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Cutting torque stabilization system synthesis of the shearer loader with a fuzzy controller

Gennadii I. Babokin[1], Dmitrii M. Shprekher[2]*, Evgenii B. Kolesnikov[3]
[1] National University of Science and Technology MISIS, Moscow, Russia
[2] Tula State University, Tula, Russia
[3] Novomoskovsk Institute of Russian Chemical Technology University named after D. I. Mendeleev, Novomoskovsk, Tula region, Russia
e-mail: shpreher-d@yandex.ru

Abstract

Introduction. *The efficiency of mineral production carried out by the shearer loaders entering the winning and heading mechanized systems is improved by their design and control systems development. At mineral resistance variation, in order to provide the full capacity utilization of shearer executive body electric motors, cutting electric drive torque (load) controller is used, control quality parameters of which depend on the value of cutting resistance. In this regard, relevant is the task of developing cutting torque stabilization system for shearer loader drive with constant control quality parameters through the use of intelligent control systems.*

Research aims *to synthesize the fuzzy controller of the shearer loader electric drive cutting torque which increases the quality of cutting torque stabilization at material cutting resistance variation and to assess its efficiency by the mathematical modeling method.*

Methodology. *The mathematical model of shearer loader electric drive cutting torque stabilization has been worked out; structure and parameters of cutting torque fuzzy regulator have been substantiated. The comparison of the proposed fuzzy controller with a typical PI controller has been carried out with the use of the model experiment method.*

Results. *The mathematical model of shearer loader cutting torque stabilization system has been obtained which takes into account material cutting resistance variability, the constant of chip formation and the dynamic properties of cutting drives and feed drives. Shearer loader cutting torque fuzzy controller has been synthesized, in which four fuzzy sets have been applied at proportional part fuzzification, providing an automatic variation of the controller gain depending on error ratio. The model experiment has shown that the use of a fuzzy controller makes it possible to reduce the transient overshoot by torque by 15% and increase its speed by 25% under material cutting resistance variation by a factor of 2.*

Summary. *The use of the proposed fuzzy controller makes it possible to obtain the quality of control action transition process independent of cutting resistance variation and lower overshoot under perturbing actions.*

Key words: *fuzzy controller; coal shearer; feed drive; cutting drive; mathematical model; transition process; coal hardness.*

Introduction. The efficiency of mineral production by the shearer loaders (SL) entering the winning and heading mechanized systems is improved by their design and control systems development. Nowadays, shearer loaders which mine minerals (coal and sylvinite) have got the drives of shearer cutting and feed mechanism interacting at mineral stratum disintegration.

As a rule, cutting drive consists of two unregulated asynchronous electric motors, which rotate screws equipped with cutters through the reduction gears. As a feed mechanism drive the variable frequency asynchronous electric drive is used which includes general frequency changer (FC) feeding one or two asynchronous electric motors (AM) agitating the chainless feed system mover. In order to provide the full capacity utilization of cutting electric motors, power controller or torque controller

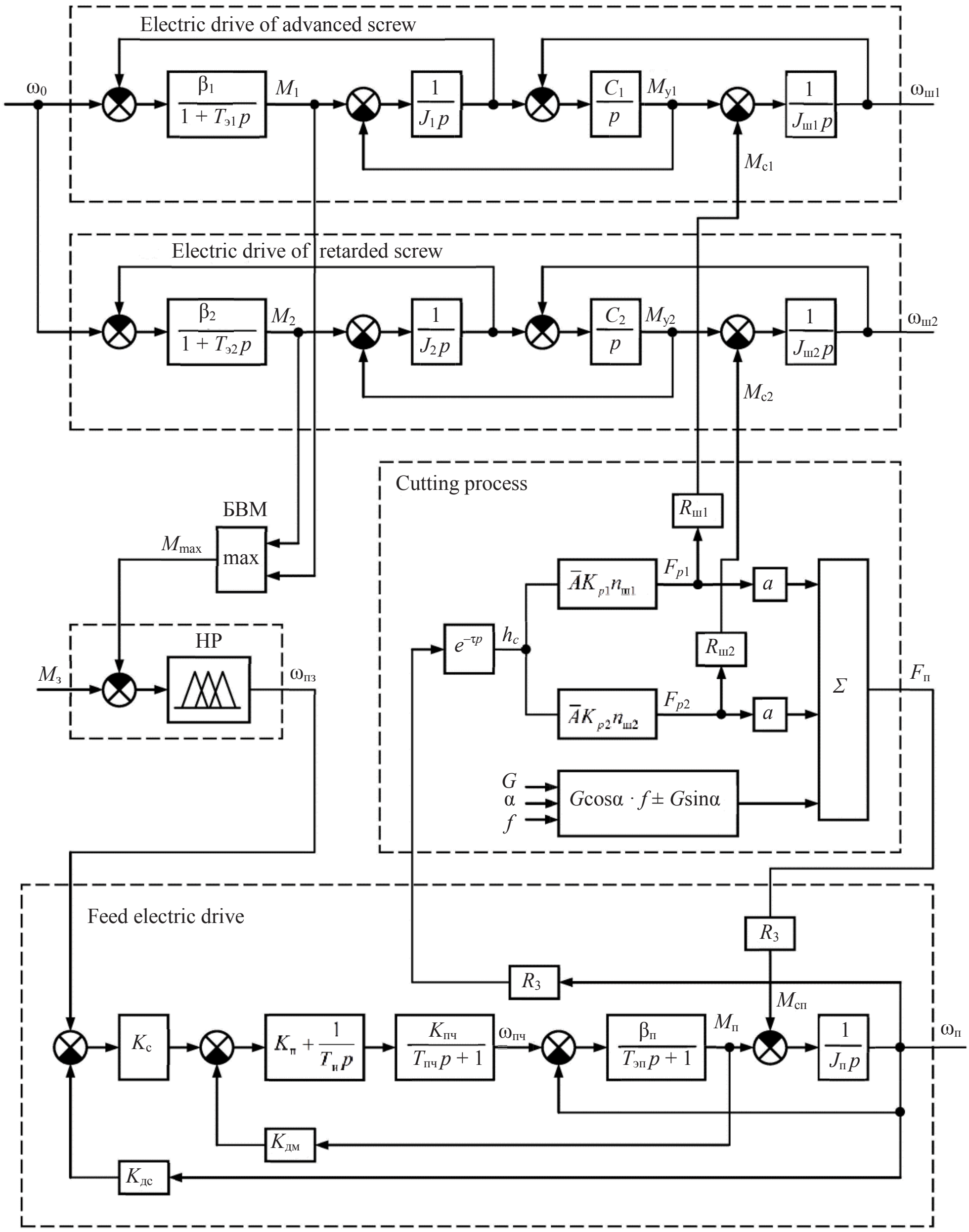

Fig. 1. Operator structural scheme of shearer cutting torque stabilization system
Рис. 1. Операторная структурная схема системы стабилизации момента резания комбайна

(TC) is used in shearer loader electric drive (ED) control system; it is aimed at providing the full power capacity of screws electric motors by means of changing feed velocity of a shearer under mineral cutting resistance variation and the conditions of shearer's operation.

The use of the indicated control scheme ensures maximum productivity of a shearer under some restrictions by gas factor, roof support speed, cutter overhang, etc., typical of various operation conditions.

Researches and publications analysis. As a controlled member, SL automation system represents a complex electromechanical system including a number of nonlinearities, variable gain and the retardation of chip formation of an executive body [1, 2]. The object's gain is defined by material cutting resistance which changes within the mineable stratum according to normal law in the range of 0.5 to 1.5 from the average value. The retardation of chip formation makes up 0.3–0.6 s [1]. In accordance with the indicated features of the object, shearer ED torque controllers in service do not ensure the required features of transition processes when working in the stope which mines one stratum.

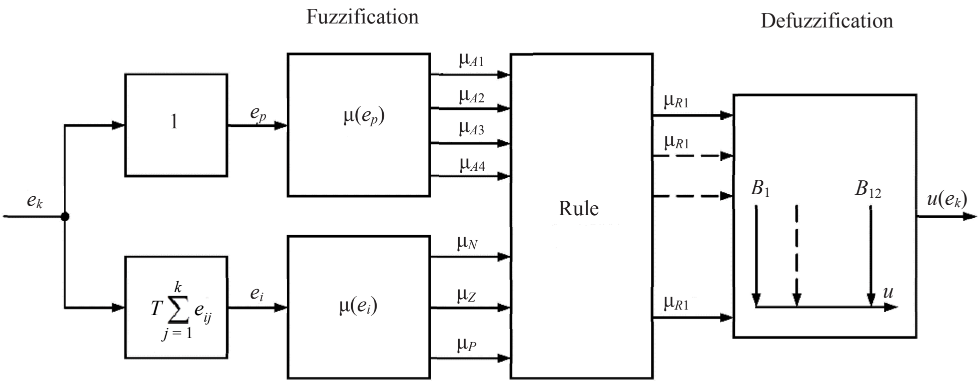

Fig. 2. Structural scheme of torque fuzzy controller
Рис. 2. Структурная схема нечеткого регулятора момента

Works [3–6], in order to stabilize the quality of transition processes, propose using self-adjusting parametric automation control systems (ACS) with the adjustment of the torque controller gain by the indirectly measured material cutting resistance. However, the accuracy of measurement for this parameter is rather low because of the influence of a large number of unmeasurable parameters. Because of the relevance of the shearer loader ED cutting torque stabilization task in the conditions of vaguely changing gain of an object, the present research sets the task of synthesizing the fussy controller of torque and assessing the quality of its operation under material cutting resistance variation by the mathematical modeling method. The preconditions of this task solution are presented in works [7–10].

Body. Based on the generalization of experience of K10PM shearer feed frequency-controlled ED application [1] and machining devices cutting efforts stabilization [11–13], shearer loader cutting torque stabilization system has been proposed, operator structural scheme of which is presented at fig. 1. The scheme includes unregulated asynchronous electric drives of advanced and retarded screws, feed variable frequency electric drive, mineral cutting process model taking into account the retardation of chip formation process and disintegrated material cutting resistance variation. According to operation and technical parameters of a shearer, the model of cutting process forms the torque of resistance at screw executive bodies M_{c1}, M_{c2} and the torque of feed drive resistance $M_{сп}$. Electromechanical system of each cutting drive is represented as a two-masses mechanical model with the J_1, J_2 motors and $J_{ш1}$, $J_{ш2}$ screws moments of inertia, mechanical transition elasticity C_1, C_2, and the account of the electromagnetic time constant of electric motors $T_{э1}$, $T_{э2}$.

Shearer variable frequency electric drive includes asynchronous electric motor with the following parameters: moment of inertia $J_п$, electromagnetic time constant $T_{эп}$, torque transfer coefficient $\beta_п$, frequency changer (FC) with transfer coefficient $K_{ПЧ}$ and time constant $T_{ПЧ}$, feed control slave system of a shearer with the proportional-integral current controller (CC) and proportional speed controller (SC). At fig. 1 the following notations are used: $K_с$ – speed controller gain, $K_{дм}$ – torque feedback gain (torque sensor) of a feed electric motor, $K_{дс}$ – rotation velocity feedback gain (speed sensor) of a feed electric motor, $\omega_{пз}$ – feed drive reference velocity. The synthesis of CC and SC of feed electric drive is implemented according to the criterion of technical optimum [1].

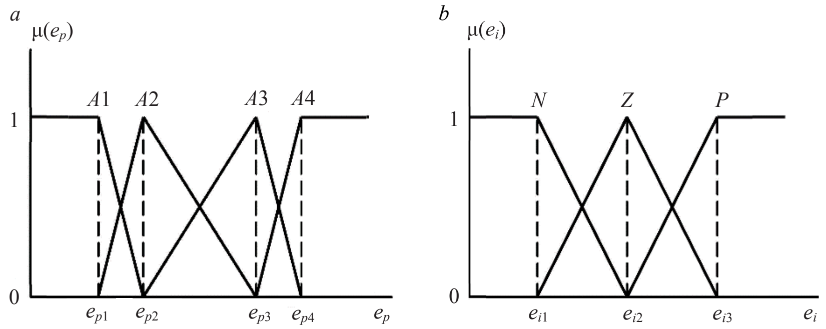

Fig. 3. Torque fuzzy controller membership functions:
a – proportional part; *b* – integral part
Рис. 3. Функции принадлежности нечеткого регулятора момента:
a – пропорциональной части; *b* – интегральной части

Shearer ED cutting torque stabilization loop includes the fuzzy controller (FC), to the input of which the preset value of torque $M_з$ and the maximum actual value of torque M_{max} are applied out of two values M_1 or M_2, detected by the maximum detector (MD), while the signal from the output of FC is applied to the input of the feed electric drive control system forming the traversing speed of a shearer $V_п$.

The system of equations for the advanced screw in the operator form is [14]:

$$M_1(p)(1+T_{э1}p)=\beta[\omega_0(p)-\omega_1(p)]; \quad (1)$$

$$M_1(p)-M_{у1}(p)=J_1p\omega_1(p); \quad (2)$$

$$M_{у1}(p)-M_{с1}(p)=J_{ш1}p\omega_{ш1}(p); \quad (3)$$

$$M_{у1}=\frac{C_1}{p}\left[\omega_1(p)-\omega_{ш1}(p)\right], \quad (4)$$

where M_1 – electromagnetic torque of an electric motor which rotates the head screw in the cutting electric drive; $T_{э1}$ – electromagnetic time constant for this motor; C_1 – head screw electric drive transmission elasticity torque moment; J_1 – cutting drive electric motor moment of inertia; $M_{с1}$ – torque of resistance at the executive body head screw; $J_{ш1}$ – head screw moment of inertia; ω_1, $\omega_{ш1}$ – rotation velocity of a rotor of the first cutting electric motor and the head screw correspondingly; p – Laplace operator.

Set of equation for the retarded screw has got the same equations (1)–(4), while their parameters have got index 2 instead of 1 (fig. 1).

When describing the process of cutting, an assumption has been made that the constant of chip formation τ for the screws is the same and does not depend on the frequency of the screws rotation, for example, slip of cutting asynchronous motors in the standard operating mode is 0.02–0.05.

The connection between power parameters of cutting electric drive and feed drive in the process of rock massif disintegration is described by the following equations [15]:

$$h_{\text{с}} = V_{\text{п}} e^{-\tau p},$$

where $h_{\text{с}}$ – the thickness of the coal chip; $V_{\text{п}}$ – the traversing speed of a shearer; τ – the constant of chip formation retardation.

In its turn, the constant of chip formation retardation is described by the following formula

$$\tau = l / (\omega_{\text{ш}} R_{\text{ш}}),$$

where l – the distance between the cutters in one cutting line of a screw; $\omega_{\text{ш}}$ – screw rotation frequency; $R_{\text{ш}}$ – screw radius.

Cutting resistance force $F_{\text{р}}$ and feed resistance force $F_{\text{п}}$ are determined by the following formulae:

$$F_{\text{р1}} = \overline{A} k_{\text{р1}} n_{\text{ш1}} R_{\text{ш1}} e^{-\tau p} V_{\text{п}}(p);$$

$$F_{\text{р2}} = \overline{A} k_{\text{р2}} n_{\text{ш2}} R_{\text{ш2}} e^{-\tau p} V_{\text{п}}(p);$$

$$F_{\text{п}} = [(\overline{A} k_{\text{р1}} n_{\text{ш1}} + \overline{A} k_{\text{р2}} n_{\text{ш2}}) e^{-\tau p} a V_{\text{п}}(p) + G \cos\alpha \cdot f \pm G \sin\alpha)] R_{\text{з}},$$

where $\overline{A}$ – material cutting resistance; $k_{\text{р1}}$, $k_{\text{р2}}$ – coefficients taking into account material cutting resistance softening in the cutting zone and cutters parameters for the advanced and retarded screws; $n_{\text{ш1}}$, $n_{\text{ш2}}$ – the number of cutters in service at the advanced and retarded screws; $R_{\text{ш1}}$, $R_{\text{ш2}}$, $R_{\text{з}}$ – the radii of the advanced and retarded screws and the radius of a star wheel of the shearer chainless feed system; a – the coefficient taking into account the cutting force projection on the vector of shearer traversing speed; G – shearer weight; f – shearer legs friction coefficient in the guides of the shearer; α – strata descent angle of incidence.

The torques of cutting and feed resistance forces:

$$M_{\text{с1}} = F_{\text{р1}} R_{\text{ш1}}; \qquad M_{\text{с2}} = F_{\text{р2}} R_{\text{ш2}}; \qquad M_{\text{п}} = F_{\text{п}} R_{\text{з}}.$$

The present research proposes proportional-integral FC as a cutting torque controller, the structure of which is presented at fig. 2.

At the structural scheme, the signal of error in discrete form $e_k = M_{\text{з}} - M_{\max}$ ($M_{\text{з}}$, $M_{\max}$ – correspondingly preset and actual maximum value of cutting torque of one screw) incomes to evaluation units of proportional part e_p and integral part e_i. In fuzzification block for signal e_p, four fuzzy sets have been applied $A1$, $A2$, $A3$, $A4$, and for signal e_i – three fuzzy sets N, Z, P. The membership functions for FC inputs are presented at fig. 3. The use of four fuzzy sets for proportional part fuzzification makes it possible to automatically change the gain of FC proportional part depending on the error signal ratio.

Thus, if error signal is within $e_{p1} < e_p < e_{p2}$ or $e_{p3} < e_p < e_{p4}$, then gain is the same and is determined by static slope $u(e_k)$ and is equal to K_2, and if the error signal is within $e_{p2} < e_p < e_{p3}$,then gain is equal to K_1, which is less than K_2. Thus, FC gain variation at cutting error ratio variation makes it possible to keep the general coefficient of torque stabilization system constant and ensure permanent transient performance.

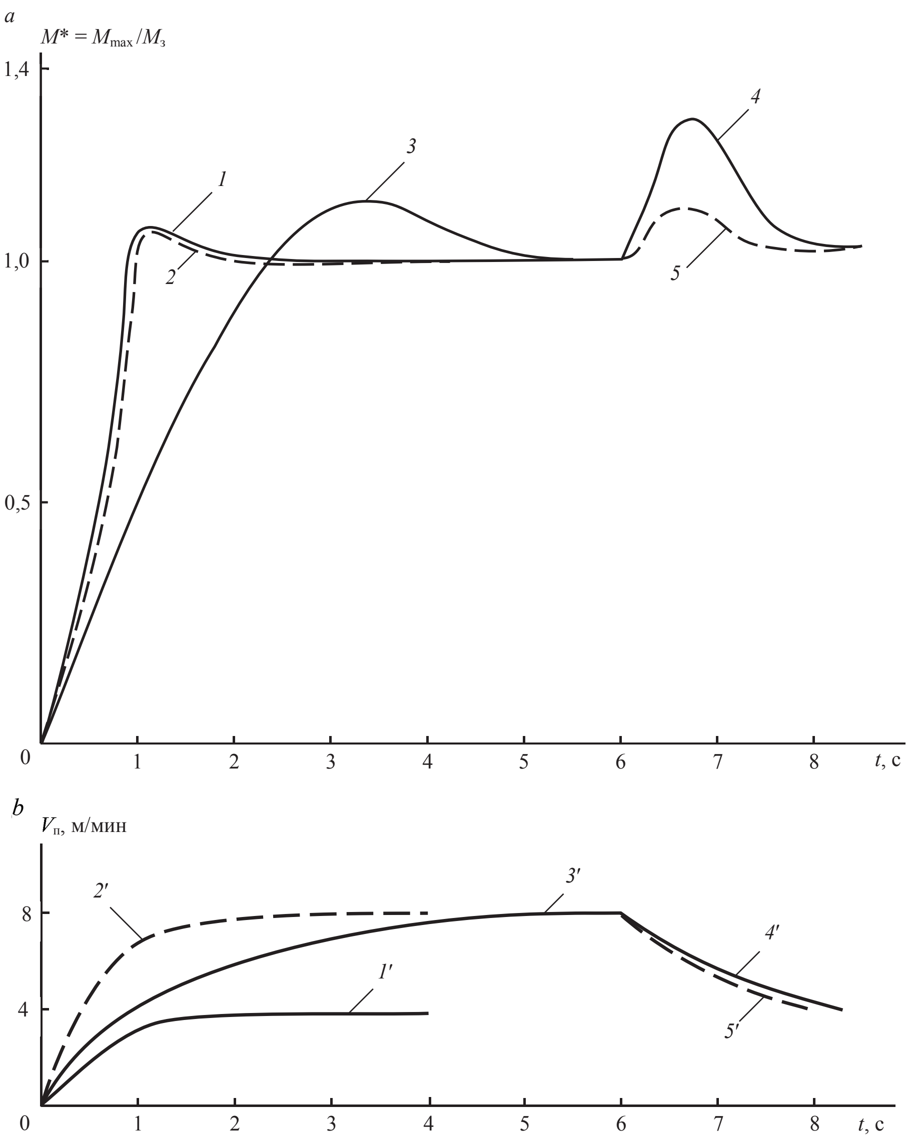

Fig. 4. Graphs of transition processes of the nominal torque $M^* = M_{max}/M_з$ – *a* and feed velocity $V_п$ of the shearer – *b* under step control action and perturbing action

Рис. 4. Графики переходных процессов относительного момента $M^* = M_{max}/M_з$ – *a* и скорости подачи $V_п$ комбайна – *b* при ступенчатом управляющем и возмущающем воздействиях

The rule of the worked out structure of FC (fig. 2) includes 12 elements of linguistic rules:

$$\text{R1: if } (e_p = A1) \text{ and } (e_p = N), \text{ then } (u - B_1);$$

$$\dots \quad \dots \quad \dots$$

$$\text{R12: if } (e_p = A4) \text{ and } (e_p = P), \text{ then } (u - B_{12}).$$

Defazzification is carried out according to the method of one-element fuzzy sets with the use of sets $B_1 \dots B_{12}$ (fig. 2). In this case the signal at the output of torque controller also takes on one of discrete values $B_1 \dots B_{12}$.

The comparison of the quality of shearer cutting torque stabilization and the traditional PI controller and the proposed FC is carried out using the method of mathematical modeling in MATLAB in Fuzzy Logic Toolbox section. As a result of modeling the graphs are drawn (fig. 4) for nominal cutting torque transition processes $M^* = M_{max} / M_з$ and feed velocity $V_п$ of a shearer under step control: the graphs of torque *1* and velocity *1′* correspond to the transition process for PI controller and FC under material cutting resistance $\overline{A}$ = 200 kN/m; graphs *2* and *2′* correspond to the transition process for PI controller and FC under $\overline{A}$ = 100 kN/m; graphs *3* and *3′* – transition process for PI controller, under $\overline{A}$ = 100 кН/м. It follows from the analysis of graphs that the time of cutting torque transition process and feed velocity for PI controller increases approximately twice if material cutting resistance reduces, and for FC the time of the transition process remains almost permanent.

For step perturbing action and material cutting resistance variation from 100 to 200 kN/m the graphs of torque and velocity of feed are shown at fig. 4: for PI controller – *4* and *4′*, for FC – *5* and *5′*. Graphs analysis has shown that the use of FC has made it possible to reduce the system overshoot by 15% and increase the speed by 25%.

Summary. The mathematical model of shearer loader cutting torque stabilization system has been obtained which takes into account material cutting resistance variability, the constant of chip formation and the dynamic properties of cutting drives and feed drives.

Shearer loader cutting torque fuzzy controller has been synthesized, in which four fuzzy sets have been applied at proportional part fuzzification, providing automatic variation of the controller gain depending on error ratio.

The results of mathematical modelling of the shearer cutting torque stabilization system have shown that the use of the proposed fuzzy controller makes it possible to obtain control action transition process independent of cutting resistance variation and lower overshoot under perturbing actions.

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Information about authors:

Gennadii I. Babokin – DSc (Engineering), Professor, professor of the Department of Energy and Energy Efficiency, National University of Science and Technology MISIS, College of Mining. E-mail: babokinginov@yandex.ru
Dmitrii M. Shprekher – DSc (Engineering), Associate professor, professor of the Department of Electrical Engineering and Electrical Equipment, Tula State University. E-mail: shpreher-d@yandex.ru
Evgenii B. Kolesnikov – PhD (Engineering), Associate professor, associate professor of the Department of Industrial Power Supply, Novomoskovsk Institute of Russian Chemical Technology University named after D. I. Mendeleev. E-mail: kolesnikov55@mail.ru

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Синтез системы стабилизации момента резания выемочного комбайна с нечетким регулятором

Бабокин Г. И.[1], Шпрехер Д. М.[2], Колесников Е. Б.[3]
[1] Национальный исследовательский технологический университет "МИСиС", Горный институт, Москва, Россия.
[2] Тульский государственный университет, Тула, Россия.
[3] Новомосковский институт Российского химико-технологического университета, Новомосковск, Тульская обл., Россия.

Реферат
Введение. *Повышение эффективности добычи полезных ископаемых выемочными комбайнами, применяемыми в очистных и проходческих механизированных комплексах, достигается совершенствованием их конструкции и систем управления. При вариации сопротивляемости полезного ископаемого для полного использования мощности электродвигателей исполнительного органа комбайна применяется регулятор момента (нагрузки) электропривода резания, параметры качества регулирования которого зависят от величины сопротивляемости резанию. В связи с этим актуальна задача разработки системы стабилизации момента резания привода выемочного комбайна с неизменными параметрами качества регулирования путем применения интеллектуальных систем управления.*
Цель работы. *Синтез нечеткого регулятора момента резания электропривода выемочного комбайна, повышающего качество стабилизации момента резания при изменении сопротивляемости материала резанию, и оценка его эффективности методом математического моделирования.*
Методология. *Разработана математическая модель стабилизации момента резания электропривода выемочного комбайна, обоснована структура и параметры нечеткого регулятора момента резания. Методом модельного эксперимента проведено сравнение предложенного нечеткого регулятора с типовым ПИ-регулятором.*
Результаты. *Получена математическая модель системы стабилизации момента резания угольного комбайна, учитывающая изменчивость сопротивления материала резанию, постоянную стружкообразования и динамические свойства приводов резания и подачи. Синтезирован нечеткий регулятор момента резания выемочного комбайна, в котором при фаззификации пропорциональной части применены четыре нечетких множества, обеспечивающие автоматическое изменение коэффициента усиления регулятора в зависимости от величины рассогласования. Модельный эксперимент показал, что применение нечеткого регулятора позволяет уменьшить перерегулирование переходного процесса по моменту на 15 % и повысить его быстродействие на 25 % при изменении сопротивляемости материала резанию в 2 раза.*
Выводы. *Применение предложенного нечеткого регулятора позволяет получить не зависимое от изменения сопротивляемости резания качество переходного процесса по управляющему воздействию и меньшее перерегулирование при возмущающем воздействии.*

Ключевые слова: *нечеткий регулятор; угольный комбайн; привод подачи; привод резания; математическая модель; переходный процесс; крепость угля.*

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Сведения об авторах:

Бабокин Геннадий Иванович – доктор технических наук, профессор, профессор кафедры энергетики и энергоэффективности Горного института Национального исследовательского технологического университета "МИСиС". E-mail: babokinginov@yandex.ru
Шпрехер Дмитрий Маркович – доктор технических наук, доцент, профессор кафедры электротехники и электрооборудования Тульского государственного университета. E-mail: shpreher-d@yandex.ru
Колесников Евгений Борисович – кандидат технических наук, доцент, доцент кафедры электроснабжения промышленных предприятий Новомосковского института Российского химико-технологического университета. E-mail: kolesnikov55@mail.ru

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