Journal of Theoretical and Applied Information Technology
15th September 2020. Vol.98. No 17

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DEVELOPMENT OF ADAPTIVE LOAD REGULATOR FOR SHEARER ELECTRIC DRIVE, PROVIDING MAXIMUM RESPONSE TIME OF CONTROL SYSTEM

[1]SHPREKHER D.M., [2]BABOKIN G.I., [3]ZELENKOV A.V.

[1]Department of Electrical Engineering and Electrical Equipment, Tula State University, Tula, Russia

[2]Department of Electrical Engineering and Electrical equipment, National research technological University "MISIS", Mining Institute, Moscow, Russia

[3]Department of Electrical Engineering and Electrical Equipment, Tula State University, Tula, Russia

E-mail: [1]shpreher-d@yandex.ru, [2]babokinginov@yandex.ru., [3]sashazelnkv@mail.ru

ABSTRACT

Using the Matlab/Simulink software package a mathematical model of the electromechanical system of a shearer with an built-in moving system has developed. It takes into account all the main factors that determine its operating modes: electro-magnetic transients in drive motors for cutting and moving; dynamic forces in transmissions; the distribution of the cutting force between the cutting drive and drive for moving, the nature of the change in the moment of resistance forces during operation by changing the strength of the coal. The shearer control system contains a load regulator with a PI-controller. However, it was found that, despite the simplicity of the configuration and physical implementation, as well as the relatively high reliability, this class of control devices may not provide optimal operation of the control system in all modes due to the non-linearity of the control object and the random nature of the coal force changes as the shearer moves in the coal face. To overcome these shortcomings, the possibility of a neural-network implementation of correction of the PI-controller coefficients is considered. The possibility of the correction of the PI-controller coefficients controlling the speed of the shearer movement, with a random nature of the coal strength changing, is proposed and experimentally proved. It is shown that the use of the PI-controller with the corrector in the form of the neural network in the control system will increase performance of the load regulator by an average of 1.5–3 times in comparison with the classical regulator. All this will allow to avoid critical overloads, and hence the possible breakdown of the mechanical parts in the transmission of the shearer in case of a sudden collision of the executive body of the shearer with a solid inclusion.

Keywords: *Shearer, cutting drive, coal strength, neural network, PI-controller*

1. INTRODUCTION

In the modern coal industry, much attention is paid to such aspects of the industry as energy saving and production safety. In this regard, in solving modern automation problems, preference is given to advanced, technological and highly intelligent systems. These systems are capable of not only maintaining the technological process in a normal state, but also responding to extreme situations, thereby preventing accidents and deviations of adjustable parameters from the norm, which will ensure a more complete use of the energy capabilities of the electric drive, reduce the likelihood of “tipping” of electric motors, and increase the durability by reducing overloads of the electric motor and the mechanical part, and therefore reduce their accident rate.

The main method of coal mining remains the use of mechanized complexes with narrow-range combines[1]. The structure of the shearer consists of two main components: an electric drive for cutting and an electric drive for moving. The electric drive for cutting carries out the destruction of the coal massif, and the drive for moving has a traction body, which promotes the executive body of the combine in the coal mass. The coal seam is a heterogeneous massif with the presence of solid inclusions of the rock, which, when cut through, lead to the appearance of strong shock loads on the executive body. Thus, the cutting drive accepts high dynamic loads[2].

The control system of the shearers operates under conditions of parametric disturbances, which are caused by a change in the coal strength, which has random nature, wear and dullness of the cutters of the executive body. The action of disturbances causes a change in the transmission coefficients of the control object, which leads to a deterioration in the quality of transients in the system and can lead to a loss of stability of the control system.

Therefore, the task of developing automatic control systems for such an important technological object as a shearer is really relevant.

2. LITERATURE ANALYSIS

Issues in the field of automation of shearer operating modes are devoted to the work of domestic and foreign scientists. So, in[3], shearer was studied with a remote displacement system based on a slip clutch; in[4], the dynamics and optimization of the parameters of power systems of shearers under random loads were investigated; in [5–6], an attempt was made to predict the load, acting on the drive of the combine. In [7–8], devices were used to automate the management of coal combines. In [9–10] the solutions to the control problems of complex technical objects based on the development of mathematical models, which further determine the control algorithm. The result of the study[11] was the proposal to use intelligent controllers in the control system of shearers based on fuzzy logic and neural networks. Attempts to control using intelligent controllers were considered in[12] using fuzzy logic, and using the standard Matlab neural network controller were considered in[13]. However, in all these works, the shearer was considered simplistically by one or few dynamic links, the coefficients of which are constant. In fact, it is a complex object with a large number of nonlinearities.

3. MAIN CONTENT

The mathematical model of the shearer with its control system is a multi-stage system. The drive for moving consists of a frequency converter (*FC*), an induction motor for moving (*IM.m*) with parameters ($J_{IM.m}$, $\omega_{IM.m}$), a transmission for moving ($J_{tr.m}$, $\omega_{tr.m}$, $c_{tr.m}$, $b_{tr.m}$) and remote or built-in moving mechanisms (m_{sh}, V_m, c_{st}, b_{st}). The cutting drive contains an induction motor for cutting (*IM.c*) with parameters ($J_{IM.c}$, $\omega_{IM.c}$), a transmission for cutting ($J_{tr.c}$, $\omega_{tr.c}$, $c_{tr.c}$, $b_{tr.c}$) and an executive body in the form of a screw or drum (J_{EB}, ω_{EB}, c_{EB}, b_{EB}). With the change in the hardness of coal, the resistance force of the coal seam also changes, and therefore the load on the cutting drive and this change is random. The current value of the current of the cutting motor characterizes the magnitude of this load. In order to make full use of the power of the cutting motor and increase its operation period and efficiency, the cutting motor must work with a nominal current (power), the value of which must be controlled.

But since the cutting drive is unregulated; the cutting current cannot be controled. At the same time, it is possible to regulate the moving speed of the shearer (moving the traction body), thereby providing fluctuations in the cutting current around the nominal value. Thus, in the control system of the shearer, the object of control is the shearer in combination with the technological process, the control action is the speed of the shearer, and the main disturbing action is the change in the strength of coal. The adjustable signal is the cutting current of the electric motor for cutting drive, the control parameter is the linear speed of the combine, the speed of moving.

To develop a control system for the shearer, we first mathematically describe the simulated object itself (Fig. 1).

We write the following equations in a form convenient for making up structural diagrams in the form

$$\frac{Y(p)}{U(p)}=\frac{B(p)}{C(p)}\ , \tag{1}$$

where *Y(p)* and *U(p)*- the operator form for recording input and output quantities the respectively; *B(p)* and *C(p)* – characteristic polynomials of the differential equation of the system.

The equations for describing the electric drive for moving of shearer in operator form:

– frequency converter (FC)

$$W_{FC}(p)=K_{FC}, \tag{2}$$

where K_{FC} – the linear coefficient.

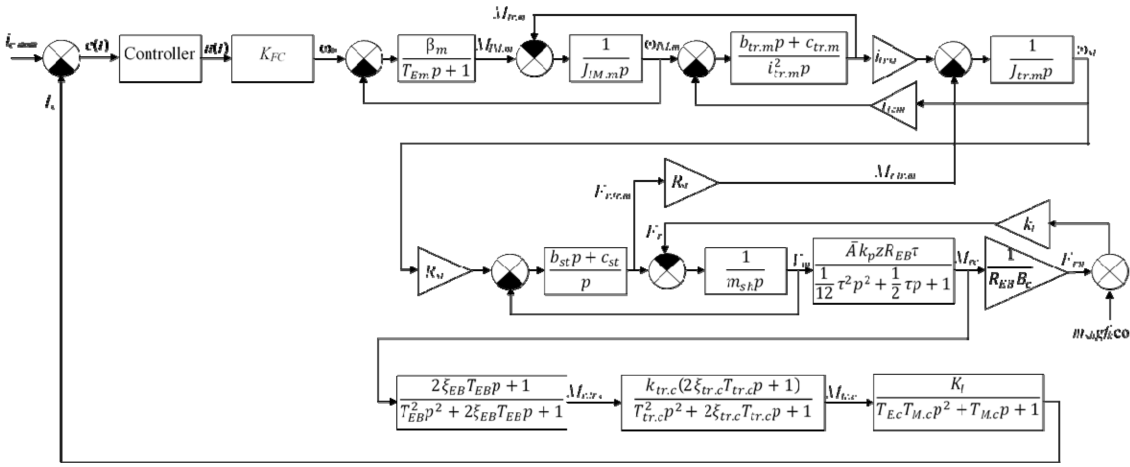

Figure 1: Mathematical model of a shearer as a control object

– for the induction motor for moving of shearer

$$\frac{M_{IM.m}}{\omega_0 - \omega_{IM.m}} = \frac{\beta}{1 + T_{Em}p}\,, \qquad (3)$$

$$\frac{\omega_{IM.m}}{M_{IM.m} - M_{tr.m}} = \frac{1}{J_{IM.m}p}\,, \qquad (4)$$

$$\beta_m = \frac{2M_{max}}{\omega_0 s_{max}},\ \omega_0 = \frac{2\pi f}{p_p},\ T_{Em} = \frac{1}{\omega_0 s_{max}}, \qquad (5)$$

where β_m – the stiffness module of the linearized mechanical characteristic of the induction motor for moving; M_{max} – is the critical (maximum) torque of the induction motor for moving; s_{max} – critical slip of an induction motor for moving; ω_0 – the angular frequency of the ideal idle speed of the induction motor for moving, p_p – the number of pole pairs of the induction motor for moving; $\omega_{IM.m}$ – the angular frequency of rotation of the rotor of an induction motor for moving, $M_{tr.m}$ – torque on the input shaft of the transmission for moving, T_{Em} – electromagnetic time constant.

– transmissions of drive for moving taking into account dissipative losses in operator form[10]:

$$M_{tr.m} = \frac{c_{tr.m}}{i_{tr.m}^2}\left(\frac{\omega_{IM.m}}{p} - \frac{\omega_{st}}{p} i_{tr.m}\right) + \frac{b_{tr.m}}{i_{tr.m}^2}(\omega_{IM.m} - \omega_{st} i_{tr.m}), \qquad (6)$$

$$J_{tr.m}\,\omega_{st}\,p = M_{tr.m}\,i_{tr.m} - M_{r.tr.m}. \qquad (7)$$

We rewrite equations (6) and (7) in the form (1), we get

$$\frac{M_{tr.m}}{\omega_{IM.m} - \omega_{st} i_{tr.m}} = \frac{b_{tr.m}p + c_{tr.m}}{i_{tr.m}^2 p}\,, \qquad (8)$$

$$\frac{\omega_{st}}{M_{tr.m} i_{tr.m} - M_{r.tr.m}} = \frac{1}{J_{tr.m}p}\,, \qquad (9)$$

where ω_{st} – rotation speed of the drive star of the drive for moving; $i_{tr.m}$ – gear ratio of the transmission of drive for moving; $J_{tr.m}$ – moment of inertia of the transmission of drive for moving; $c_{tr.m}$, $b_{tr.m}$ – respectively, the stiffness and viscosity coefficients of the transmission of drive for moving; $M_{r.tr.m}$ – torque of resistance on the output shaft of the transmission of drive for moving.

$$M_{r.tr.m} = c_{st}R_{st}\left(\frac{\omega_{st}}{p}R_{st} - \frac{V_m}{p}\right) + b_{st}R_{st}(\omega_{st}R_{st} - V_m)\,, \qquad (10)$$

where c_{st}, b_{st} – respectively, the stiffness and viscosity coefficients of the drive star of the shearer; V_m – linear speed of the shearer (moving speed); R_{st} – the radius of the drive star (pinion gear).

– the mechanical part of the drive for moving the shearer in operator form[4]:

$$m_{sh}V_m p = \frac{M_{r.tr.m}}{R_{st}} - F_r = F_{r.tr.m} - F_r\,, \qquad (11)$$

where F_r – the force of resistance to motion of the shearer mass m_{sh}, equal to the sum of the forces from resistance to motion of the screw and resistance to motion of the shearer along an inclined axis[9,14].

$$F_r = k_f(F_{r.m.} + m_{sh}gf_k\cos\alpha), \tag{12}$$

where f_k – coefficient of friction of the shearer on the guides of the conveyor; α – angle of incidence (rebellion) of the reservoir; F_{rm} – the force of resistance to the moving of the shearer; g – the acceleration of gravity; k_f – coefficient taking into account additional resistance to motion of the shearer is taken equal to 1.4.

We rewrite equations (10) and (11) of the combine moving system in the form (1), and we obtain

$$\frac{F_{r.tr.m}}{\omega_{st}R_{st} - V_m} = \frac{b_{st}p + c_{st}}{p}, \tag{13}$$

$$\frac{V_m}{F_{r.tr.m} - F_r} = \frac{1}{m_{sh}p}. \tag{14}$$

The equations for describing the electric drive for cutting in operator form:

– the induction motor for cutting:

Since the induction motor of the cutting drive is unregulated, and it is important for us to know the value of its current only I_c (the angular frequency of a screw or drum is constant), it can be represented by the transfer function proposed in[14], assuming that the moment in the working part of the mechanical characteristic cutting motor is proportional to its current $(M_{IM.c} \cong \frac{1}{k_I}I_c)$ we get:

$$W_{IM.c} = \frac{I_c(p)}{M_{tr.c}(p)} = \frac{K_I}{T_{E.c}T_{M.c}p^2 + T_{M.c}p + 1}, \tag{15}$$

where $T_{M.c} = \frac{J_{IM.c}}{\beta_c}$ – electromechanical time constant of an induction motor for cutting; K_I – the current transfer coefficient of the induction motor for cutting.

The calculation procedure of K_I is presented in[15], and the parameters of an induction motor for cutting are given in[9].

– transmissions of drive for cutting[11]:

$$W_{tr.c}(p) = \frac{M_{tr.c}(p)}{M_{r.tr.c}(p)} = \frac{1}{i_{tr.c}}\frac{\frac{b_{tr.c}}{c_{tr.c}}p + 1}{\frac{J_{tr.c}}{c_{tr.c}}p^2 + \frac{b_{tr.c}}{c_{tr.c}}p + 1},$$

where $i_{tr.c}$ – gear ratio of the transmission of the drive for cutting; $J_{tr.c}$ – moment of inertia of the transmission of the drive for cutting; $c_{tr.c}$, $b_{tr.c}$ – respectively, the stiffness and viscosity coefficients of the transmission of the drive for cutting; $M_{tr.c}$ – moment on the input shaft of the transmission of the drive for cutting; $M_{r.tr.c}$ – moment of resistance of the transmission of the drive for cutting.

To bring to a standard simplified form, we

introduce the following notation: $\frac{b_{tr.c}}{c_{tr.c}} = 2\xi_{tr.c}T_{tr.c}$

$\frac{J_{tr.c}}{c_{tr.c}} = T_{tr.c}^2$

where do we get

$$\xi_{tr.c} = \frac{b_{tr.c}}{2\sqrt{c_{tr.c}J_{tr.c}}}, \quad T_{tr.c} = \sqrt{\frac{J_{tr.c}}{c_{tr.c}}}, \quad k_{tr.c} = \frac{1}{i_{tr.c}}.$$

Then

$$W_{tr.c}(p) = \frac{M_{r.tr.c}(p)}{M_{r.c}(p)} = \frac{k_{tr.c}(2\xi_{tr.c}T_{tr.c}p + 1)}{T_{tr.c}p^2 + 2\xi_{tr.c}T_{tr.c}p + 1}, \tag{16}$$

where $\xi_{tr.c}$ – the damping coefficient of the transmission for cutting, $T_{tr.c}$ – transmission time constant in the cutting drive.

– Executive body:

The equations describing the work of the executive body in operator form are of the form [10]

$$\begin{aligned} J_{EB}\omega_{EB}p = c_{EB}\left(\frac{\omega_{tr.c}}{p} - \frac{\omega_{EB}}{p}\right) + \\ + \beta_{EB}(\omega_{tr.c} - \omega_{EB}) - M_{rc}, \end{aligned} \tag{17}$$

where M_{rc} – the resistance moment from cutting forces.

In order to obtain the transfer function for the disturbing action, we take the control action for speed $\omega_{tr.c} = 0$, then we get

$$W_{EB}(p) = \frac{M_{r.tr.c}(p)}{M_{rc}(p)} = \frac{\frac{b_{EB}}{c_{EB}}p + 1}{\frac{J_{EB}}{c_{EB}}p^2 + \frac{b_{EB}}{c_{EB}}p + 1},$$

If we introduce the notation

$$\frac{b_{EB}}{c_{EB}} = 2\xi_{EB}T_{EB}, \quad \frac{J_{EB}}{C_{EB}} = T_{EB}^2$$

then we get

$$\xi_{tr.c} = \frac{b_{tr.c}}{2\sqrt{c_{tr.c}J_{tr.c}}}, \quad T_{tr.c} = \sqrt{\frac{J_{tr.c}}{c_{tr.c}}}$$

and

$$W_{EB}(p) = \frac{M_{tr.c}(p)}{M_{rc}(p)} = \frac{2\xi_{EB}T_{EB}p + 1}{T_{EB}p^2 + 2\xi_{EB}T_{EB}p + 1}, \quad (18)$$

where ξ_{EB} – damping coefficient of the executive body; T_{EB} – time constant of the executive body.

The process of cutting coal is as follows. The executive body rotates and enters the coal mass due to the translational motion of the shearer along the coal face. This leads to occurrence a moment of resistance to cutting, which is described by the following transfer function[16]

$$W_{cc}(p) = \frac{M_{rc}(p)}{V_m(p)} \approx \frac{\overline{A} \cdot k_p \cdot z \cdot R_{EB} \cdot \tau}{(1/12)\tau^2 p^2 + (1/2)\tau p + 1}, \quad (19)$$

where k_p – the coefficient taking into account the weakening of the resistance to cutting of the material in the cutting zone and the parameters of the auger cutters; R_{EB} – radius of the screw (executive body), τ – the delay constant by the formation of coal shavings ($\tau = 1/(z\nu_c)$), z – the number of incisors in one cutting line; ν_c – frequency of rotation of the screw of the cutting drive.

The relation of the influence of the mechanical properties of the coal face on the power parameters of the electric drive for cutting and the electric drive for moving of the shearer can be taken constant[17]:

$$\frac{F_{rc}}{F_{rm}} = \frac{M_{rc}/R_{EB}}{M_{rm}/R_{st}} = B_c = \frac{1}{0{,}7}, \quad (20)$$

where B_c – the parameter characterizing the interaction of the electric drive for cutting, the electric drive for moving the shearer and the coal face.

The parameters of the shearer, which is accepted as the control object, are presented in table. 1

Table 1: The Parameters Of The Shearer.

	Main parameters
Induction motor for moving	Rated power 30 kW; Synchronous speed 1000 rev/min; Rated speed 972 rev/min; Rated voltage 1140 V; $J_{IM.m}$=1,12 kg·m^2; Pole pairs 3; R_s=0,41 Om; R_r=0,52 Om; L_m= 0,201 H; L_s=0,2175 H; L_r=0,215 H
Induction motor for cutting	Rated power 150 kW; Synchronous speed 1500 rev/min; Rated speed 1471 rev/min; Rated voltage 1140 V; $J_{IM.c}$=1,37 kg·m^2; Pole pairs 2; R_s=0,51 Om; R_r=0,13 Om; L_m= 0,0696 H; L_s=0,0698 H; L_r=0,0733 H
Drum	J_{EB}=36,1 Kg·m^2; D_{EB}= 0,9 m; ν_{EB}=78 min^{-1}
Shearer	m_{sh}=17500 kg; C_{st}=7,7652·10^{11} N·m·rad^{-1}; b_{st}=13330 N·m·s·rad^{-1}; R_{st}=0,15 m;
Transmission for moving	$J_{tr.m}$=451,7 kg·m^2; $C_{tr.m}$=1000000 N·m·rad^{-1}; $b_{tr.m}$=100000 N·m·s·rad^{-1}; $i_{tr.c}$=104,9
Transmission for cutting	$J_{tr.c}$=1371,8 kg·m^2; $C_{tr.c}$=675070 N·m·rad^{-1}; $b_{tr.c}$=2688,35 N·m·s·rad^{-1}; $i_{tr.c}$=19

4. ESTABLISHMENT OF THE SIMULINK SIMULATION MODEL OF THE SHEARER

MATLAB language is powerful in numerical computation. Its Simulink is a software package for modeling, simulation and analysis of all kinds of dynamic systems. The whole simulation process is very simple, convenient and intuitive[18].

To verify the effectiveness of controlling the speed of the shearer with the aim of the stabilization mode of the cutting current based on the PI-control, the UDK-300 shearer was taken as the control object. Its structural scheme, compiled on the basis of equations (2)-(20) in MATLAB/Simulink has the following form (Fig.2).

When cutting a homogeneous coal seam, the resistance to cutting can be modeled at a constant value. When the formation with solid inclusions is destroyed, the resistance to cutting increases sharply, exceeding the nominal one by 1.7–2 times[1].

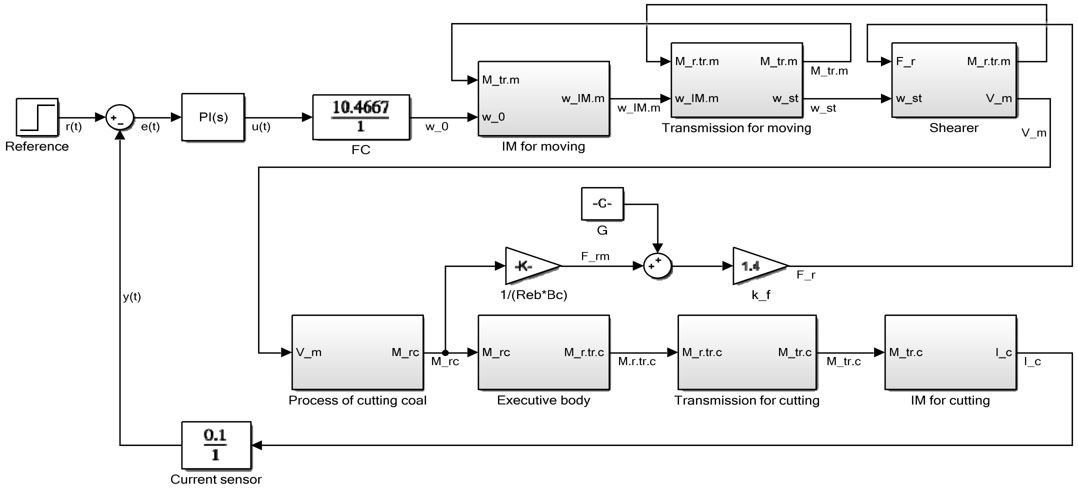

Figure 2: The simulation model of the control system of the shearer in the stabilization mode of the cutting current with a PI-controller

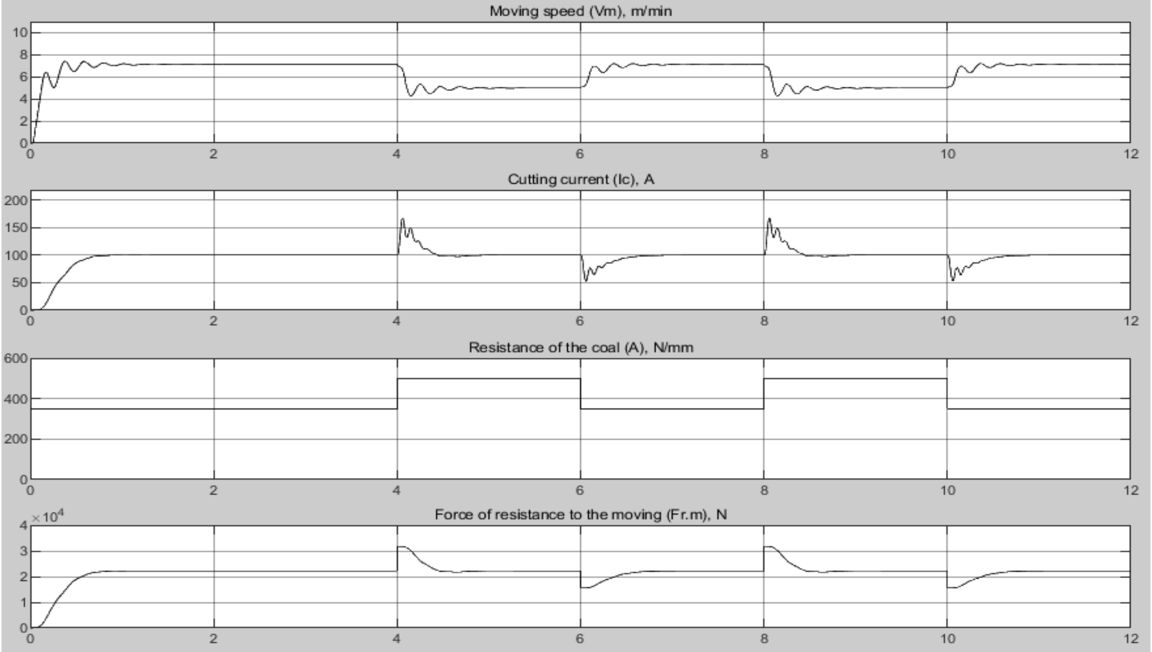

Figure 3: Oscillograms of the automatic control system under a stepwise change in the resistance of coal to cutting in the range from 350 N/mm to 500 N/mm

In the work, the obtained model was used to study the electromechanical processes occurring in a shearer with automatic current control of the electric motor for cutting drive with a stepwise change in the resistance of coal to cutting and the work of the shearer on weak and strong coals. As a result, we obtained the oscillograms shown in Fig. 3, 4.

From the oscillograms (Fig. 3) it can be seen that with a stepwise change in the resistance of coal to cutting in the range from 350 N/mm to 500 N/mm, the speed of the cutting current controller is 0.4 s with a load surge, at reset a load- 0.5 s. Furthermore, the maximum current value of the cutting motor is 170 A.

It can be seen from the oscillograms (Fig.7) that with a stepwise change in the resistance of coal to cutting in the range from 250 N/mm to 400 N/mm, the speed of the cutting current controller is 0.6 s with a load surge and 1.0 s, at reset a load. Wherein, the maximum current value of the cutting motor is 195 A.

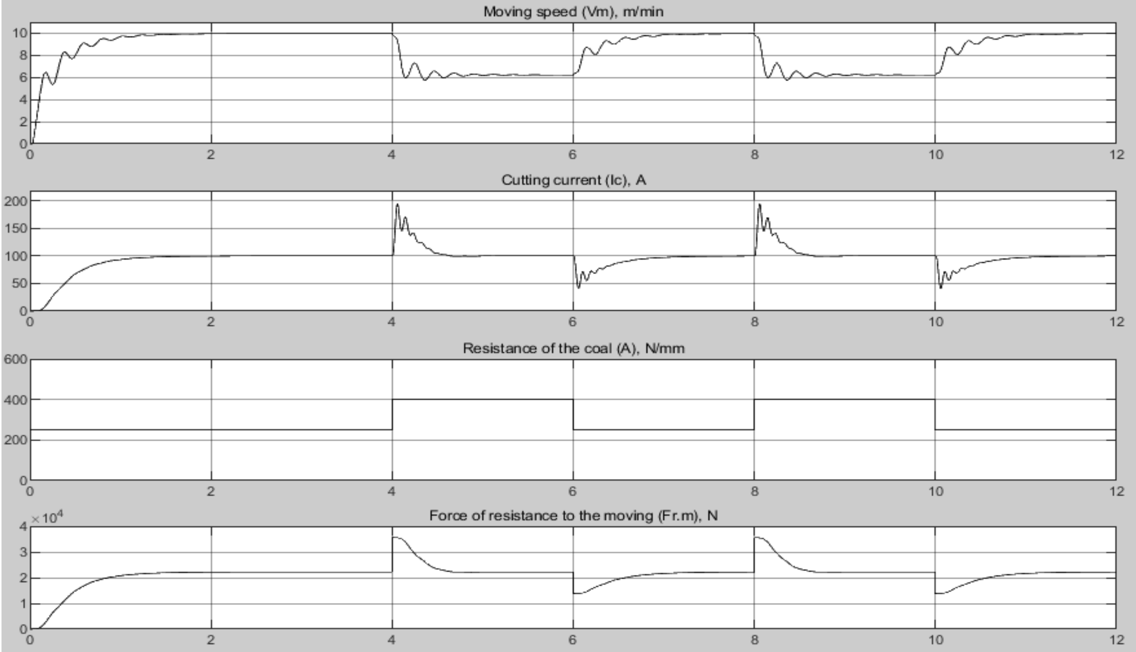

Figure 4: Oscillograms of the automatic control system under a stepwise change in the resistance of coal to cutting in the range from 250 N/mm to 400 N/mm

Thus, when the shearer is working on weak coals, there is a decrease in the performance of the automatic control system for the cutting motor current by almost 1.5-2.0 times relative to the speed of this system when the shearer is working on hard coals.

Therefore, to ensure the constant performance of the automatic control system when the strength of coal is changing in a wide range, there is a need to adjust the transmission coefficient of the cutting current controller.

The solution of this problem is possible, for example, by constructing adaptive process control systems[19] that automatically select the PI-controller coefficients, pre-adjusting tuning them using the Ziegler-Nichols method[20], or using the artificial intelligence methodology.

The authors propose to solve this problem using the coefficient corrector of the classical PI-controller, based on the feedforward neural network.

5. DESIGN OF CORRECTOR FOR THE COEFFICIENTS OF THE PI-CONTROLLER BASED ON THE NEURAL NETWORK

The authors propose to solve this problem using the coefficient corrector of the classical PI-controller, based on the feedforward neural network.

The PI-control system with corrector of its coefficients based on the neural network has good ability of self-learning and self-adjusting. At the same time, compared with the traditional PI-control system, the system has the advantages of small overshoot, higher control accuracy, faster response speed, stronger adaptability and robustness. Its control block diagram is shown in Fig. 5.

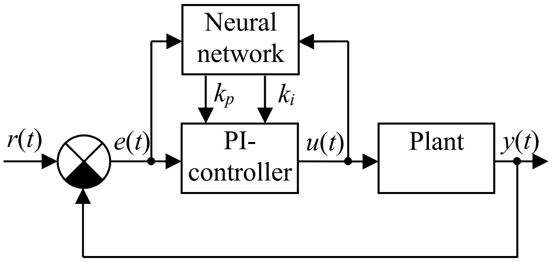

Figure 5: The control block diagram of the shearer with the PI-controller and the neural network block for adjusting its coefficients

It is known that the control signal processed by the PI-controller has the form:

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau) d\tau \, , \qquad (21)$$

where $e(t)$ - the discrepancy between the task and the output of the control object; K_P, K_I – customizable controller parameters (coefficients). The mismatch is calculated as the difference between the reference signal (setpoint) – $r(t)$ and the output of the control object – $y(t)$. Paying attention to the fact that the signal for setting the set value is a constant value, in the future we will deal only with the error signal. A constant positive value only affects the shift of the output signal in the ordinate up, which in some cases can be useful, for example, to avoid zero intersections, which is crucial for training a neural network.

Equation (21) in operator form takes the form:

$$U(p) = \left(K_P + \frac{K_I}{p}\right)Y(p)\ , \qquad (22)$$

where $U(p)$ and $Y(p)$ – the Laplace transforms for $u(t)$ and $y(t)$, respectively.

Based on (22), the transfer function of the controller has the form:

$$W(p) = \frac{U(p)}{Y(p)} = K_P + \frac{K_I}{p}\ , \qquad (23)$$

If we translate (23) into a discrete form using a replacement $p = (1 - z^{-1})/\Delta t$, we obtain:

$$W(z) = K_P + \frac{K_I\Delta}{1 - z^{-1}} = \frac{1}{1 - z^{-1}}\left(K_P\left(1 - z^{-1}\right) + K_I\Delta t\right) =$$

$$= \frac{1}{1 - z^{-1}}\left(\left(K_P + K_I\Delta t\right) - K_P z^{-1}\right)$$

We denote $a_1 = (K_P + K_I\Delta t)$, $a_2 = K_P$.

Then, the difference equation, which is an analog of (21), for the k-th control step (for time t_k) takes the form:

$$u(t_k) = a_1 e(t_k) + a_2 e(t_k - \Delta t) + u(t_k - \Delta t)\ . \qquad (24)$$

That is, the PI-controller, according to (24), should actually have information about the mismatch (error signal) at the current time, the mismatch at the time one step backward and about the control signal one step backward. Therefore, the corrector of coefficients based on a neural network must have 3 inputs.

It is accepted that neurons of the 1-st layer have an activation function - sigmoid, and for neurons of the 2-nd (output) layer the activation functions are linear. The number of neurons in the output layer is 2, corresponding to the PI coefficients of the controller K_P and K_I.

To solve this problem, a neural network training method with a teacher was chosen. The neural network was trained using the Levenberg-Marquardt algorithm[21]. In fig. 6 a model for generating a training sample is shown.

The "In" array is an array for recording training input signals, and the "Out" array is an array for recording output signals, i.e., it is the neural network output (the PI coefficients of the controller). The resistance of the material to cutting A was modeled by a Random Source block generating evenly distributed random numbers corresponding to a specific coal strength in the range from 250 to 1000 N/mm with an interval of 2 s. Additionally, a program was implemented that compares the values of the fortress with the proportional and integral coefficients of the PI-controller obtained earlier for each discrete value of the fortress according to the Ziegler-Nichols method. Intermediate controller coefficients are calculated by spline interpolation implemented in the Matlab Function block.

To test the developed corrector of the neural network, which changes the coefficients of the PI-controller, we used a simulation model pictured on the block diagram, as shown in Fig. 8 and implemented in a Simulink simulation environment.

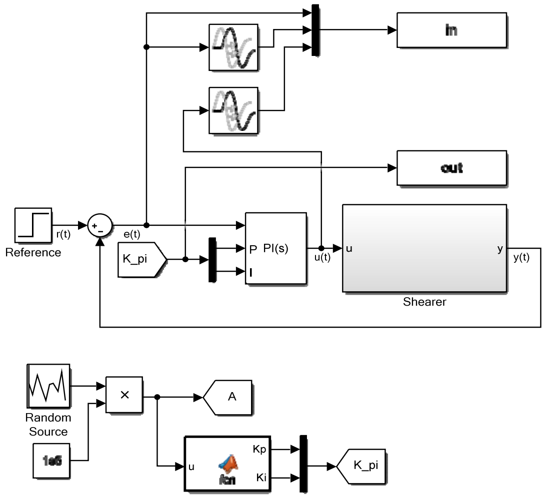

Figure 6: Model for creating a training sample

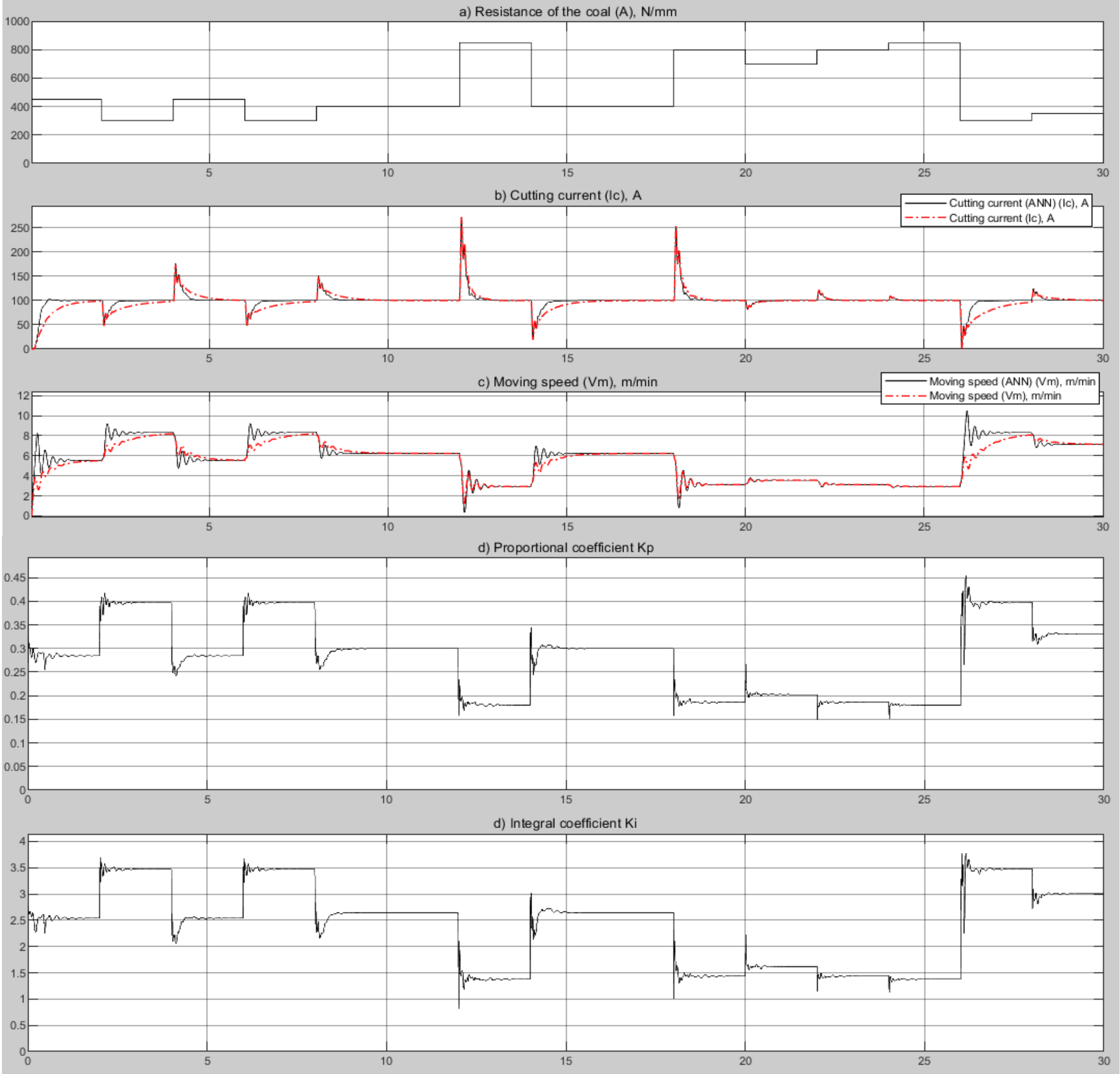

Figure 7: Results of comparing the work of the classical PI-controller and the controller with the corrector of coefficients based on the neural network

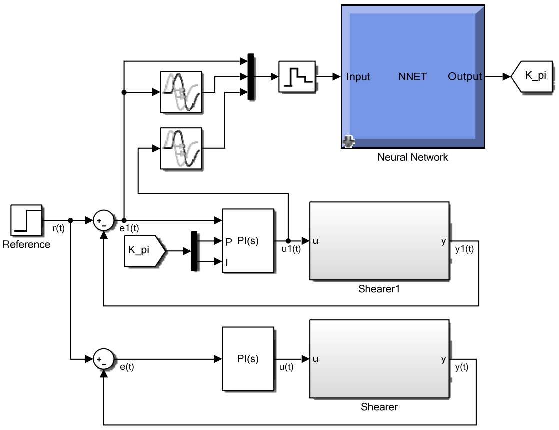

Figure 8: The simulation model comparing the operation of the two PI-controllers

In this scheme, the operation of the classical PI-controller with constant coefficients and the PI-controller with the corrector of its coefficients based on the neural network were compared.

In Fig. 7 the simulation results are presented. From graphs b) and c) in Fig. 7 it can be seen that when the coal strength changed within 150 - 450 N/mm, the speed of a conventional PI-controller amounted at increase in load 0.97 s, while reducing load - 1.4 s; with a change in the strength of coal in the range of 400 - 800 N/mm, by response time was 0.66 s with an increase in load, and 1.25 s with a decrease. With a change in the strength of coal within 150 - 450 N/mm, the speed of the PI-controller with the corrector of its coefficients based on the neural network amounted while increase and reducing in load of 0.37 s; with a change in the strength of coal in the range of 400 - 800 N/mm, the speed of the PI-controller while increase and reducing in load was equal 0.43 s.

Thus, the use of the PI-controller with the corrector of its coefficients based on the neural network can significantly increase the speed of the load controller on average from 1.5 to 3 times. This will ensure a reduction in dynamic loads during cutting of solid inclusions by the working body of the combine and at possible blocking of the working body and thereby increase the reliability of the shearer.

According to graphs d) and e) in fig. 7 the coefficients of the PI-controller, providing the required quality of the transition process, vary significantly depending on changes in load (coal strength). It can also be seen that their behavior is essentially non-linear, which justifies the use of the neural network to correct the coefficients of the PI-controller for different loads on the control object.

This work was supported by the Russian Foundation for Basic Research (Grant No. 20-07-00914 \ 20).

6. CONCLUSION

1. In the framework of this work, it was proposed to increase the speed of the regulatory system by using the PI-controller, the coefficients of which are adapted to the external working conditions of the shearer with sudden changes in load (coal strength). The correctness of the synthesized controller was verified using computer simulation.

2. The use of the PI-controller with the corrector of its coefficients based on the neural network in the control system will increase the speed of the load controller by an average of 1.5–3 times compared with the classical controller. This will allow to avoiding critical overloads and possible breakdown of mechanical parts in the transmission of the shearer with a sudden meeting of its working body with a solid inclusion.

3. The approach proposed in the article can be used to solve other applied problems in which the control object is complex, non-linear and the control algorithm needs to adapt to the changing state of the object. It is planned to use the results obtained in the future to improve the load management system of shearers.

REFRENCES:

[1] R. Shu, Z. Liu, C. Liu, X. Lin, D. Qin, “Load sharing characteristic analysis of short driving system in the longwall shearer”, *Journal of Vibroengineering*, Vol. 29, No. 4, 2015, pp. 3572-3585.

[2] C. Liu, D. Qin, Y. Liao, “Electromechanical dynamic analysis for the drum driving system of the long-wall shearer”, *Advances in Mechanical Engineering*, Vol. 7, No. 10, 2015, pp. 3572-3585.

[3] S.V. Dubinin, “Reducing dynamic loads and increasing the efficiency of the removed feed system of the shearer”, PhD (Engineering) dissertation, Donetsk, 1991, 209 p.

[4] N.G. Boyko, “Optimization of parameters of power systems of shearer”, monograph, Donetsk, Donetsk National Technical University, 2012, 214 p.

[5] P.A. Gorbatov, M.V. Perinskiy, “Mathematical models for predicting maximum loads in the drive subsystems of shearer based on simulation”, *Mechatronic mining equipment – 2010: International scientific and technical conference*, Donetsk, Donetsk National Technical University, 2010, pp. 25-34.

[6] S.G. Zubarev, “Improving the forward motion system of a coal combine by predicting the load”, *Technological audit and production reserves*, Vol. 6, Issue 4(20), 2014, pp. 17-20.

[7] A.S. Ivanov, “Development of a nonlinear load control system for the electric cutting drive of a tunneling combine”, PhD (Engineering) dissertation, Novokuznetsk, 2010, 160 p.

[8] E.B. Kolesnikov, “Development and research of the mechanism of forward motion with a frequency-controlled electric drive”, PhD (Engineering) dissertation, M., 1996, 249 p.

[9] V.V. Tkachev, A.V. Bublikov, “The use of simulation to study the automatic control system for cutter-loader”, monograph, Dnepropetrovsk, National Mining University, 2015, 182 p.

[10] D.M. Shprekher, G.I. Babokin, E.B. Kolesnikov, “Mathematical modeling of the electric drive of a shearer with a built-in moving system”, *Bulletin of Tula State University, technical science*, No 3, 2019, pp. 645-651.

[11] D.M. Shprekher, G.I. Babokin, E.B. Kolesnikov, A.V. Zelenkov, “Study

loading dynamics for adjustable electric drive of shearer loader", *Bulletin of Tula State University, technical science*, No. 2, 2020, pp. 514-525.

[12] ZhaoYi-hui, "Constant Power Automatic Control System of Electric Haulage Shearer Based on Fuzzy Control", *Coal mine electromechanical*, Vol. 12, 2012, pp. 41-43.

[13] Zhou Yuan-hua, Ma Hong-wei, Wu Hai-yan, Zhao You-jun., "Constant Cutting-Power Control of Shearer Based on Neural Network Model Predictive Control", *Advanced Materials Research*, Vol. 823, 2013, pp. 340-344.

[14] B.Y. Starikov, V.L. Azarh, Z.M. Rabinovich, "Asynchronous electric drive of shearers", M.: Nedra, 1981, 288 p.

[15] L.S. Udut, O.P. Maltseva, N.V. Koyain, "Design and research of automated electric drives. Part 8 Asynchronous frequency-controlled electric drive: a training manual", Tomsk Polytechnic University, Tomsk: Publishing House of Tomsk Polytechnic University, 2009, 448 p.

[16] D.M. Shprekher, G.I. Babokin, E.B. Kolesnikov, A.V. Zelenkov "Research of a system for automatic load control of an electric drive for cutting a shearer", *News of higher educational institutions. Electromechanics*, Vol. 63(2-3), 2020, pp. 30-37.

[17] OST 12.44.258–84. Shearers. Selection of parameters and calculation of cutting and movement forward forces at executive bodies. Methodology Introduced from 01.01.1986. M.: Minugleprom USSR. 1984. 107 p.

[18] V.S. Medvedev, V.G. Potemkin, "Neural network. MATLAB 6", M.: Dialog MIFI, 2001, 630 p.

[19] A.M. Shubladze, S.I. Kuznetsov "Automatically tuned industrial PI and PID-controllers", *Automation in industry*, No. 2, 2007, pp. 15-17.

[20] A. Leva, C. Cox, A. Ruano, "Hands-on PID autotuning: a guide to better utilisation", *IFAC Professional Brief*, Laxenburg, 2002, 84 p.

[21] S.S. Parkhomenko, T.M. Ledeneva, "Learning neural networks by the Levenberg-Marquardt method in a large amount of data", *Bulletin of Voronezh State University. Series: System Analysis and Information Technology*, No. 2, 2014, pp. 98-106.