДК-400 can be taken as constant:

$$F_{\mathrm{rf}} / F_{\mathrm{rc}} = B_{\mathrm{s}} = 2\,, \tag{1}$$

where F_{rf} is the force of resistance to feed, F_{rc} is the force of resistance to cutting, B_{s} is a parameter characterizing the interaction of electric drives for cutting, feed and slaughter.

The relationship of the power parameters of the electric drive cutting and feed drive in the process of destruction of the rock massif is described by the following equations [4]:

$$h = \frac{100 \cdot V_{\text{r}}}{n_{\text{rf}} \cdot m}, \tag{2}$$

where h is the chip thickness, cm; Vr - feed rate CC, m / s; n_{rf} - screw rotation frequency, rpm; m - the number of incisors in the cutting line.

The moment of resistance to cutting force is

$$M_{\text{rc}} = h \cdot A \cdot Ra, \tag{3}$$

where A is the resistance of coal to cutting, kN / cm, Ra is the radius of the executive body (auger), m.

The force of resistance to movement of the combine is equal to the sum of the forces from the resistance of the screw and the resistance to movement of the combine on an inclined plane and is calculated as:

$$F_{\text{c}} = \frac{F_{\text{rf}}}{\eta} + F_{\text{tr}} = \frac{F_{\text{rc}}}{\eta} + m_{\text{к}} g(f_k \cos\alpha \pm \sin\alpha), \tag{4}$$

where η is the total efficiency of the movement mechanism CC, f_k is the relative resistance to movement of CC, α is the angle of incidence (uprising) of the reservoir.

Then the classical block diagram of the drive control CC will look like that shown in Figure 1:

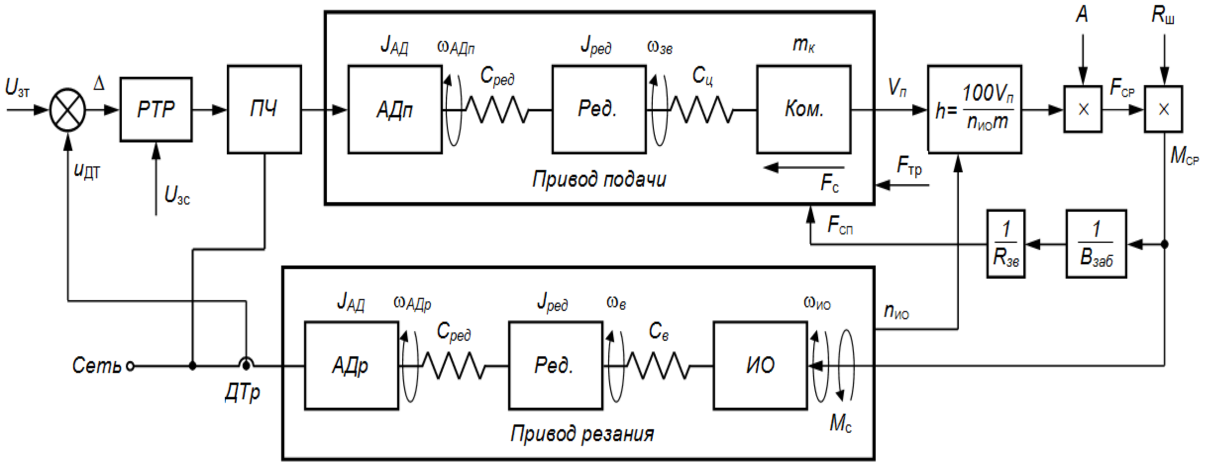

Figure 1. Block diagram of the control drive feed CC.

To ensure the full load on the power of the cutting motors in the control system of the electric drive CC, a cutting current controller (PTP) is used, which provides the change in the feed motor speed ($\omega_{\text{АД.к}}$) of the combine and as a consequence of the CC speed (*Vn*).

The load of the cutting motors is determined by the thickness of the chips cut by the screws, proportional to the cutting speed and inversely proportional to the feed rate *Vr* and the strength of the coal being destroyed A, which varies over a rather large range [5].

A classic PI controller is used as a current controller (PT).

The algorithm of this control scheme is as follows. Voltage setting the feed speed Uзс limits the output voltage of the PTP. First, the cutting drive is turned on, while the asynchronous mashine (АД) works without load. The error signal Δ at the regulator input is of great importance, and the regulator does not work correctly. As a result, the voltage at its output should tend to the maximum value, i.e. the value of the supply voltage.

At the same time, the voltage for setting the feed rate *Uзс* is zero. This zero voltage limits the PTP output voltage to zero. By setting the voltage of the setting *Uзс* in some range, you can adjust the feed rate. Increasing the feed speed reference signal *Uзс* will increase the feed rate. This will lead to an increase in chip thickness, an increase in the load on the cutting asynchronous mashine and, as a consequence, an increase in its current *Ip*.

This will continue until the feedback signal *U*дт from the cutting current sensor is equal to the current reference signal *U*зт.

Based on the described mathematical model and control flow chart, a simulation model of the speed control system CC was built, shown in Figure 2, the model parameters were selected in accordance with the parameters of the УДК-400 combine. The choice of this combine was justified by the availability of statistical data from a real production facility, to adjust the model and confirm its authenticity.

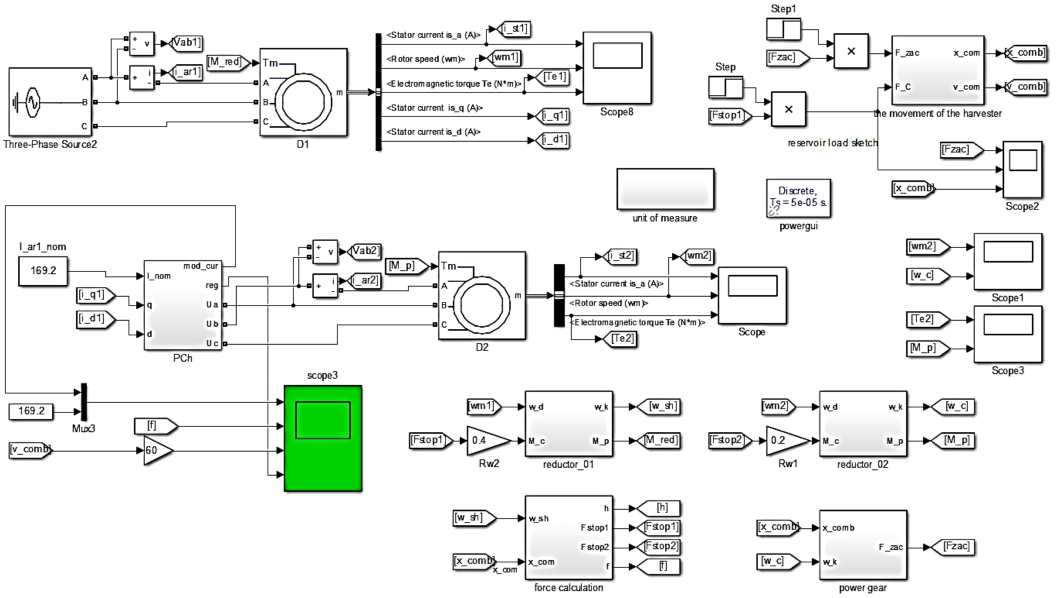

Figure 2. Simulation model of the control system drive feed CC.

Directly the engine control loop using the PI controller is implemented in the PCh block and is shown in Figure 3:

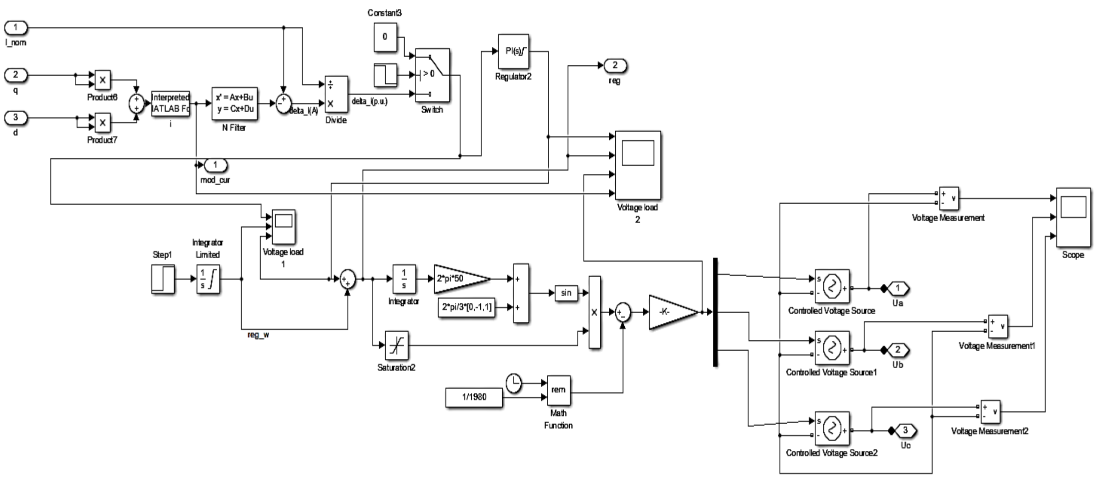

Figure 3. Feed speed control unit using a PI controller and a frequency converter.

The results of the model are presented in Figure 4. From the simulation results, it can be concluded that the PI controller performs the functions of controlling the operation mode of the combine, it is obvious that when the load changes, the cutting engine current does not go beyond the allowable range, and the rotation speed of the cutting organ engine is almost constant. The use of an automatic regulator of the operating mode CC frees the driver from the need to track the readings of the cutting current asynchronous mashine, which change with the rock strength. In general, the use of the classical management option is justified from a technical point of view, but this scheme has a significant drawback - it does not take into account the readings of methane sensors emitted during coal mining in the mine.

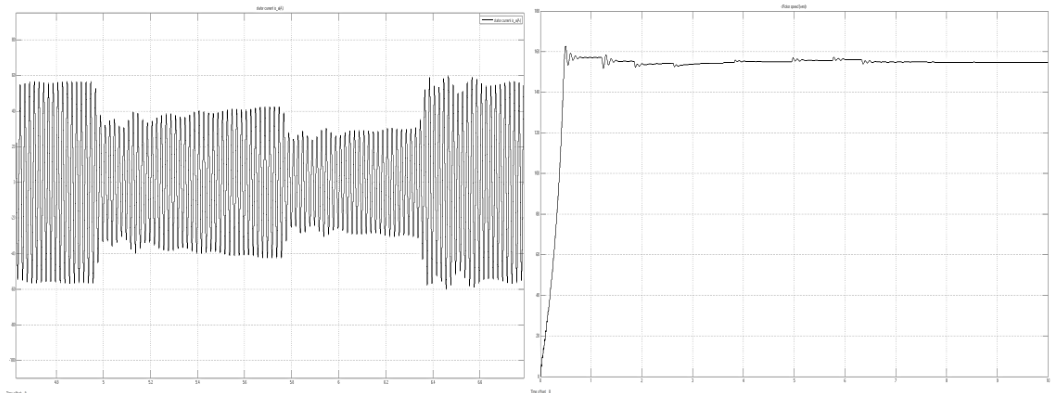

Figure 4. Simulation results (cutting motor rotor current on the left, rotational speed on the right).

The content of methane in the atmosphere of the mine is a vital parameter that must be considered when managing any equipment, including CC, in order to avoid emergency sexplosions. Methane is released into the air from the destroyed coal seam due to the operation of the combine. Theoretically, the higher the rate of penetration of the combine, the higher should be the content of methane in the air. In practice, to combine the speed of the combine and the methane content in the air using classical mathematics is not possible.

The amount of gas emitted is fixed by gas analyzers installed throughout the mine. With an increase in methane concentration in the air, it is necessary to reduce the rate of penetration of the combine, so that the ventilation system would bring the gas content to normal, in some cases it is required to stop the CC completely.

The task of choosing the speed of movement of the combine is one of the most important tasks of the operator-operator, the purpose of including fuzzy logic tools in the control system, is to minimize the driver's intervention in the control process.

Regulators based on fuzzy logic, in some cases capable of providing higher quality indicators of transient processes in comparison with classical regulators. The main purpose of the application of these regulators in the control system under consideration is to predict the change in gas content and the choice of control based on a comparison of various system parameters.

3. Preemptive control system for electric coal cleaning combine

In the modern world, in the management of technological processes, proactive control systems are widely used, predicting the development of the process in a certain time interval in order to select a control action [5].

They have proven themselves in solving similar problems of controlling a system using neuroregulators as well as fuzzy logic methods [6, 7].

This article proposes the introduction into the classical scheme of regulating the feed rate CC of two additional regulators implemented using fuzzy logic.

The goal of the first regulator, which would more correctly be called a predictive device, is the implementation of a gas emission forecast, based on previously obtained readings of gas analyzing devices. Analysis of the available real statistical data from the existing mine showed that the change in the concentration of gas in the air is stochastic in nature. Such parameters in technical systems, cannot be approximated in the form of mathematical functions, it is not possible to explicitly describe their relationship with other parameters. In the case of CC, the emission of methane into the air directly depends on the rate of penetration, this fact is confirmed by the opinion of operators-machinists working with real installations. Previously, it was possible to take into account such parameters in the control process only by relying on the empirical experience of the operator.

In the theory of fuzzy logic, there are prediction algorithms that allow the interconnection of parameters with implicit dependency, as well as the forecast of changes in such quantities.

In the model of the control system proposed in the work, the prediction device is implemented on the basis of the Fuzzy-controller block.

A signal is simulated to the input of this controller, imitating the gas sensors (the variation of gas concentration), the values of this signal were implemented as time series (a series of values of time-varying simulation). During the simulation, these can be any values that are within the available statistics of changes in the concentration of gas in the mine. In work for adjustment of the regulator real statistical data were used. The regulator was configured according to the Mamdani method. Figure 5 shows the windows of the controller settings (the training sample, the structure of the Anfis network, the graphical representation of the rules and the rules themselves); more details on the algorithm for setting up such prediction devices can be found in [8, 9]. Neuro-network technologists have also become widespread in the administration [10].

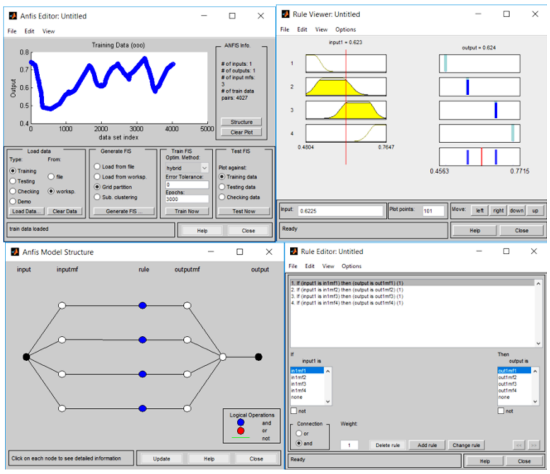

Figure.5. Predictor configuration windows.

Attention should be paid to the simplicity of the structure of the obtained fuzzy prediction device, this indicates the revealed regularity in the sequence of values describing the change in gas concentration. If there were no such regularity, and this change was random, it would not have been possible to configure the predictor.

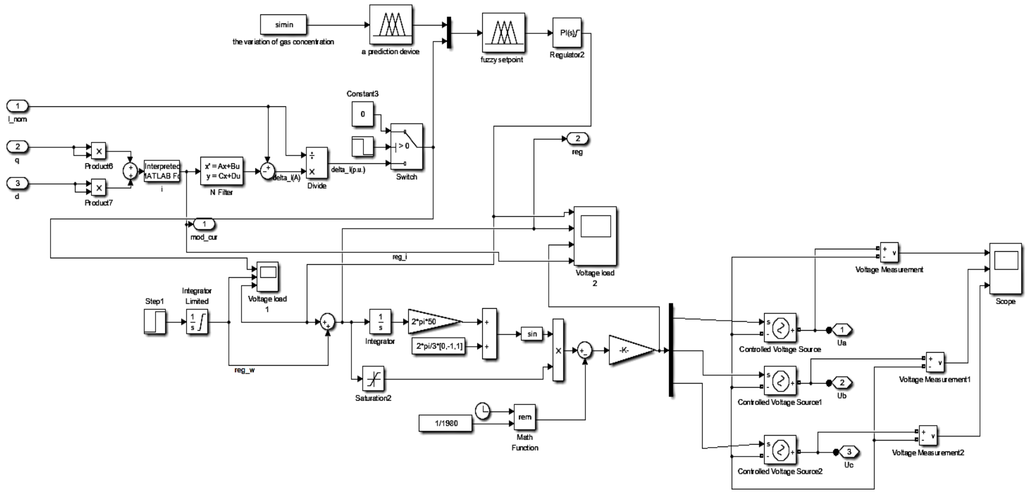

Figure 6**.** Upgraded feed speed control unit using fuzzy controls.

The second fuzzy regulator (fuzzy setpoint) is intended for the implementation of the task - controlling the speed of the displacement engine CC, taking into account the predicted change in methane emissions into the air and estimating the value of the stator current of the rotating screw engine. Using this approach, the regulatory system will perform the functions of the operator, which he performed on the basis of his qualifications, logical thinking, and experience.

This regulator was configured according to the Mamdani method, like the first one, but the difference was in the input and output parameters. In the first case, the value that appeared at the output was fed to the input of the regulator; in the second case, two values are fed to the input (predicted change in gas concentration and stator current) and the output appears to set the speed of the drive motor.

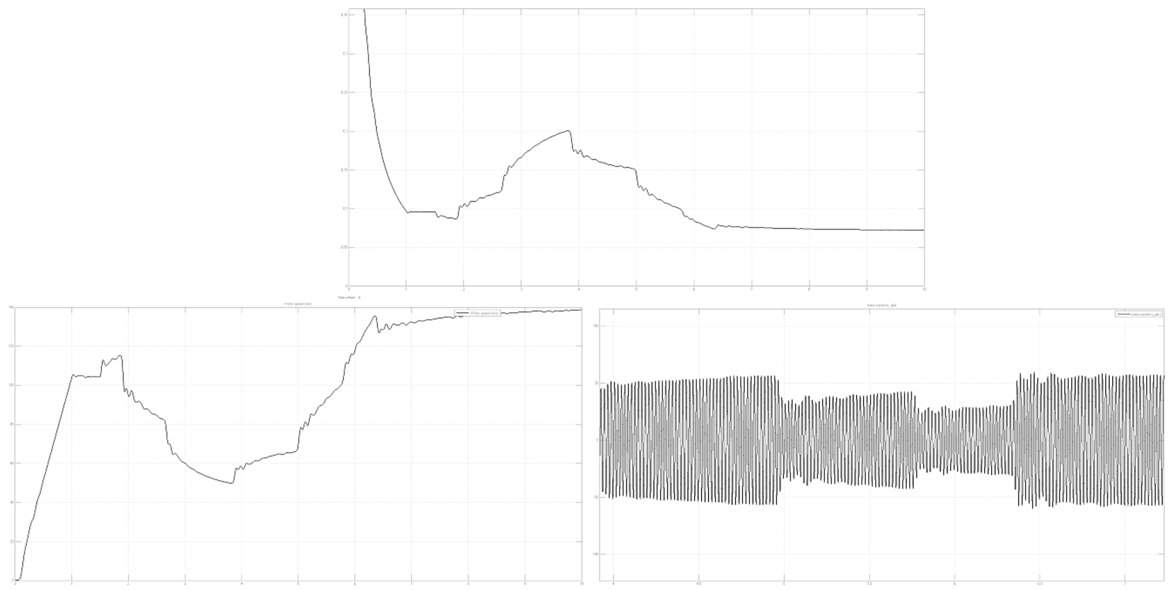

Figure 7. Results of the operation of the model.

Figure 7 shows the results of the operation of the model of this control system, it is obvious that the change in the speed of the CC has a pronounced inverse relationship to the gas concentration in the air; minimum. This simulation result indicates that the proposed system qualitatively implements the management functions assigned to it and has the prospect of applying it to control of CC. The experience of foreign countries, in particular Norway, is described in [11].

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