Статтю присвячено розробці методу спільної роботи нейромережевих настройщіков швидкості і струму якоря для додання адаптивних властивостей електроприводу прокатної кліті. Основною метою даного дослідження є узгодження корекцій параметрів регуляторів, вироблених згаданими настроювачами в режимі реального часу. Розроблено алгоритм, що забезпечує рішення даної задачі. Ефективність алгоритму показана на математичній моделі електричного приводу прокатної кліті

Ключові слова: електропривод постійного струму, нейромережевий настройщік, прокатна кліть

Статья посвящена разработке метода совместной работы нейросетевых настройщиков скорости и тока якоря для придания адаптивных свойств электроприводу прокатной клети. Основной целью данного исследования является согласование коррекций параметров регуляторов, производимых упомянутыми настройщиками в режиме реального времени. Разработан алгоритм, обеспечивающий решение данной задачи. Эффективность алгоритма показана на математической модели электрического привода прокатной клети

Ключевые слова: электропривод постоянного тока, нейросетевой настройщик, прокатная клеть

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DEVELOPMENT OF THE METHOD FOR JOINT OPERATION OF NEURAL-NETWORK TUNERS FOR CURRENT AND SPEED CIRCUITS

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1. Introduction

Among the main consumers of energy resources in metallurgical industry we can distinguish rolling production, including the rolling mills. Improving a rolling process at crimping machines is one of the most important challenges solving which would have an impact on both the efficiency of overall production and the quality of rolled products. Even a slight reduction in the energy consumption by electric drives of the rolling mills would reduce the cost of production. In this case, the automation issues are crucial for solving a problem on energy saving in the control systems of an automated electric drive.

The relevance of present study is determined by a wide distribution of high- power direct current electric rivers in the rolling production, improving energy efficiency of which even by 1–2 % would bring a significant economic effect.

2. Literature review and problem statement

The subject of present study is the system of control over motion speed of a two-high reversing rolling mill. Roughing rolling stands belong to sophisticated non-linear metallurgical aggregates whose parameters can change during operation [1, 2]. The systems of control over given units widely employ direct current electric drives and P- and PI-controllers with constant parameters. Such systems are built using the principles of subordinate regulation [3, 4], according to which the two control circuits are synthesized: an external circuit to control rotation frequency of the electric motor and the internal circuit to control current of the anchor. Applying the specified linear controllers leads to the deterioration in quality of transition processes under conditions of changing modes of operation [1, 2]. Specifically, parameters of the armature winding and mechanical part can change in the examined drive. This leads to a decrease in the energy efficiency of the rolling stand's electric drive. A given problem can be solved by adapting the parameters of the employed linear controllers under a real-time mode [5–8].

In paper [5], based on the conducted analysis of existing methods for tuning linear controllers, the authors propose using methods of indirect adaptation as the most promising approach. However, conducting an identification procedure under industrial conditions is a difficult task. Similar idea has been further developed in other studies. Specifically, in paper [6], authors apply a stepwise test signal for the identification; in article [7] – a signal based on one harmonic, and in [8] – based on two harmonics. The problem is the fact that the introduction of test signals for the identification may disrupt the required technological mode.

At the same time, the authors have already designed neural-network tuners for current controllers [9] and speed regulators [10], which operate in real time and do not require a model of the control object. Effectiveness of the tuners was tested in situations when only one of them was functioning during experiment. However, in order to improve energy efficiency of the main electric drive of a rolling stand under industrial conditions, it is necessary to employ neural-network tuners simultaneously in the circuits for speed control and anchor current. Direct application of tuners results in a "conflict" in the work logic of rule bases of each tuner. This occurs for the following reason: a change in the parameters of armature winding (which must be compensated for by a current tuner) can, under certain conditions, degrade transition processes in the speed circuit. Such a deterioration triggers a rule base of the speed circuit tuner and consequently, the tuning of the speed regulator. An opposite situation is also possible: a change in the mechanical part of an electric drive can lead to a change in the quality of work of the current circuit and subsequent tuning of the respective controller.

3. The aim and objectives of the study

The aim of present study is to devise a method for the joint operation of neural-network tuners in the control circuit of anchor speed and current in real time by designing an appropriate algorithm, which would determine which controller requires tuning.

To accomplish the aim, the following tasks have been set:

– to develop a rule base that would account for the specificity of joint operation of tuners for current circuit and speed circuit, and to represent its performance in the form of an algorithm;

– to test effectiveness of the designed rule base within the framework of a model experiment on the system that includes a neural-network tuner of speed circuit and a neural-network tuner of current circuit for a direct current electric drive.

4. Description of a neural-network tuner

We shall consider a structure of the neural-network tuner. It combines a method of the application of neural networks (NN) for the correction of coefficients of the controller and a rule base of situations when such a tuning is required. A given approach makes it possible to eliminate shortcomings of intelligent methods applied separately. Neural networks provide the capability of learning, and a rule base – information on the specificity of control object (permissible ranges of signals, setpoints, a task change form, etc.). The learning speeds of NN neurons act as corollaries of the rules. From a functional point of view, the neural-network tuner is a combination of two interconnected elements: a neural network and a rule base.

We propose the following procedure for applying a neural-network tuner in the control circuits of speed and anchor current of the main electric drive of a rolling stand (Fig. 1).

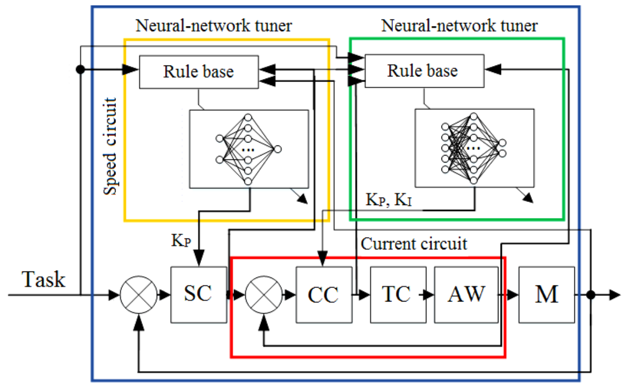

Fig. 1. Functional diagram of the application of a neural-network tuner: SC – speed controller, CC – current controller, TC – thyristor converter, AW – armature winding, M – mechanical part

In accordance with the method proposed in paper [11], the tuner of speed control circuit employs an artificial neural network with the structure 2-7-1, the tuner of current control circuit – 5-14-2. A description of the rule bases of tuners is given in [9].

5. Development of the algorithm for a joint operation of tuners

In the process of joint operation of rule bases of the examined tuners, there may appear conflicts. We shall consider the rules that cause "conflict" situations.

1. Rules for a current tuner:

– IF the first peaks in the curves of current and the task are reached, AND the task extremum module equals maximally permissible current, AND an extremum of current exceeds the extremum of task (larger than by 3 %), AND the current curve reached an extremum at a time when the task deviated from its the peak by larger than 20 % for amplitude, it is necessary to increase $K_{P\,\mathrm{curr}}$.

– IF there was no decrease in $K_{P\,\mathrm{curr}}$ during a given transition process, AND the first and second current and task extrema are reached, AND the task extremum is less than the current maximum, AND the current extremum exceeds the task extremum by not larger than 3 %, AND the second current extremum is less than the second task extremum, THEN it is necessary to increase $K_{P\,\mathrm{curr}}$.

2. Rules for a speed tuner:

– IF the overshoot for speed does not reach the required value chosen by the operator, AND the overshoot is greater than zero, THEN it is necessary to increase $K_{P\,\mathrm{speed}}$.

– IF a transition process is completed, AND the speed curve did not reach the task curve, THEN it is necessary to increase $K_{P\,\mathrm{speed}}$.

To distinguish between cases of rule triggering, we designed the algorithm shown in Fig. 2. A call for a neural-network tuner of speed controller is enabled only when two or more transition processes took place in a speed circuit without tuning a speed controller. The tuner of current controller can increase the value of $K_{P\,\mathrm{curr}}$ applying the specified rules only if overshoot in a speed circuit falls within the valid range.

6. Experimental testing of the developed algorithm on a model of the direct current electric drive

Experiments were performed on a model of the main electric drive of a two-high rolling stand, designed in MATLAB Simulink. The model represents a two-circuit control system of a DC motor with separate excitation. Controllers of current and speed are configured for the technical optimum ($K_{P\,\text{curr}}$=0.489; $K_{I\,\text{curr}}$=13.649; $K_{P\,\text{speed}}$=1.745). An armature winding model represents an aperiodic link of first order, with rated values of parameters $K_{a\,\text{nom}}$=41.67 and $T_{e\,\text{nom}}$=0.036 s. A model of the mechanical part of an electric drive is designed in the form of an integrator with a rated value of the integration time constant J_{nom}=4,798 kg·m².

Control objects, which are characterized by large moments of inertia (such as a rolling stand), require a smooth start. This leads to the impossibility of using stepwise task changes because of the likelihood of impermissible surges and high dynamic loads. The most common way to reduce dynamic loads under industrial conditions is the application of setting devices, which are called the intensity setting devices. Given the above, a task signal is implemented using an S-function. A task for speed represents the following sequence of setpoints: 0 rpm (0 V)→60 rpm (4 V)→0 rpm (0 *V*)→–60 rpm(–4 V). Neural-network tuners are also implemented in the form of *S*-functions. A more detailed description of the model is given in [9].

In the first experiment (Fig. 3), we simulated a change in the parameters of an electric motor armature windings. K_a and T_e changed in the range of 80÷120 % of rated values (Fig. 3, *f*, *g*). In line with the designed algorithm, we tuned a current controller only (Fig. 3, *d*, *e*), and the rule base of the speed tuner was not used.

In the second experiment (Fig. 4), the opposite situation was simulated: we changed a moment of inertia of mechanical part of the electric drive *J* in the range of 50÷150 % from the rated value (Fig. 4, *i*). During experiment, we tuned the speed circuit only (Fig. 4, *c*); the rule base of the current circuit tuner was not called. Based on the results of experiments we can conclude that the designed algorithm made it possible to eliminate the "conflict" situations of the current and speed tuners.

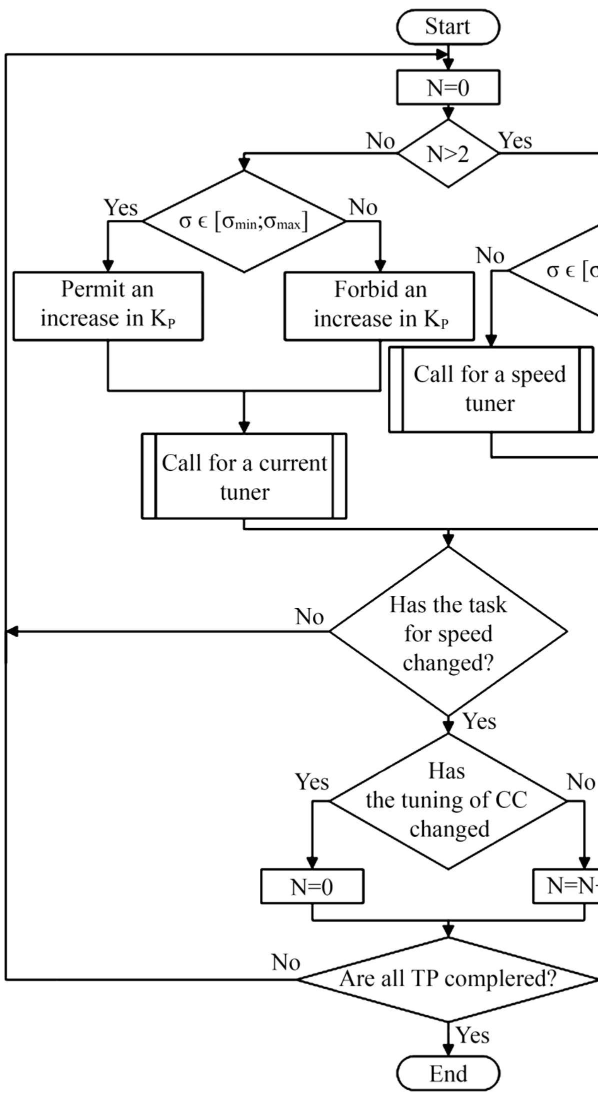

Fig. 2. Algorithm of joint operation of two neural-network tuners: *N* – number of transition processes (TP) in the speed circuit during which the tuning of CC was not performed; σ – overshoot in the speed circuit; [σ_{min}; σ_{max}] – permissible range of values for the overshoot in the speed circuit

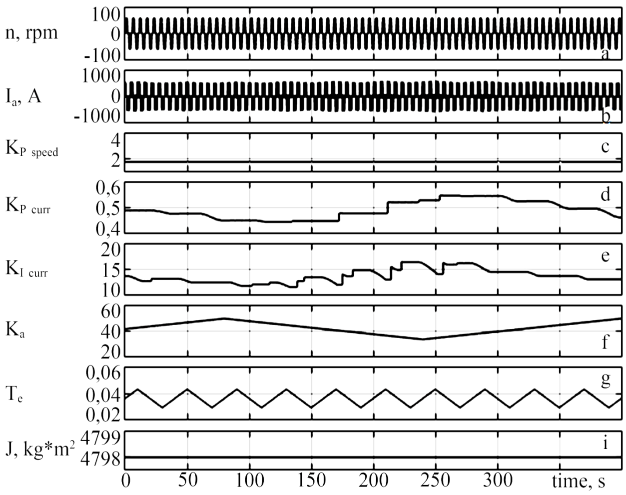

Fig. 3. Experiment with a drift in the parameters of armature winding: *a* – rotation speed, *b* – armature current, *c* – coefficient of proportional part of the speed controller, *d* – coefficient of proportional part of the current controller, *e* – coefficient of integral part of the current controller, *f* – gain factor of armature winding, *g* – time constant of armature winding, *i* – moment of inertia of the electric drive

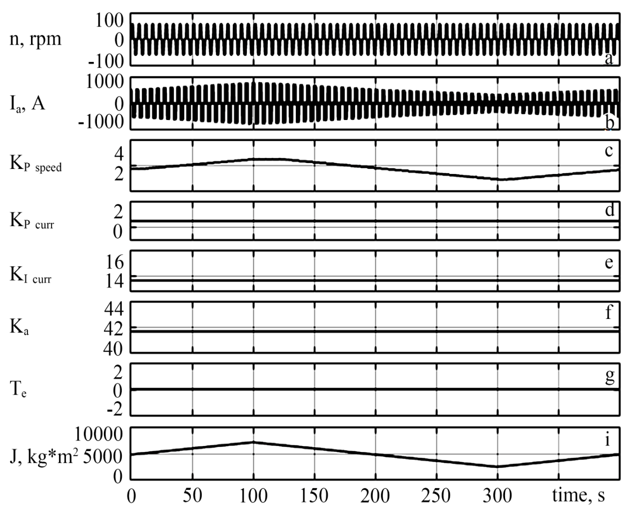

Fig. 4. Experiment with a drift in the electric drive's moment of inertia: *a* – rotation speed, *b* – armature current, *c* – coefficient of proportional part of the speed controller, *d* – coefficient of proportional part of the current controller, *e* – coefficient of integral part of the current controller, *f* – gain factor of armature winding, *g* – time constant of armature winding, *i* – moment of inertia of the electric drive

Fig. 5 shows results of the experiment, in which we simultaneously changed parameters of the motor's armature winding (Fig. 5, *f, g*) and the moment of inertia of mechanical part of the electric drive (Fig. 5, *i*).

Joint application made it possible to reduce energy consumption by the electric drive in the course of experiment, compared with the system without tuning, by 1.9 %.

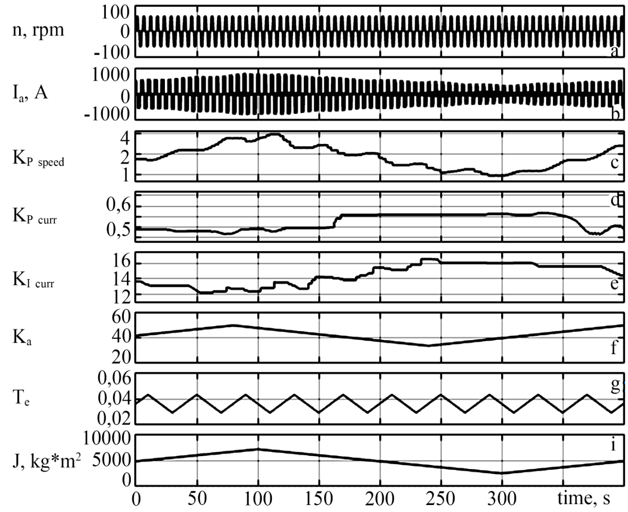

Fig. 5. Experiment with a drift in the electric drive's moment of inertia and parameters of armature winding: *a* – rotation speed, *b* – armature current, *c* – coefficient of proportional part of the speed controller, *d* – coefficient of proportional part of the current controller, *e* – coefficient of integral part of the current controller, *f* – gain factor of armature winding, *g* – time constant of armature winding, *i* – moment of inertia of the electric drive

7. Discussion of results of studying a joint application of a neural-network tuner of speed controller and a neural-network tuner of current controller

The main advantage of joint application of neural-network tuners in the circuits of speed control and current control is the simultaneous accounting for changes in the parameters of armature link of the motor and mechanical part of the electrical drive. We developed a rule base within the framework of present study, which makes it possible to maintain the order of work of the tuners.

The results obtained can be explained in the following way: we revealed two pairs of conflicting rules (chapter 5). In order to avoid their simultaneous triggering, an algorithm was developed that established priorities when calling the tuners. The primary one is tuning a current circuit controller, and only in the case that a given tuner was not called over several transitional processes, there is the possibility to call the tuner of speed circuit.

However, it cannot be argued that this method is universal as it was not validated for the circuits of excitation current and emf control, as well as for more complex control systems of electric drives. This is actually the main shortcoming of the proposed method.

The result of present study enables simultaneous application of neural-network tuners in the circuits for speed and current control. This will make it possible to estimate the character of changes in the parameters of control object more accurately. The application of tuners could improve the quality of regulation in the system of control over a DC electric drive, which in turn would improve energy efficiency of the entire unit.

A limitation on the use of the proposed method is the need to correct values for time delays in the work of neural network tuners for each particular control system over electric drive. In addition, the operation of a neural-network tuner in the speed circuit requires that a map of task in a given circuit should take the stepwise form, or the linearly growing with a restriction.

Our study is continuation of a larger study into development and application of a neural-network tuner in the control systems of a direct current electric drive [9, 10]. The aim of further research is to apply a neural-network tuner for the more complex systems of electric drive control.

The alternating current electric drive control systems are much more complicated than the one we considered: they contain a large number of interrelated control loops, and they can utilize relay, hysteresis controllers, switching tables, etc. All this makes the task of applying a neural-network tuner much more difficult, especially in terms of eliminating contradictions in the rule bases of such tuners.

8. Conclusions

1. We analyzed rule bases of neural network tuners for controllers of current and speed circuits for the existence of rules, which can be triggered simultaneously. A rule base of joint operation of tuners is developed in terms of enabling the rules depending on the quality of transition processes in the current and speed circuits, which differs from those existing in that we excluded situations involving simultaneous calling conflicting rules. One of these rules is located in the base of a current circuit tuner, and another one is in the base of a speed circuit tuner.

2. The experiments were performed on a mathematical model of the main electric drive of a rolling stand under conditions of change in the parameters of armature winding and mechanical part of the drive, both in separate experiments and together in one. Control system with two neural-network tuners has improved energy efficiency of work of the electric drive by 1.9 % compared to the system without tuning. Given the high power of the examined drive, even such a reduction in energy consumption would lead to a substantial economic effect and could bring down the cost of the rolled products.

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