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Reduction of the Fluctuation Range of Hot-Rolled Strip Coiling Temperature Using Mixed Control with Variable Coefficients

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Abstract

The trilinear neighborhood model of the process of forming the coiling temperature of a hot-rolled strip is considered, where state, control and information are used as parameters. Mixed control with variable coefficients is performed to reduce the coiling temperature fluctuations along the strip.

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

INTRODUCTION

The microstructure of hot-rolled steel depends on the temperature of end of rolling and the coiling temperature [1,2]. In order to obtain a uniform fine-grained structure of the low carbon steel metal, it is necessary to finish rolling at the temperature of 760-900 °C, and to coil the strip at the coiling temperature of 540-720 °C [3]. After the finishing stands the strip is cooled out on the run-off table.

The run-off table of the hot rolling mill is a significant section through which the strip passes the winders after rolling. The main function of the run-off table section is to cool the strip from the rolling temperature to the temperature suitable for coiling. Above and below the strip moving along the table, tanks with water for cooling are installed. Tanks are combined into half-sections – minimal controlled cooling devices. The system consists of 40 strip cooling sections (80 half-sections). Water sprays the strip surface through a series of pipes installed along the width of the tank. In order to control the sequential turning on and off the tanks, an automated control system for the sprayer is installed on the mill. It should be noted that some of the variables of the real technological process are measured with a large error, since the direct contact of the temperature sensor with a fast-moving strip is difficult, and some disturbing variables and factors are difficult to measure and control. This complicates the construction of technological parameter regulation systems.

The problem of forming the hot-rolled strip coiling temperature lies in the temperature fluctuation along the strip and the history of the difference of temperatures of the end of rolling and of coiling (Figure 1).

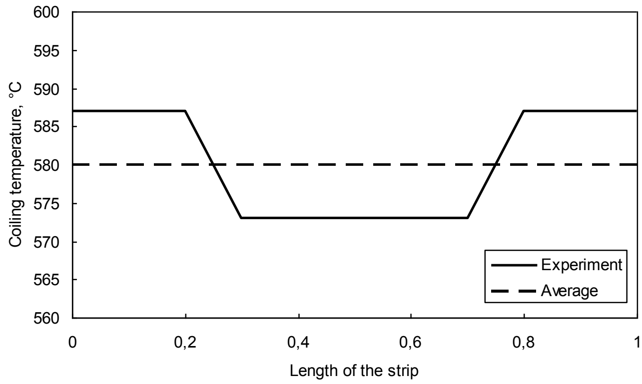

Figure 1. Temperature distribution along the strip

In order to increase the homogeneity and reproducibility of the mechanical properties of the strip during hot rolling, it is necessary to reduce the coiling temperature fluctuation range along its length, which can be achieved by improving the algorithm for controlling the sprayer’s modes.

MATHEMATICAL MODEL

In order to solve the problem, a trilinear neighborhood model was chosen [4], where information can be taken as the third parameter y. The significant components of state x, control v, and information y are givtn in Table 1.

Table 1. Components of state, control and information.

x[1]	Coiling temperature for the first area of the strip section,°C
x[2]	Coiling temperature for the second area of the strip section,°C
x[3]	Coiling temperature for the third area of the strip section,°C
v[1]	The amount of included half-sections of water cooling for the first area of the strip section

v[2]	The amount of included half-sections of water cooling for the second area of the strip section
v[3]	The amount of included half-sections of water cooling for the third area of the strip section
y[1]	Cooling water temperature, °C
y[2]	Cooling water temperature, °C
y[3]	Cooling water temperature, °C

We set the values of the state, control, and information components of the trilinear neighborhood model according to previously developed algorithms [5].

The state values in accordance with technological parameters are:

x[1] = 587 °C; x[2] = 573 °C; x[3] = 587 °C.

The values of control in accordance with the technological parameters are:

v[1] = 15 pcs.; v[2] = 28 pcs.; v[3] = 18 pcs.

The values of information in accordance with technological parameters are:

y[1] = y[2] = y[3] = 40 °C.

We will identify the trilinear neighborhood model, the meaning of which is to find the values of the coefficients which will be fixed at mixed control with variable coefficients, as well as the initial values of those coefficients which will change at mixed control.

The analysis of the thermal state of the hot-rolled strip in real production conditions on a wide-strip hot-rolling mill demonstrates a significant coiling temperature fluctuation range. Coiling temperature fluctuations along the strip are primarily related to the change in the rolling speed, the heat release during phase transformations, as well as in accordance with the sprayer's operating mode. This in turn leads to heterogeneity in the hot-rolled product structure.

We assume that the coiling temperature in the first and third areas of the strip section is similar: x[1] = x[3]. In order to perform mixed control, you need to know the permissible limits of state, control and information components' change: $x[1]_{min}$=580 °C, $x[1]_{max}$=600 °C, $x[2]_{min}$=560 °C, $x[2]_{max}$=580 °C, v_{min}=0 шт., v_{max}=80 шт., y_{min}=20 °C, y_{max}=60 °C.

Mixed control is based on the search for the minimum value of the objective function of the neighborhood model Z [6], which is the sum of the moduli of the left-hand sides of the system's equations. Here the requirement must be fulfilled $\Delta = x[1]-x[2] \rightarrow \min$, where Δ is the temperature difference between the first and second area of the strip section, which is set and varies from 13 °C to 4 °C. As a result, mixed control indicates the values of variables for which the left-hand side is minimal [7].

RESULTS AND DISCUSSION

The results of mixed control without variable coefficients are given in Table 2.

Table 2. Results of mixed control for the parameters x [1], x [2] and y.

Δ, °C	x[1], °C	x[2], °C	y, °C	Z
13	586.6	573.6	35.9	$2.383 \cdot 10^{-3}$
12	586.3	574.3	32	$3.192 \cdot 10^{-3}$
11	586	575	28.5	$3.943 \cdot 10^{-3}$
10	585.9	575.9	25.3	$4.633 \cdot 10^{-3}$
9	586.9	577.9	20	0.044
8	585	577	20	0.011
7	583.1	576.1	20	0.056
6	581.1	575.1	20	0.101
5	580	575	20	0.187
4	580	576	20	0.33

In accordance with [8], the minimum point is a stable equilibrium point. In order to reduce the value of the objective function, it was suggested to perform control with variable coefficients. The results of mixed control with one, two and three variable coefficients are given in Table 3.

Table 3. Results of mixed control with variable coefficients.

Δ, °C	The value of the objective function Z		
	One variable coefficient	Two variable coefficients	Three variable coefficients
13	$2.412 \cdot 10^{-3}$	$2.413 \cdot 10^{-3}$	$2.357 \cdot 10^{-3}$
12	$3.151 \cdot 10^{-3}$	$3.17 \cdot 10^{-3}$	$4.986 \cdot 10^{-3}$
11	$3.978 \cdot 10^{-3}$	$3.388 \cdot 10^{-3}$	$3.815 \cdot 10^{-3}$
10	$4.627 \cdot 10^{-3}$	$4.572 \cdot 10^{-3}$	$2.295 \cdot 10^{-3}$
9	0.045	0.053	$1.517 \cdot 10^{-6}$
8	$5.928 \cdot 10^{-3}$	0.079	$1.392 \cdot 10^{-6}$
7	0.054	$3.305 \cdot 10^{-3}$	$1.627 \cdot 10^{-6}$
6	0.103	$2.152 \cdot 10^{-3}$	$4.257 \cdot 10^{-3}$
5	0.288	0.154	$2.457 \cdot 10^{-3}$
4	0.353	0.189	0.04

CONCLUSION

Mixed control is performed of the process of forming the hot-rolled strip coiling temperature based on the search for the minimum value of the objective function with the condition that the coiling temperature difference between the first and second areas of the strip section is less than or equal to the preset value. In order to reduce the minimum value of the objective function, mixed control was performed in the space of coefficients and states where the number of variable coefficients varied from one to three. Mixed control with variable coefficients gives a smaller value of the objective function with variation of a larger number of coefficients, compared with the traditional mixed control in neighborhood modeling.

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