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PARAMETRICAL NEIGHBORHOOD MODELLING OF THE PROCESS OF FORMING THE TEMPERATURE OF HOT-ROLLED STRIP COILING

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ABSTRACT

The possibility of applying the trilinear neighborhood model for controlling the coiling temperature of a strip when rolled on a hot rolling mill is investigated. State, control and information act as parameters. The identification of the model parameters and a mixed control of the accelerated cooling system are performed. Reduction of coiling temperature fluctuation along the length of the strip is shown.

Keywords: neighborhood system, mixed control, hot-rolled strip, run-off table, coiling temperature.

INTRODUCTION

The homogeneity of mechanical properties and the finite structure along the length of rolled stock result from the sequential formation of a homogeneous and stable structure at all the stages of controlled rolling [1]. Generally, all controlled rolling patterns are connected with the following temperatures - temperature up to which the recrystallization process runs completely ($T_{95\%}$), temperature after which recrystallization does not run ($T_{5\%}$), and the temperature of the beginning of transformation (Ar_3) [2]. The structure is finally formed on the runoff table due to the accelerated cooling of the strip from the end of rolling temperature to the coiling temperature and the subsequent cooling in the roll.

The runoff table of the hot rolling mill also includes the accelerated cooling system formed by sprayers installed above and under a moving strip (Fig. 1) and combined into 40 sections (80 half-sections) [3]. In order to control the on-off use of half-sections, an automated control system is installed on the mill, which provides the required intensity of cooling according to the rolling mode (Fig. 2) in the range of the end of rolling temperatures of 760 - 900^{o}C and the coiling temperatures of 540 - 720^{0}C characteristic for the mill [4].

In order to implement the strategy of controlling the cooling of the strip, various algorithms are used based on the linearization of the results of mathematical modeling of strip cooling on the runoff table [3, 5-7]. It should be noted that a number of parameters of a real technological process on which the control is based are measured with a considerable error due to high rolling speeds and the extent of the rolled strips, while some disturbing variables and factors cannot be measured and controlled at all. This causes fluctuation of the coiling temperature and, as a result, the heterogeneity of the structure.

The paper discusses the possibility of decreasing the fluctuation range of coiling temperature along the hot-rolled strip due to the use of a model constructed on the basis of the neighborhood approach in the water spraying control system. Neighborhood models [8, 9] are a promising direction in simulating complex systems since they are characterized by a flexibility of description by means of neighborhoods of the structure of the connections between the units of the system. The theory of neighborhood systems is a universal means of modeling a class of discrete distributed systems: stationary and dynamic, clear and fuzzy, with linear and nonlinear connections. The neighborhood models develop the general approaches of the theory of systems and the theory of

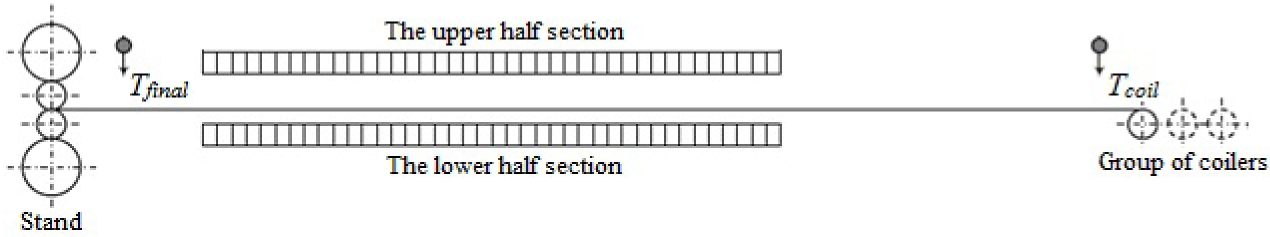

Fig. 1. The runoff table with the accelerated cooling unit diagram.

control, they generalize such traditional discrete models as finite and cellular automata, Petri nets, differential equations, etc. As a generalization for many discrete and spatial models symmetric, mixed linear, bilinear neighborhood models were introduced. This theory is generalizing for many discrete distributed systems, the use of the neighborhood approach in applied problems covers systems of different nature and orientation – from technical to economic ones. In the question of improving the system work it is relevant to study the connection of the values of the system performance indicator with a neighborhood structure. Through neighborhood models it is possible to consider both variable neighborhoods of units (variable connections within neighborhoods themselves) and the change of the structure of the neighborhood of units.

MATHEMATICAL MODEL

We will consider the implementation of the method of constructing a trilinear neighborhood model on the example of a complex distributed object – the technological process of the accelerated cooling of a hot rolled strip on a broadband hot rolling mill.

In its general form the trilinear neighborhood model takes the form:

$$\sum_{\alpha\in O_x[a]} w_x[a,\alpha]X[\alpha]+\sum_{\beta\in O_v[a]} w_v[a,\beta]V[\beta]+\sum_{\gamma\in O_y[a]} w_y[a,\gamma]Y[\gamma]+$$
$$+\sum_{\alpha\in O_x[a]}\sum_{\beta\in O_v[a]} w_{xv}[a,\alpha,\beta]X[\alpha]V[\beta]+\sum_{\alpha\in O_x[a]}\sum_{\gamma\in O_y[a]} w_{xy}[a,\alpha,\gamma]X[\alpha]Y[\gamma]+$$
$$+\sum_{\beta\in O_v[a]}\sum_{\gamma\in O_y[a]} w_{vy}[a,\beta,\gamma]V[\beta]Y[\gamma]+$$
$$+\sum_{\alpha\in O_x[a]}\sum_{\beta\in O_v[a]}\sum_{\gamma\in O_y[a]} w_{xvy}[a,\alpha,\beta,\gamma]X[\alpha]V[\beta]Y[\gamma]=0 \qquad (1)$$

where $X[a]\in R^n$, $V[a]\in R^m$, $Y[a]\in R^l$ - state, control and information in the system's unit;

$w_x[a,\alpha]\in R^{c\times n}$ $w_v[a,\beta]\in R^{c\times m}$

$w_y[a,\gamma]\in R^{c\times l}$ $w_{xv}[a,\alpha,\beta]\in R^{c\times n\times m}$

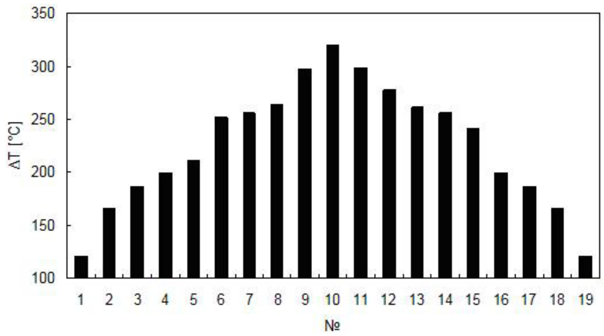

Fig. 2. Strip cooling modes (ΔT - difference of the end of rolling temperature and the coiling temperature).

$w_{xy}[a,\alpha,\gamma]\in R^{c\times n\times l}$, $w_{vy}[a,\beta,\gamma]\in R^{c\times m\times l}$, $w_{xvy}[a,\alpha,\beta,\gamma]\in R^{c\times n\times m\times l}$ - matrixes-parameters;

$O_x[a], O_v[a], O_y[a]$ - neighborhoods of the unit a according to state, control and information respectively;

$a,\alpha,\beta,\gamma\in A, A=\{a_1,a_2,...,a_n\}$ - finite set of the system's units.

The paper considers a trilinear neighborhood model which includes three units.

A detailed model (1) takes the form:

$$\begin{cases} w_x[1,1]\cdot x[1]+w_x[1,2]\cdot x[2]+...+w_{xvy}[1,2,1,1]\cdot x[2]\cdot v[1]\cdot y[1]+ \\ +w_{xvy}[1,2,1,2]\cdot x[2]\cdot v[1]\cdot y[2]=0; \\ ... \\ w_x[3,2]\cdot x[2]+w_x[3,3]\cdot x[3]+...+w_{xvy}[3,3,3,2]\cdot x[3]\cdot v[3]\cdot y[2]+ \\ +w_{xvy}[3,3,3,3]\cdot x[3]\cdot v[3]\cdot y[3]=0. \end{cases} \qquad (2)$$

Many factors influence the cooling of a strip [10-13]: chemical composition, geometrical parameters, end of rolling temperature, environmental temperature, expenditure and temperature of the cooling water on the runoff table, etc. These factors change over time along the length of the strip. Essential components of state, control and information were allocated for the model: end of rolling temperature, coiling temperature, strip speed on the runoff table.

Due to the different order of the entrance data, we normalize them in order to improve the identification results according to the formula:

$$x' = \frac{x - \bar{x}}{\sigma}$$

where x is normalized value, $\bar{x}$ - arithmetic mean, σ - standard deviation of values.

The identification procedure includes the following three stages [8]:

1. The choice of the structure of the model on the basis of the available apriori information on the studied process and some heuristic reasons.

2. The choice of the criterion of the object and model proximity based on specificity of the problem.

3. The determination of the model parameters optimal from the point of view of the selected criterion of proximity.

After identification the model coefficients (2) take the values:

$w_x[1,1]=-0.051$, $w_x[1,2]=0.04$, ..., $w_{xvy}[1,2,1,1]=0.028$, $w_{xvy}[1,2,1,2]=-0.052$;

...

$w_x[3,2]=-0.077$, $w_x[3,3]=-0.021$, ..., $w_{xvy}[3,3,3,2]=-0.04$, $w_{xvy}[3,3,3,3]=0.019$.

In order to obtain the optimal results according to state, control and information, a mixed control is performed of the accelerated cooling system during which the mean square criterion of deviation is used of the left part of the equations of system (2) from zero [8].

RESULTS AND DISCUSSION

The analysis of the thermal condition of a hot-rolled strip in the conditions of real production on a broadband hot rolling mill shows a considerable coiling temperature fluctuation range. The coiling temperature fluctuations along the length of the strip are first of all connected with the change of rolling speed, heat emission at phase transformations, and with the sprayer's operating mode. It, in its turn, results in the heterogeneity of the structure of hot rolled stock.

In order to increase the homogeneity and reproducibility of the mechanical properties of the strip, it is necessary to provide the decrease of the coiling temperature fluctuation range along its length, which can be achieved by improving the algorithm of controlling the sprayer modes. A mixed control of the accelerated cooling system is performed for this purpose.

Accepting as parameters the end of rolling tempera-

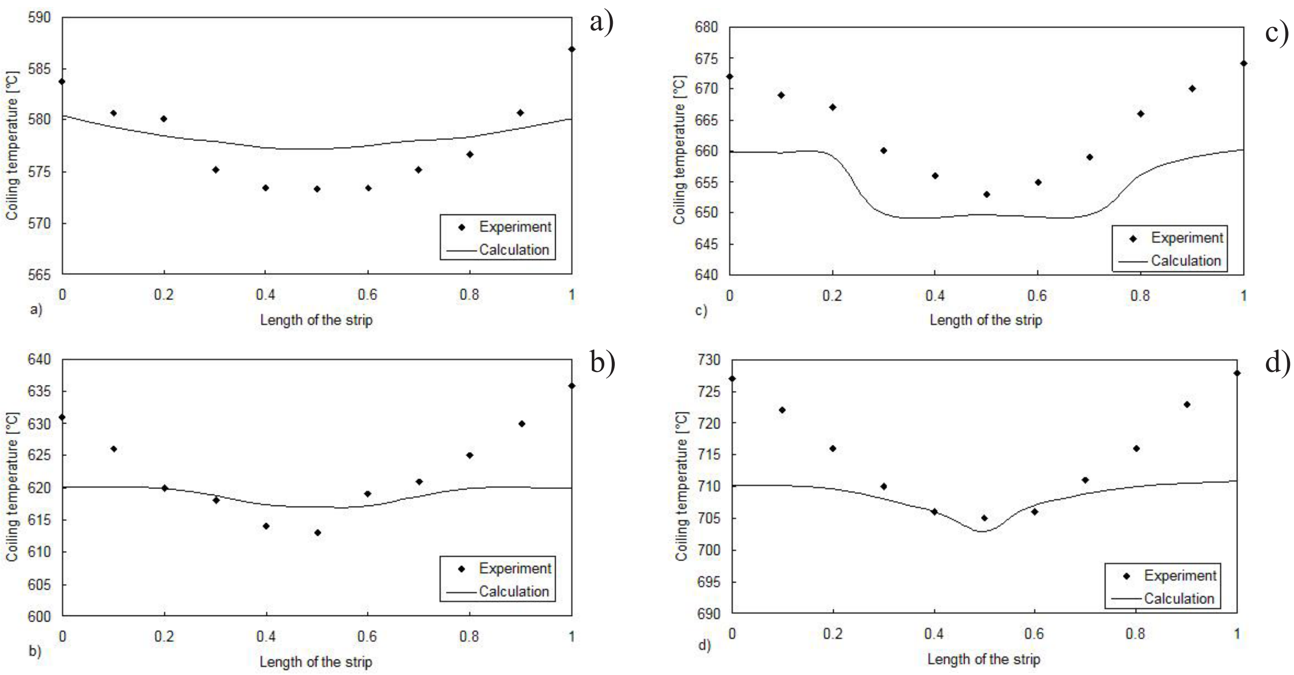

Fig. 3. Coiling temperature change along the strip:
a - T_{final} = 840°C, T_{coil} = 580°C, v_{roll} = 7.5 m s^{-1}, h = 4 mm; b - T_{final} = 780°C, T_{coil} = 620°C, v_{roll} = 7.5 m s^{-1}, h = 10 mm;
c - T_{final} = 830°C, T_{coil} = 660°C, v_{roll} = 7.5 m s^{-1}, h = 8 mm; d - T_{final} = 840°C, T_{coil} = 710°C, v_{roll} = 7.5 m s^{-1}, h = 6 mm.

ture (T_{final}) and the speed of the strip on the table (v_{roll}), operating the quantity of the cooling half-sections, a simulation was performed of cooling a strip with thickness of (h) and obtaining the required strip temperature when coiling (T_{coil}) with the use of the considered algorithm. The results are presented in Fig. 3.

The calculations show that the use of a trilinear neighborhood model in the algorithm of controlling coiling temperature makes it possible to reduce the temperature fluctuation range to 3 - 11°C, against 14 - 23°C, which is typical in real rolling production. Thus, the application of the considered algorithm with other things being equal, will provide the increase of the homogeneity of the structure of hot rolled stock along the length of the strip. In order to increase the accuracy, the model makes it possible to consider other technological parameters registered both in real-time mode on the hot rolling mill and obtained from previous reprocessing, e.g. the chemical composition of steel.

CONCLUSIONS

The problem of reducing the fluctuation of coiling temperature on the runoff table was studied. As a tool of scientific research, the neighborhood mathematical model of the accelerated cooling system was used. The results obtained by means of a mathematical model made it possible to obtain the technological operating modes of the sprayer unit on the runoff table which reduce the coiling temperature fluctuation range along the length of the strip.

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