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STRUCTURAL-PARAMETRIC SYNTHESIS OF ROLLING MILLS MULTI-MOTOR ELECTRIC DRIVES

***Aim.** Improving of control accuracy by rolling strip thickness and tension and reducing of sensitivity to changes of plant parameters based on structural-parametric synthesis of robust control by rolling mills multi-motor electric drives with parametric uncertainty. **Methodology.** The method of structural-parametric synthesis of robust control by rolling mills multi-motor electric drives with parametric uncertainty which improves control accuracy by rolling strip thickness and tension and reducing of sensitivity to changes of plant parameters is developed. The method based on the multi-criteria game decision in which payoff vectors are dispersions of longitudinal thickness and tension of the rolled. The calculation of the payoff vector associated with modeling of the synthesized system with different input signals and for various values of the plant parameters for various modes of operation of the system. The multi criterion game solution is calculated based on particles multiswarm optimization algorithms. **Results.** The results of the structural-parametric synthesis of robust control by 740 three-stand cold rolling mills multi-motor electric drives are presented. Comparisons of the strip thickness and tension accuracy of the synthesized robust system with the existing system are completed. It is showed that the use of synthesized robust controllers allowed to improve strip thickness and tension accuracy and reduce the sensitivity of the system to changes of plant parameters in comparison with the existing system. **Originality.** For the first time the method of structural-parametric synthesis of robust control by rolling mills multi-motor electric drives with parametric uncertainty based on multi-criteria game decision and particles multiswarm optimization algorithms to improve the control accuracy by rolling strip thickness and tension and to reduce of sensitivity to changes of plant parameters is developed. **Practical value.** Practical recommendations on reasonable choice of the structure and parameters of robust control by 740 three-stand cold rolling mills multi-motor electric drives to improving of control accuracy by rolling strip thickness and tension and reducing of sensitivity to changes of plant parameters are given.* References 20, figures 2.

Key words: **rolling mill, multi-motor electric drive, rolling strip thickness and tension control, computer simulation.**

***Цель.** Повышение точности регулирования толщины и натяжения прокатываемой полосы и снижение чувствительности к изменениям параметров объекта управления на основе структурно-параметрического синтеза робастного управления многодвигательными электроприводами прокатных станов с параметрической неопределенностью. **Методология.** Разработан метод структурно-параметрического синтеза робастного управления многодвигательными электроприводами прокатных станов с параметрической неопределенностью, который позволяет повысить точность регулирования толщины и натяжения прокатываемой полосы и снизить чувствительность к изменениям параметров объекта управления. Метод основан на решении многокритериальной игры, в которой вектором выигрыша являются дисперсии продольной толщины и натяжения прокатываемой полосы. Вычисление вектора выигрыша связано с моделированием синтезированной системы при различных входных сигналах, для различных значений параметров объекта управления и в различных режимах работы. Решение многокритериальной игры основано на алгоритмах оптимизации роем частиц. **Результаты.** Приводятся результаты структурно-параметрического синтеза робастного управления многодвигательным электроприводом трехклетьевого стана холодной прокатки 740. Проведено сравнение точности регулирования толщины и натяжения полосы в синтезированной робастной и в существующей системах. Показано, что применение синтезированного робастного регулятора позволило повысить точность регулирования толщины и натяжения полосы и снизить чувствительность системы к изменениям параметров объекта управления по сравнению с существующей системой. **Оригинальность.** Впервые разработан метод структурно-параметрического синтеза робастного управления многодвигательными электроприводами прокатных станов с параметрической неопределенностью на основе решения многокритериальной игры и алгоритмов оптимизации роем частиц для повышения точности регулирования толщины и натяжения прокатываемой полосы и снижения чувствительности к изменениям параметров объекта управления. **Практическая ценность.** Даны практические рекомендации по обоснованному выбору структуры и параметров робастного управления трехклетьевым станом холодной прокатки 740 для повышения точности регулирования толщины и натяжения прокатываемой полосы и снижение чувствительности к изменениям параметров объекта управления.* Библ. 20, рис. 2.

Ключевые слова: **прокатный стан, многодвигательный электропривод, регулирование толщины и натяжения прокатываемой полосы, компьютерное моделирование.**

Introduction. A rolling mill is complex multi-motor unit in which individual stands are interconnected by a rolling metal strip [1-5]. The multi stands rolling rolls rates using the main electric drives must be strictly coordinated to maintain a given strip tension in the inter-chain spaces. In addition, in hot rolling mills, loopers electric drives are used to control by strip tension. The strip tension is controlled by a simultaneous change the looper elevation angle and a coordinated change of the rolls rates of the previous and subsequent stands [6-9]. By means of front and rear winders, the specified strip tension at the inlet and outlet of the rolling mill is controlled. Regulation of the rolling rolls position is carried out with the help of electric drives of pressure screws [10-14].

The regulation system uses gauges of thickness, tension and speed of movement of the rolled strip at the inlet and outlet of the rolling mill, as well as in the inter-clearances [15-18].

The rolling process is accompanied by fluctuations in technological parameters – thickness, rolling pressure, strip tension, etc. Moreover, if the fluctuations in the strip thickness are caused by both the unevenness of the thickness and mechanical properties of the rolled products, as well as by the eccentricities of the rolls of the rolling stand, then the fluctuations in the strip tension and proportional fluctuations in the currents of the main drives are due to the presence of elastic elements in the transmissions of the rolling moment from the drive motor to the rolling roll.

Fluctuations of the rolling mill rolls due to the presence of elastic elements (natural vibrations) have a decisive influence on the quality of the rolled products and are referred to as «vibrations». At the same time, in rolling mills, the frequencies of natural vibrations are in the range of 10-70 Hz [16–18].

The strip tension is influenced to the output strip thickness, so there is a fundamental possibility of «thin» thickness control by influencing the peripheral of the rolls rates (the main drives rates). In addition, the strip tension contributes to the production of a higher quality of strip with respect to the thickness difference in the strip width, which obtained due to the uneven production of work rolls «barrels».

Strip tension is an important technological factor that ensures the normal operation of the entire mill. The strip tension is a complex function of the speed difference of two adjacent stands and created due to the traction force of the drive motor of each subsequent stand. With a change in tension, the pressure of the metal on the rolls changes: with an increase in tension, the pressure of the metal on the rolls decreases, with a decrease in tension, the pressure increases. This is true for both front and rear strip tension changes. A metal pressure change on the rolls, in turn, leads to a change in the elastic deformation of the cage elements, i.e. at the same position of the pressure screws, the output strip thickness may be different.

Therefore, the design of advanced automatic control systems for a rolling mill requires the consideration of a multi- motor electromechanical mill system as a single electromechanical system. The synthesis of control systems by geometric parameters of multi-strand rolling mill is a complex problem that has a high dimension and cannot be solved by traditional methods.

The purpose of the work is improving of control accuracy by rolling strip thickness and tension and reducing of sensitivity to changes of plant parameters based on structural-parametric synthesis of robust control by rolling mills multi-motor electric drives with parametric uncertainty.

Problem statement. Let us consider the main provisions of the concept for design of automated control by rolling technological processes based on the synthesis of a two-level optimal control, which allows to synthesize optimal control systems for the main drives roll rate, position of pressure screws, positions of loop holders and of individual rolling stands at the lower level, and to synthesize optimal controllers at the upper level automatic control systems by thickness, tension, and loop of rolling strip.

Mathematical models of electric drives. At the beginning let us consider the mathematical models of electric drives which is need to synthesize of control systems by the position of pressure screws, positions of loop holders and rate of the main drives for individual rolling stands.

All the main electric drives of newly built rolling mills are AC electric drives. Upgrading of existing main drive lines due to limited production space, existing DC motors replaced by AC motors. These motors have a greater degree of load, higher dynamics due to a decrease in the moment of inertia of the rotor and almost twice as much output power with the same requirements for the size of the installation site. In addition, synchronous motors have higher efficiency, a large available field weakening zone and high accuracy of torque maintenance.

Each individual main drive has its own setting action supplied through the regulator to the input of the frequency converter [15].

In the vector control by synchronous drives in most control systems, an algorithm for direct control of the motor torque is implemented [16]. Moreover, according to the majority of manufacturers of frequency converters, the rise time of the moment does not exceed 2 ms. The decay time of the moment with such a control algorithm is generally practically taken to be zero. Therefore, we will assume that the system uses frequency control of drive motors, implements hardware-software direct torque control, and we will take mathematical models of direct torque control loops in the form of proportional links.

Let us consider the mathematical models of individual main drives in the form of two-mass and three-mass electromechanical systems [16]. The mathematical model of the main electric drive, the motor is located closer to the rolling stand, takes into account two concentrated moments of inertia of the motor rotor and the rolling roll connected by an elastic shaft.

The equations of such main electric drive can written as follows

$$\begin{aligned} J_R \frac{d\omega_R}{dt} &= M_E + \beta_E(\omega_M - \omega_R) - M_P; \\ \frac{dM_E}{dt} &= C_E(\omega_M - \omega_R); \\ J_M \frac{d\omega_M}{dt} &= M_M - M_E - \beta_E(\omega_M - \omega_R), \end{aligned} \qquad (1)$$

where ω_R, ω_M – rotation rate of the roll and the motor; J_R, J_M – moment of inertia of the roll and motor; M_E – elasticity moment; M_P – rolling moment; C_E, β_E – stiffness and internal viscous friction coefficient of the elastic shaft on twisting.

The mathematical model of the main drive, the motor of which is located further from the rolling stand, takes into account three concentrated moments of inertia - the rotor of the motor, the coupling and the rolling roll connected by elastic shafts.

The equations of such main electric drive can written as follows

$$
\begin{aligned}
&J_R \frac{d\omega_R}{dt} = M_{E2} + \beta_{E2}(\omega_C - \omega_R) - M_P;\\
&\frac{dM_{E2}}{dt} = C_{E2}(\omega_C - \omega_R);\\
&J_C \frac{d\omega_C}{dt} = M_{E1} + \beta_{E1}(\omega_M - \omega_C) - M_{E2} - \ldots\\
&\qquad \ldots - \beta_{E2}(\omega_C - \omega_R)\\
&\frac{dM_{E1}}{dt} = C_{E1}(\omega_M - \omega_C);\\
&J_M \frac{d\omega_M}{dt} = M_M - M_{E1} - \beta_{E1}(\omega_M - \omega_C),
\end{aligned}
$$

where ω_R, ω_C, ω_M and J_R, J_C, J_M – are the rotation rate and moments of inertia of the roll, coupling and motor; M_{E1}, M_{E2} – are elasticity moments in high-rate and low-rate shafts; C_{E1}, C_{E2} and β_{E1}, β_{E2} – are stiffness and internal viscous friction coefficient of the elastic high-rate and low-rate shafts on twisting.

For hot rolling mills, the mathematical model of the electric drives of looper positions usually are adopted two-mass electromechanical systems form.

The equations of such main electric drive can written as follows

$$
\begin{aligned}
&J_L \frac{d\omega_L}{dt} = M_{EL} + \beta_{EL}(\omega_{ML} - \omega_L) - M_L;\\
&\frac{dM_{EL}}{dt} = C_{EL}(\omega_{ML} - \omega_L);\\
&J_{ML} \frac{d\omega_{ML}}{dt} = M_{ML} - M_{EL} - \beta_{EL}(\omega_{ML} - \omega_L),
\end{aligned}
\tag{2}
$$

where ω_L, ω_{ML} – rotation rate of the looper and the motor; J_L, J_{ML} – moment of inertia of the looper and looper motor; M_{EL} – elasticity moment; M_L – looper moment; C_{EL}, β_{EL} – stiffness and internal viscous friction coefficient of the elastic shaft on twisting for looper.

However, the feature of work of electric drives of looper positions is the nonlinear (sinusoidal) dependence of the looper load moment on the looper table angular position, that makes such electromechanical systems a substantially non-linear plant [4, 5].

The mathematical model of the electric drives of pressure screws usually are adopted in the form of single-mass electromechanical systems.

$$
J_{PS} \frac{d\omega_{PS}}{dt} = M_{MPS} - M_{PPS} - M_{FPS}\,\mathrm{sign}(\omega_{PS}), \tag{3}
$$

where ω_{PS} – rotation rate of the pressure screws; J_{PS} – moment of inertia of the pressure screws; M_{MPS} – moment of the pressure screws motor; M_{PPS} – load moment to the pressure screws by rolling pressure; M_{FPS} – dry friction moment on the pressure screws.

Moreover, the dry friction moment on the shaft of the compression screws makes up a significant part of the moment of motor breakdown, which makes it necessary to consider such electromechanical systems as a substantially nonlinear plant [4, 5].

Mathematical model of rolling mills multi-motor electric drives.

Consider now the mathematical model of rolling mills as plant by multi-motor electric drives. For the design of local subsystems for automatic control of the thickness, tension and loop of the strip, a mathematical model of the rolling mill as a plant is required. Let us first consider the basic equations relating the energy-power parameters of one rolling stand. The quantitative increment of the final thickness Δh_1, the total rolling force ΔP and the rolling moment ΔM, as well as the increment of the rolling metal lead value ΔS, are as follows [1]:

$$
\begin{aligned}
\Delta h_1 = {}& \frac{\partial h_1}{\partial h_0}\Delta h_0 + \frac{\partial h_1}{\partial T_0}\Delta T_0 + \frac{\partial h_1}{\partial T_1}\Delta T_1 + \frac{\partial h_1}{\partial z_0}\Delta z_0 + \ldots\\
&\ldots + \frac{\partial h_1}{\partial \sigma_T}\Delta\sigma_T + \frac{\partial h_1}{\partial f}\Delta f;
\end{aligned}
\tag{4}
$$

$$
\begin{aligned}
\Delta P = {}& \frac{\partial P}{\partial h_0}\Delta h_0 + \frac{\partial P}{\partial h_1}\Delta h_1 + \frac{\partial P}{\partial T_0}\Delta T_0 + \ldots\\
&\ldots + \frac{\partial P}{\partial T_1}\Delta T_1 + \frac{\partial P}{\partial \sigma_T}\Delta\sigma_T + \frac{\partial P}{\partial f}\Delta f;
\end{aligned}
\tag{5}
$$

$$
\begin{aligned}
\Delta M = {}& \frac{\partial M}{\partial h_0}\Delta h_0 + \frac{\partial M}{\partial h_1}\Delta h_1 + \frac{\partial M}{\partial T_0}\Delta T_0 + \frac{\partial M}{\partial T_1}\Delta T_1 + \ldots\\
&\ldots + \frac{\partial M}{\partial \sigma_T}\Delta\sigma_T + \frac{\partial M}{\partial f}\Delta f;
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
\Delta S = {}& \frac{\partial S}{\partial h_0}\Delta h_0 + \frac{\partial S}{\partial h_1}\Delta h_1 + \frac{\partial S}{\partial T_0}\Delta T_0 + \frac{\partial S}{\partial T_1}\Delta T_1 + \ldots\\
&\ldots + \frac{\partial S}{\partial \sigma_T}\Delta\sigma_T + \frac{\partial S}{\partial f}\Delta f,
\end{aligned}
\tag{7}
$$

where Δh_0, ΔT_0, ΔT_1, Δz_0, $\Delta\sigma_T$, Δf are the absolute increments, respectively, of the initial thickness, the rear and front tension of the strip, the roll gap, mechanical properties, rolled metal and the value of the external friction coefficient in the deformation zone.

Based on these equations, we consider a mathematical model of a multi-stand rolling mill consisting of k stands located at a distance L_i from each other and interacting through an elastically strained strip following [1].

We introduce the vectors of the input $\boldsymbol{H}_i^*$ and output $\boldsymbol{H}_i$ thicknesses, the input $\boldsymbol{T}_i^*$ and output $\boldsymbol{T}_i$ tension and the position $\boldsymbol{B}_i$ of the pressure devices, the components of which are the corresponding values for each stand $J = \overline{1,n}$, for the linearized model and small deviations of the values from their nominal values, we obtain the following relation

$$
\begin{aligned}
\boldsymbol{H} = {}& \boldsymbol{HH} \otimes \boldsymbol{H}^* + \boldsymbol{HT}^* \otimes \boldsymbol{T}^* + \boldsymbol{HT} \otimes \boldsymbol{T} + \ldots\\
&\ldots + \boldsymbol{HB} \otimes (\boldsymbol{B} + \boldsymbol{\eta}\sin\omega t),
\end{aligned}
\tag{8}
$$

where $\boldsymbol{HH}$, $\boldsymbol{HT}^*$, $\boldsymbol{HT}$, $\boldsymbol{HB}$ are the vectors of the corresponding transmission coefficients; $\boldsymbol{\eta}$ – vector of eccentricities of rolls; $\otimes$ – Kronecker (element-wise) multiplication of vectors. The time index hereinafter, where it is not needed, is omitted.

Similar relations can be obtained for the moment vectors of the main drives and the advance of the strip speed:

$$
\begin{aligned}
\boldsymbol{M} = {}& \boldsymbol{MH}^* \otimes \boldsymbol{H}^* + \boldsymbol{MH} \otimes \boldsymbol{H} + \ldots\\
&\ldots + \boldsymbol{MT}^* \otimes \boldsymbol{T}^* - \boldsymbol{MT} \otimes \boldsymbol{T};
\end{aligned}
\tag{9}
$$

$$
\begin{aligned}
\boldsymbol{S} = {}& \boldsymbol{SH}^* \otimes \boldsymbol{H}^* + \boldsymbol{SH} \otimes \boldsymbol{H} + \ldots\\
&\ldots + \boldsymbol{ST}^* \otimes \boldsymbol{T}^* + \boldsymbol{ST} \otimes \boldsymbol{T},
\end{aligned}
\tag{10}
$$

where the vectors of transmission coefficients with respect to the moment $\boldsymbol{MH}^*$, $\boldsymbol{MH}$, $\boldsymbol{MT}^*$, $\boldsymbol{MT}$ and leading $\boldsymbol{SH}^*$, $\boldsymbol{SH}$, $\boldsymbol{ST}^*$ according to the corresponding variables are determined by the technique described in [1].

The strip output speed vector is determined by the relation

$$\boldsymbol{v} = \boldsymbol{v\omega} \otimes \boldsymbol{\omega} + \boldsymbol{vS} \otimes \boldsymbol{S}, \tag{11}$$

where $\boldsymbol{\omega}$, $\boldsymbol{v\omega}$ – are the vectors of speed of rotation of the drive rolls and the circumference of the rolls barrel; $\boldsymbol{vS}$ – the vector of transmission coefficients of the change in the strip output speed when changing the lead $\boldsymbol{S}$.

From the second volume constancy equation during rolling

$$\boldsymbol{v}^* \otimes \boldsymbol{H}^* = \boldsymbol{v} \otimes \boldsymbol{H}, \tag{12}$$

the input velocity vector $\boldsymbol{v}^*$ can be determined. Neglecting the mass of the strip and assuming the instantaneous propagation of stresses along the length of the strip, we obtain

$$\boldsymbol{T}(j) = \boldsymbol{T}^*(j+1) \text{ for } j = \overline{1,(n-1)}, \tag{13}$$

where $\boldsymbol{T}^*(j)$ is the tension on the strip unwinder.

Strip winding tension

$$\boldsymbol{T}(j) = \boldsymbol{TL}(j)\left\lfloor \boldsymbol{v}^*(j+1) - \boldsymbol{v}(j) \right\rfloor \Delta t; \quad j = \overline{1,(n-1)}, \tag{14}$$

where $\boldsymbol{TL}$ is the vector of specific stiffness of the strip in tension in the inter-cleft gap between the j-th and (j+1)-th stands, having a (n–1) dimension.

The thickness $\boldsymbol{H}^*(j+1)$ of the strip at the entrance of the (j+1) stand is equal to the thickness $\boldsymbol{H}(j)$ of the strip at the exit of the j-th stand, taking into account the time of transport delay

$$\boldsymbol{H}_i^*(j+1) = \boldsymbol{H}_{i-k}(j) \text{ and } j = \overline{1,(n-1)},$$

where $k = \mathrm{int}(L_{j,\,(j+1)} / L_{bj})$ – is the integer part of the number equal to the deviation of the length of the inter-cleft gap $L_{j,\,(j+1)}$ between the j-th and (j+1)-th stands from the base length L_{bj} of the strip in this gap.

Mathematical models of the main electric drives, winder drives, loop holder drives, push-button electric drives are described in the form of a state space in the form of corresponding state equations.

Method of synthesis. We form the structure of a multi-connected system for automatically controlling by thickness, tension and loop of the strip based on typical schemes for a broadband mill. We introduce the vector $\boldsymbol{X}$ of the desired parameters, the components of which are the gain of the regulators (P, PI, PID, etc.).

We also introduce the vector Δ of uncertainties of the system characterizing the real deviation of the system parameters from their calculated values. Note, then the transmission coefficients in the (1-4) expressions change most strongly during the rolling process for different rolling passes and when the rolled strip assortment changing.

Changes in strip thickness and tension are random processes. The main purpose of the system for regulating the thickness, tension and loops of a broadband hot rolling mill is to maintain the set values of the strip thickness behind the rolling stands, inter-stand tension and also the rotation angles of the loop holders at given levels.

Then the problem of structural-parametric synthesis of robust control by rolling mills multi-motor electric drives with parametric uncertainty can formulated in the multi-criteria game form [12] with payoff vector

$$\boldsymbol{J}(X,\Delta) = \begin{bmatrix} \Delta\boldsymbol{H}(\boldsymbol{X},\Delta)_1^2, \Delta\boldsymbol{H}(\boldsymbol{X},\Delta)_2^2, \ldots \\ \ldots, \Delta\boldsymbol{H}(\boldsymbol{X},\Delta)_N^2, \Delta\boldsymbol{T}(\boldsymbol{X},\Delta)_1^2, \ldots \\ \ldots, \Delta\boldsymbol{T}(\boldsymbol{X},\Delta)_2^2, \Delta\boldsymbol{T}(\boldsymbol{X},\Delta)_{N-1}^2 \end{bmatrix}^T. \tag{15}$$

The components of the payoff vector are the dispersions of thicknesses $\Delta\boldsymbol{H}_i^2$ and dispersions of fluctuations in interstand tension $\Delta\boldsymbol{T}_i^2$ relative to their given values, and the deviations of the strip thickness at the exit of the i-th stand from the given value.

In the multi-criteria game (15) the first player is the vector $\boldsymbol{X}$ of the desired regulators parameters, and its strategy is the minimization of the vector gain, and the second player is a parametric external influences vectors Δ and the strategy of this player is maximization of the same vector gain [6], [7] and [12].

To find the decision of the multi-criterion games (15) from Pareto-optimal decisions [19] taking into account the preference relations [20], we used special nonlinear algorithms of stochastic multi-agent optimization.

The synthesized system parameters are determined from the multi-criteria game solution. The synthesized system structure is formed by nonzero elements from the initial excessively specified structure.

Computer simulation results. For the structural-parametric synthesis of robust control and for research of the rolling strip thickness and tension accuracy the mathematical model of multi- stands rolling mills as plant by multi-motor electric drives and the mathematical models of external influences are required. In addition, the external influences mathematical models are needed to calculate the performance and required power of electric drives, and to formulate requirements for the measuring devices accuracy.

As an example in Fig. 1 are shown experimental oscillograms of the rolling process variables on the three-stands cold rolling mill (STAN–740) with systems for controlling the thickness and tension of the strip is off. In Fig. 1 are shown: T_{12}, T_{23} – strip tension in the inter-stand spaces between the first and second stands and between the second and third stands; H_2 is the rolling pressure in the second stand; S_3 – deviation of the strip thickness behind the third stand. From these oscillograms, the mathematical model of external disturbances is constructed.

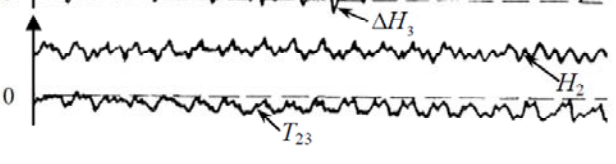

Fig. 1. Experimental oscillograms of variables of the rolling process on three-stands cold rolling mill (STAN-740)

The developed set of programs based on MATLAB was used in the synthesis of a system for automatically controlling the strip thickness and tension of a three-stand mill, on which comprehensive studies were conducted to identify the model of the mill as a control object. As an example in Fig. 2 are shown the implementation of random changes in longitudinal thickness variation and inter-stand tension in the synthesized system for three stands of the cold rolling mill (STAN–740) for the conditions of rolling steel 65G width 600 mm from thickness H_1^* = 2 mm to H_3 = 1.55 mm.

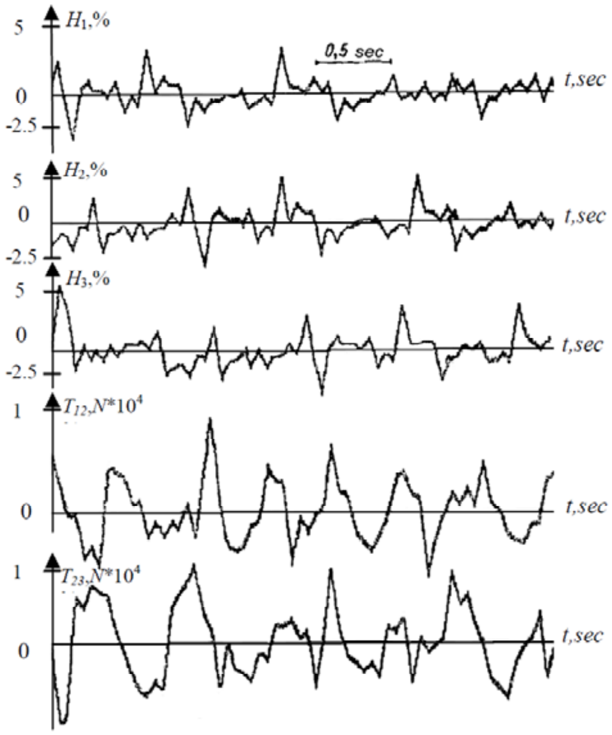

Fig. 2. Realization of random changes in longitudinal thickness variation and inter-stand tension in a synthesized system for three stands cold rolling mill (STAN-740)

The greatest decrease in the longitudinal thickness difference of the rolled strip occurred in the first stand due to the strip tension regulation between the first and second stands. However, the longitudinal thickness differences behind the second and third stands are almost the same. This, apparently, is due to an increase in the rolled strip rigidity in the second and third stands due to the strip hardening during its rolling in the first stand. As can be seen from Fig. 2, random processes of adjustable coordinates in the synthesized system satisfy the technical requirements for the system for automatically controlling the strip thickness and tension.

Numerous computer simulations of the strip thickness and tension for synthesized systems for various rolling conditions in cold and hot rolling mills were carried out.

Based on this results are shown, that the use of synthesized robust regulators made it possible to reduce the dispersions of longitudinal thickness and tension of the rolled strip in the inter-stand spaces more than 1.7-2.5 times in comparison with the existing system with typical regulator.

During the rolling process, the transmission coefficients in the (1–4) expressions change most strongly. These coefficients change most strongly for different rolling passes and when the rolled strip assortment changing. So the numerous computer simulations of the strip thickness and tension for synthesized systems for various transmission coefficients in the (1–4) expressions in cold and hot rolling mills were carried out. Based on this results are shown, that the use of synthesized robust regulators made it possible to reduce the system sensitivity to plant parameters changes on 20 % in comparison with the existing system with typical regulator.

Conclusions.

1. For the first time the method of structural-parametric synthesis of robust control by rolling mills multi-motor electric drives with parametric uncertainty based on multi-criteria game decision and particles multiswarm optimization algorithms which improves the control accuracy by rolling strip thickness and tension and reducing of sensitivity to changes of plant parameters is developed.
2. The method based on multi criterion game decision in which the vector payoff components are dispersions of longitudinal thickness and tension of the rolled strip in the inter-stand spaces. Vector payoff components calculated by modeling of the synthesized nonlinear system with different input signals, for various values of the plant parameters and for various system operation modes.
3. Based on the results of computer simulation of strip thickness and tension with the synthesized system of automatically controlling by the 740 three-stand cold rolling mill are shown, that the use of synthesized robust regulators made it possible to reduce the dispersions of longitudinal thickness and tension of the rolled strip in the inter-stand spaces more than 1.7 times, reduce on 20 % the system sensitivity to plant parameters changes in comparison with the existing system with typical regulator.

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