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REGULATION OF THE HEATING FURNACE IN TUBE ROLLING MILL

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The rolling of tube requires homogeneous heating along the tube. In steel work the difference along tube was sometimes 80 °C. The reasons for bad homogeneousness of heating were analyzed by a simulation model of heating furnace. Then the proposal was made for a new control system and also the proposal for reconstruction of furnace. In this contribution also a description of some ways for improvement of heating was made. The main contribution is the proposal of an adaptive system.

Key words: *simulation model, homogeneous heating, control system*

Regulacija zagrijevne peći u valjaonici cijevi. Proces valjanja cijevi zahtijeva ravnomjerno zagrijan cijevni uložak u zagrijevnoj peći. U realnim uvjetima procesa valjanja razlike u temperaturi duž cijevi bile su i do 80 °C. Razlog neravnomjernog zagrijavanja je analiziran na simulacijskom modelu zagrijevne peći. Na toj osnovi izrađen je prijedlog novog upravljačkog sustava kao i rekonstrukcije same peći. U okviru prijedloga dato je nekoliko mogućih rješenja za poboljšanje postojećeg stanja. Najveća vrijednost pretpostavljenog rješenja sadržana je u predloženom adativnom sustavu.

Ključne riječi: *simulacijski model, homogena zagrijavanja, kontrolni sustav*

INTRODUCTION

The heating furnace serves for heating of the semi-product (the tube) in front of tube rolling mill. The heated semi-product from furnace is moved into the tube rolling mill by a roller conveyor (see Figure 1.). The finished product after reduction in the tube rolling mill is moved to the storing place. The base characteristics of the furnace are as follows:

- the dimensions of furnace - length 17000 mm,
  - breadth 8370 mm,
  - height 1600 mm;
- the desired temperature of heating tube 900 - 1000 °C;
- the fuel is natural gas;
- the production capacity 20 - 30 $t \cdot h^{-1}$;
- the diameter of tube 100 - 200 mm;
- the thickness of wall of tube 3 - 10 mm;
- the length of tube 10 000 - 16 000 mm.

The heating of tube is provided by the burner system which consists of 26 burners. The input of fuel is regulated with the aid of three regulation zones which are localized on input and output sides of the furnace. The required temperature of tube depends on the quality of steel. This temperature would be equal along the tube. The problem with heating the tube is the homogeneousness of the temperature along the tube. The differences approx. 60 - 80 °C along the tube were measured. The bad homogeneousness of the temperature is the reason for reduction of the quality of finished tube. Therefore, the reason for bad homogeneousness of the temperature had to be determined and then propose improvements of heating.

THE ANALYSIS OF REASONS FOR BAD TEMPERATURE HOMOGENEOUSNESS DURING HEATING OF THE TUBE BY SIMULATION MODEL

The processes in heating furnace are very complex. Therefore, a simulation way was chosen. The simulation model was created on the basis of mathematical model. The basic structure of mathematical description is similar to the model of heating process of rotary hearth furnace [1].

Unlike old model [1] the new model solves the temperature field of the tube according to the following system of differential equations

$$\frac{dT}{d\tau} = \frac{1}{G \cdot c}\left(Q_1 - Q_2\right) \tag{1}$$

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where:

T - the temperature,
τ - the time,
G - the mass of material,
c - the specific heat capacity,
Q - the heat flow (input/output).

A new simulation model was verified on the basis of measurements in real furnace [2]. The simulation studies reveal the reasons of bad homogeneousness during tube heating as follows.

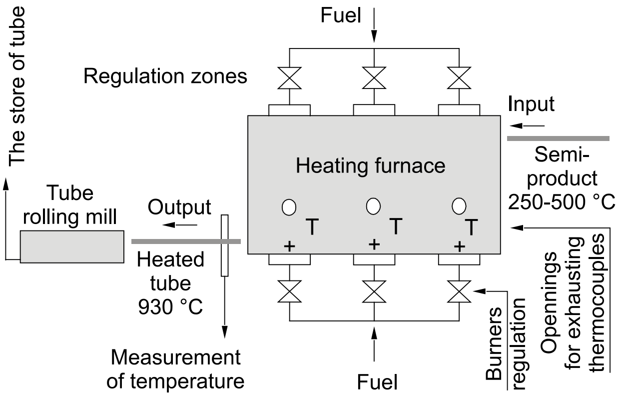

Figure.1. **The cooperation between the heating furnace and tube rolling mill**
Slika 1. **Povezanost zagrijane peći i valjaonice cijevi**

Control system

The regulation zones (input of fuel) are controlled according to signals from their own thermocouples, which are localized approx. 1/3 of distance from output side of furnace. They are near the opening for exhaust of combustion products. The regulation zones on input side do not influence the measured temperature. Therefore it is logical to divide the regulation into:

- the regulation of the input on input side,
- the regulation of the input on output side.

Then the regulation will consist of six regulation zones (see Figure 2.). The simulation study does not demonstrate a marked improvement.

Heating of the beginning and end of a tube

Sometimes the temperature of the beginning/end of an output tube is higher/lower than the required temperature. The reason is the difference in radiant surface of a line. For example, at the beginning of the significiant radiant heat flow from lateral wall still exists. If the operator lowers the required temperature then the radiant flow at the beginning of the tube will be higher (side wall) than in the centre of the tube and vice versa. Therefore, the temperature at the beginning of the tube will be higher then in the centre (the influence of heating inertial lining.). For solving this problem addition (the proposal A) of burners into the horns of furnace was proposed (see Figure 2.). These burners will be provided by individual regulation. A second proposal (B)

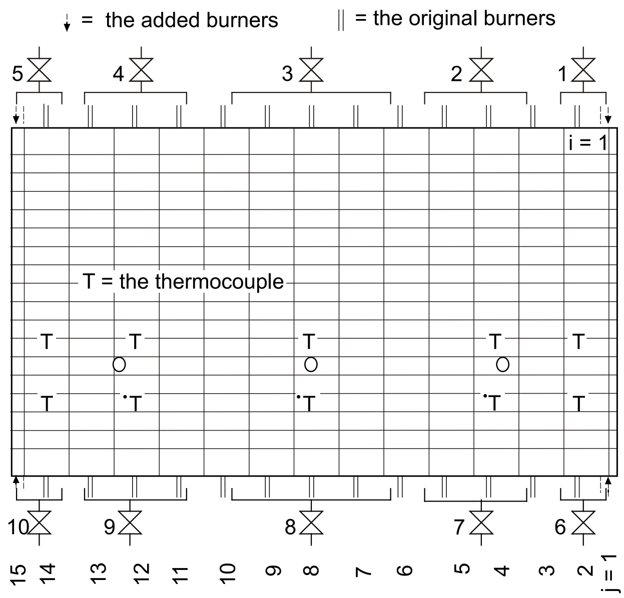

Figure 2. **The scheme of regulation 10-regulated burner zones**
Slika 2. **Shema regulacije 10 zona izgaranja**

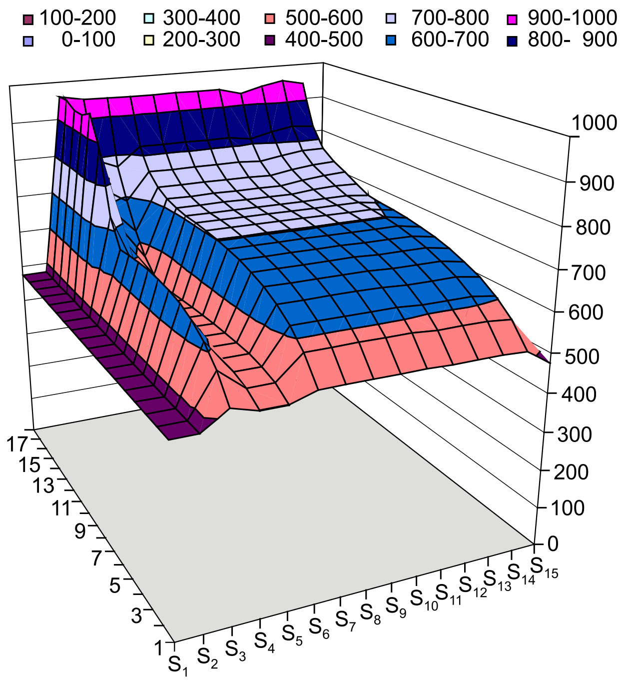

Figure 3. **Temperature field of tubes according to proposals A, B**
Slika 3. **Temperaturno polje cijevi u suglasju s prijedlozima A, B**

has been an exchange of refractory material, which would be replaced with insulating material (Sibral). In Figure 3. is shown the temperature field of the tubes during their motion in the furnace. As it can seen the temperatures along the tubes are homogeneous.

The number of regulation zones

From Figure 3. it can be seen that the beginning of the tube has the same temperature as the centre tube. But the problem is the temperature of end tubes if the tube is shorter than the breadth of the furnace. The reason is in unequal temperature field of combustion products. Two cases were analyzed by simulation model.

First case: The thermocouple of regulation zone is outside the end of tube.

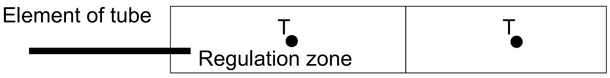

Figure 4. **Location of the thermocouple - out of the tube end**
Slika 4. **Smještaj termoelemenata - izvan kraja cijevi**

The fuel of all burners is controlled according to the measured temperature *T* in this regulation zone. In close neighborhood of thermocouple the heating power take-off is lower because in this place there is not tube. Therefore, for equal desired temperature of combustion products the regulator should give a signal for lower mass flow rate of fuel. The temperature of combustion products above the end of the tube will be lower in comparison with *T*. Therefore, the temperature at the end of the tube will be lower.

Second case: The thermocouple of regulation zone is above the end of tube.

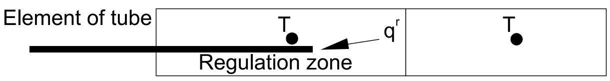

Figure 5. **Location of the thermocouple - above the tube end**
Slika 5. **Smještaj termoelemenata - iznad kraja cijevi**

In this case the regulator stabilizes the temperature of combustion products above the end of tube. Fuel consumption or heat flow instead consuption of heat to the right of the end of tube is lower (the tube does exist). Therefore, the temperature of combustion products on the right will be higher. Radiant flow q^r from this place heats the end of tube. Therefore, the temperature at the end of tube will be higher. The maximum of specific capacity near 750 °C complicates this situation still more. The specific capacity in front of 750 °C soars and then it plummets at higher a temperature. It is reason a vehement reaction of a tube temperature - see equation (1).

This case is shown in Table 1. The temperatures are in a cross section under the thermocouples along breadth of furnace.

Table 1. **The temperatures under thermocouples**
Tablica 1. **Temperature izmjerene termoelementima**

Index of length tube-j	8	7	6	5	4	3	2	1
Temperature of combustion products	911	911	914	840	892	1346	1278	864
Temperature of tube	803	801	802	730	780	1191	-	-
Index of length tube-j		15	14	13	12	11	10	9
Temperature of combustion products		830	811	903	910	913	911	911
Temperature of tube		-	723	791	802	807	802	801

For solving these problems the following changes were designed:

1. Increase the number of thermocouples.
2. Increase the number of regulation zones and decrease their range.

From the original regulation zones (1, 2 and 6, 7) 10 new regulated zones were created. Each burner zone is individually regulated. Then regulation system consists of 18 regulation zones.

THE ADAPTIVE SYSTEM

The control system controls the heating of the tube according to signals from thermocouples which measured the temperatures of combustion products. Therefore, the problem is to define the temperatures of combustion products. The aim is to define these temperatures so that the tube will reach the desired temperature. It is the task of proposed adaptation system. This algorithm is very simple.

$$Tr_j = T_j \pm \Delta T_j \tag{2}$$

where:

- Tr_j - the desired temperature of combustion products at *j*-th thermocouple,
- T_j - the previous measured temperature at *j*-th thermocouple,
- ΔT_j - the change (increase/ decrease) of temperature.

The increase/decrease can be defined as the difference between desired and measured temperatures of the tube.

Then the desired temperature of combustion products is defined as follows:

$$Tr_{j,k+1} = T_{j,k} + a_j \left(Tr_k^{tube} - Tm_{j,k}^{tube} \right) \tag{3}$$

where:

- j - the index of regulation zone,
- k - the index of time period of adaptation,
- Tr - the desired temperature of combustion products,
- T - the measured temperature of combustion products,
- a - the constant of adaptation,
- Tr^{tube} - the desired temperature of tube,
- Tm^{tube} - the measured temperature of tube.

The structure of control system is shown on Figure 6.

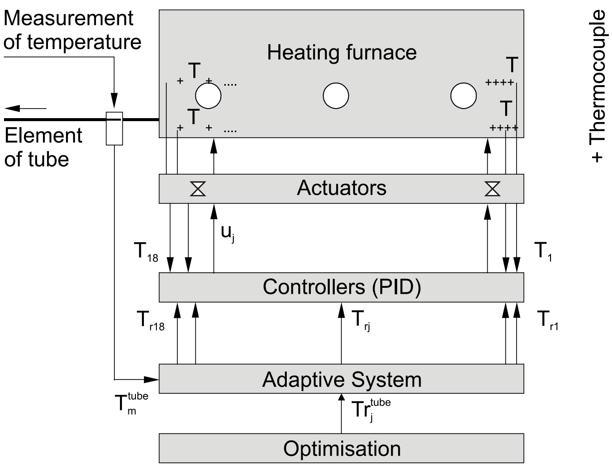

Figure 6. **The structure of control system**
Slika 6. **Struktura upravljačkog sustava**

The control system consists of three levels [3]. The optimization level computes the optimal heating regime (Tr_j^{tube}). The adaptive level adapts the desired temperatures of combustion products according to the basic equation (3). The last level is direct digital control. Its signals (u_j) control the actuators of burners.

Table 2. **The temperature along the tube pushed out from furnace**
Tablica 2. **Temperature duž cijevi na izlazu iz peći**

J	14	13	12	11	10	9	8	7	6	5	4	3
T_m^{tube} / °C	931	934	932	930	932	932	932	932	932	929	927	935

CONCLUSION

A model of control system (see Figure 6.) was created. The verification of proposed control system was made with the aid of simulation. Both models (furnace + control) have simulated mutual cooperation for real conditions. The contributions of this solution are the following:
- decrease of specific consumption of fuel approx. by about 7 %,
- homogeneous temperatures along tube were attained.

The solution of the main problem (no homogeneous heating) is shown in Table 2.

Shorter tube (j = 3, …, 14) was heated. The index j is part of tube element according length. The desired temperature of the tube was 930 °C. The maximal deviation is 5 °C. For the tube rolling this deviation is acceptable.

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