

Study on Temperature Observer of steel Slabs in Metal Smelting in Steel Milling Production

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Abstract – The quality of burning processes has a significant impact on the quality of products in the rolling steel line. Therefore, automatic control systems are developed in order to optimize the process of metal smelting and make an adaptation to the milling process. The paper proposes a model to estimate the heat distribution in burned slabs when their speed is varied. Then, the thermal field reference along the length of the furnace is determined to meet technical requirements for smelted slabs.

Keywords – Distribution parameter system, metal smelting, steel slabs, temperature of slab, heat flow.

I. INTRODUCTION

Several steel milling factories built a long time ago are running and creating low productivity with old production lines. Therefore, it is necessary to update equipment and enhance automatic ability in milling process. In other word, we need to develop the temperature control system, aiming at the optimal use of power sources. Thanks to microprocessor technology owning small structures but flexible functions to implement these difficult tasks.

The optimal solution in the laminating steel process described in [3] has to satisfy some requirements as follows:

- Burn oil effectively to reduce fuel fees
- Keep milling temperature stable
- Minimize the amount of scorched steel due to overheat
- Improve the longevity of equipment when slabs are not heated enough.

According to the analyses above, the authors introduce a calculation model of the temperature distribution in baked slabs along the length of the furnace when their speed is changed. And then necessary heat is calculated to meet the requirements. The distribution of temperature in melted slabs is simulated by MATLAB/Simulink.

II. CONTINUOUS FURNACE IN MILLING FACTORY

A. The introduction of a continuous burning technology

A continuous furnace is used to burn steel slabs, and then put them into mills. The furnace has to

supply timely the number of slabs ensuring quality to mills, and make a suitable line for mills.

Burning metal in furnace is a continuous process, in which materials are conveyed through some heat areas in succession. Controlled signals (the heat of areas and the speed of slabs) are arranged in furnace space and affect all slabs at different temperature levels. Normally, the thickness of slabs is between 0.006m and 0.4m, while its width is from 0.06m to 1.85m and 1m to 12m for its length. Steel slabs are directed by pushing motors and moved from low temperature area to high temperature one in the furnace space.

The furnace space is separated into 3 areas: drying zone, burning zone and co-heat zone. The temperature in co-heat zone is 50 degree higher than that of metal before going out furnace. The difference between furnace heat and material heat in drying zone is about 150 degrees and in burning zone is nearly 200 degrees. Usually, the heat of drying zone is about 800-1000°C.

The furnace is fired by the mixture of natural gases and heavy oils. Devices used for burning (burning beaks and spraying nozzles) are put in burning and co-heat zone. In some cases, they are located above and under slabs. In that way, burning heat created by the mixture of hot gases has reverse impacts with movement direction of slabs. This makes the distribution of temperature from high level (in co-heat area and burning area) to low level (in drying area). This helps boost heat transfer from furnace environment to metal and the effective use of heat from burned products. The object after baking will pass heat transfer system, in which it transfers heat to air or oil.

The distribution of fuel for each area is shown in table 1.

Table 1. The distribution of fuel for heat areas

Heat area	The percentage of heat capacity in each area and heat capacity in furnace (%)	
Co-heat zone	30 ÷ 45	2 zones
Above burning zone	55 ÷ 70	
Co-heat zone	18 ÷ 25	

Above burning zone	30 ÷ 40	3 zones
Below burning zone	35 ÷ 45	
Co-heat zone	15 ÷ 20	4 zones
2 above burning zones	20 ÷ 30	
Below burning zone	25 ÷ 40	
Co-heat zone	12 ÷ 18	5 zones
2 above burning zones	18 ÷ 22	
2 below burning zones	20 ÷ 25	

B. The introduction of Thai Nguyen steel milling factory

Thai Nguyen steel milling factory was constructed in June, 2002. Main equipment was provided by Danielifactory in Italy. On 19th August, 2005, this company achieved ISO certification 9001-2000 and in July, 2005, production plans were performed to solve domestic steel needs.

With modern technology and equipment applied from 1997s of G7 countries, this system obtained high automatic level and was equipped with waste treatment system in order to protect environment. This line has been considered as the most modern process in Vietnam with 300.000 tons per year for productivity. It is obvious that products have been increasingly improved in quantity and quality. Steel used in construction is made from steel with low and medium contents of carbon and some alloys.

A furnace performed as Fig.1 is a type of furnaces burned continuously by oil, following bottom-step style with burning power of 50 tones per hour. Fuel supply system exerts two types of diesel oil to produce heat at 400 to 450 degrees, and then turning into a region applying fuel oil having 9600 kcals per kilogram. The consumption of fuel oil is 26 kilogram per TSP. This system has 16 burning beaks including 10 burning beaks put on the furnace top and 6 beaks on two sides. Steel slabs are conveyed by 9 rollers driven by 9 motors and lifting devices. The system is shown in Fig.1. This is a continuous production from taking slabs to the furnace, baking and milling them. The furnace parameters are depicted and controlled directly on the interface.

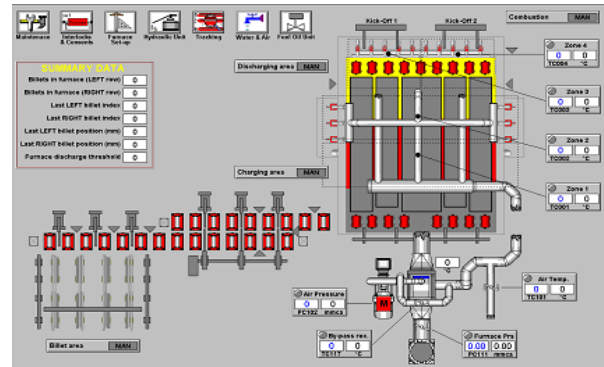


Fig 1: The simulation interface of a furnace

Supervising baking stage is conducted by cameras inside the furnace. This stage has a connection with a computer which is likely to see and adjust the use of the fuel in each zone depending on the number of slabs and their speed. The information of every slab about parameters, steel label, size parameters and baking mode are sent to a computer. It calculates appropriate temperature range for each area, and a controller is added to keep temperature stable. Furthermore, the computer also processes data to offer frequency taking steel out the furnace. The thermal inside furnace is a function of steel label, slab length, their speed and their heat before and after burning. A mathematical function is considered as optimal if errors between set value and real value and the consumption of fuel are minimum. The thermal in each zone is represented in Fig. 2.

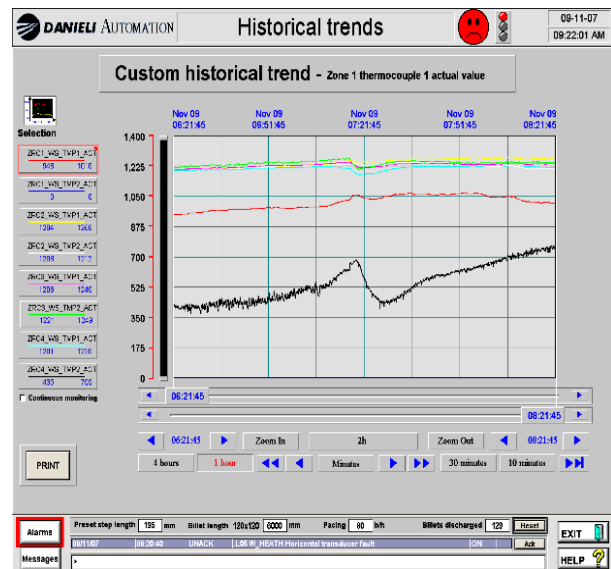


Fig 2: The temperature in a furnace

III. PROPOSED MODEL OF TEMPERATURE DISTRIBUTION

The author in [3] proposes two heat transfer problems including: heat transfer inside and outside slabs are examined.

Heat transfer from environment: based on temperature of the furnace, we determine heat on steel surface, depending on different forms of heat transfer such as convection or radiation. However, in this case, the main heat transfer is caused by radiation. Transferring heat by convection relates to several corrected factors.

Heat transfer inside steel slabs: heat conduction plays a key role in transferring heat from environment to layers of slabs.

We assume to ignore heat transfer to edges of slabs, and heat transfer equation is unidirectional. We have a differential equation (1):

$$\frac{\partial T}{\partial \tau} = a \frac{\partial^2 T}{\partial x^2} \quad (1)$$

For slabs baked both two sides, differential equations are shown in equations (2), (3):

$$\lambda \frac{\partial T}{\partial x} = c_1 \left[\frac{\beta_{sp}}{\beta_m} \left(\frac{T_{p1}+273}{100} \right)^4 - \left(\frac{T_1+273}{100} \right)^4 \right] - \alpha_{k1}(T_{p1} - T_1) \quad (2)$$

$$-\lambda \frac{\partial T}{\partial x} = c_2 \left[\frac{\beta_{sp}}{\beta_m} \left(\frac{T_{p2}+273}{100} \right)^4 - \left(\frac{T_2+273}{100} \right)^4 \right] - \alpha_{k2}(T_{p2} - T_2) \quad (3)$$

The equation (1) is analyzed into 2 differential equations having the first level of individual derivative of Q variable: $Q = Q(x, \tau)$

Equations (2), (3) become (4), (5):

$$Q(0, \tau) = c_1 \left[\frac{\beta_{sp}}{\beta_m} \left(\frac{T_{p1}+273}{100} \right)^4 - \left(\frac{T_1+273}{100} \right)^4 \right] + \alpha_{k1}(T_{p1} - T_1) \quad (4)$$

$$-Q(0, \tau) = c_2 \left[\frac{\beta_{sp}}{\beta_m} \left(\frac{T_{p2}+273}{100} \right)^4 - \left(\frac{T_2+273}{100} \right)^4 \right] + \alpha_{k2}(T_{p2} - T_2) \quad (5)$$

In order to tackle the problem about heat distribution in slabs, we divide them into n layers, n = 6 in this case. Therefore, the depth of each layer is:

$$h = \frac{n}{6}$$

By using mesh method [1, 2, and 4], the distribution of heat and current in slabs is shown in equations (6-12):

$$\frac{\partial T_1}{\partial \tau} = \beta(3Q_1 - 4Q_2 + Q_3) \quad (6)$$

$$\frac{\partial T_k}{\partial \tau} = -\beta(-Q_{k-1} + Q_{k+1}) \quad (7)$$

With $k = 2, 3, \dots, n$

$$\frac{\partial T_{k+1}}{\partial \tau} = -\beta(3Q_{k+1} - 4Q_k + Q_{k-1}) \quad (8)$$

$$Q_1 =$$

$$\alpha_1(T_{p1} - T_1) \quad (9)$$

$$Q_k = \gamma(-T_{k-1} + T_{k+1}) \quad (10)$$

$$Q_{n+1} = \alpha_2(T_{p2} - T_2) \quad (11)$$

where $T_1(0) = T_k(0) = T_{n+1}(0) = 20^\circ C$

$$\beta = \frac{\alpha}{2\lambda h}; \gamma = -\frac{\lambda}{2h} \quad (12)$$

where h is the depth of each layer; a and λ are parameters of thermal conduction and current conduction in material.

By applying differential method in [2, 4] according to mesh form, equations above are converted into equations (13)

$$T_1 = \int [3\beta\alpha_1(T_{p1} - T_1) + 4\beta\gamma(T_1 - T_3) + \beta\gamma(T_4 - T_2)] d\tau$$

$$T_2 = \int [\beta\alpha_1(T_{p1} - T_1) + \beta\gamma(T_2 - T_4)] d\tau$$

$$T_3 = \int [\beta\gamma(T_3 - T_1) + \beta\gamma(T_3 - T_5)] d\tau$$

$$T_4 = \int [\beta\gamma(T_4 - T_2) + \beta\gamma(T_4 - T_6)] d\tau \quad (13)$$

$$T_5 = \int [\beta\gamma(T_5 - T_3) + \beta\gamma(T_5 - T_7)] d\tau$$

$$T_6 = \int [\beta\gamma(T_6 - T_4) + \beta\gamma(T_{p2} - T_7)] d\tau$$

$$T_7 = \int [3\beta\alpha_2(T_{p2} - T_7) + 4\beta\gamma(T_7 - T_5) + \beta\gamma(T_4 - T_6)] d\tau$$

The equations from (1) to (12) determine the heat distribution inside steel. According to the equation (13), a thermal model of each layer is depicted in Fig. 3.

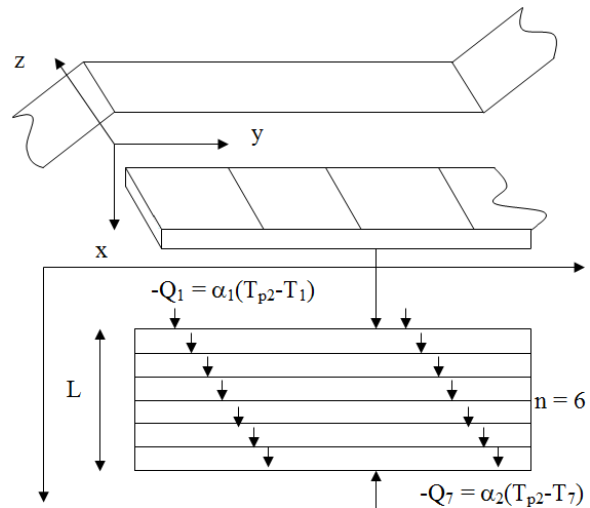


Fig 3: The heat distribution inside a slab of steel

To calculate the thermal distribution in burned slabs, physical and heat parameters are computed in equations (14):

$$\lambda(t) = 48.1 - \frac{26.9}{1 + \frac{[0.0028(t-937)]^2}{2}}$$

$$\gamma(t) = -\frac{\lambda(t)}{2h} \quad (14)$$

$$\alpha_1 = \frac{C_n \left(\frac{T_{p1}+273}{100} \right)^4 - \left(\frac{T_1+273}{100} \right)^4}{T_{p1} - T_1}$$

$$\alpha_2 = k\alpha_1$$

where $C_n = 4.95$ and $k = 0.9$

α and γ variables are computed and simulated on MATLAB/SIMULINK as Fig.4 and Fig. 5.

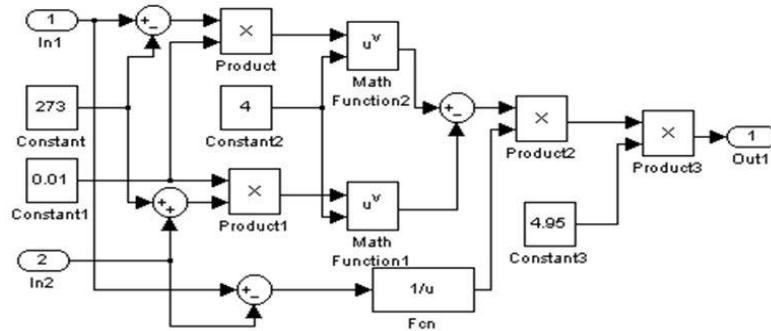


Fig 4: The diagram of calculation for α coefficient

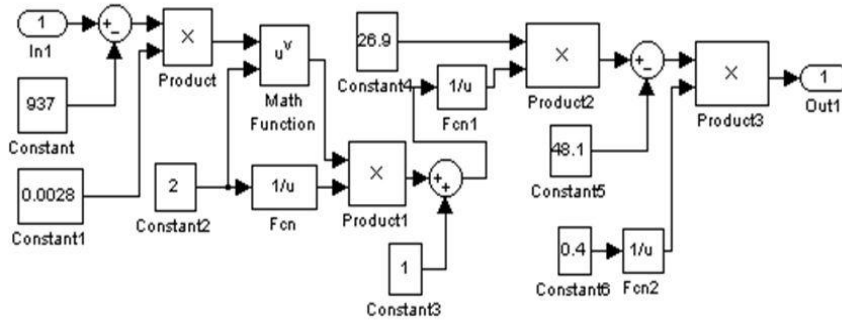


Fig 5: The diagram of calculation for γ coefficient

Calculating the thermal distribution in a baked object has to be implemented separately for each object. Each billet in different positions will be baked at different thermal levels, and temperature in a position is seen as constant. As a result, it is necessary to divide furnace length into various parts which are proportional to stopping time of an object. In a certain position, we compute baking temperature for each layer. Here, there are two problems examined. We assume that a regulated baking process having constant amount of steel going out the furnace by the time. By contrast, if this frequency changes, it is called an unregulated baking process, and burning time in each position is different.

In order to study an always-on burning process, firstly, we build a temperature characteristic in heat zones. It is obtained by measuring temperature in each billet along the furnace length. SIMULINK is applied to simulate this characteristic. A diagram of the furnace and the temperature characteristic are represented in Fig.6 and Fig.7.

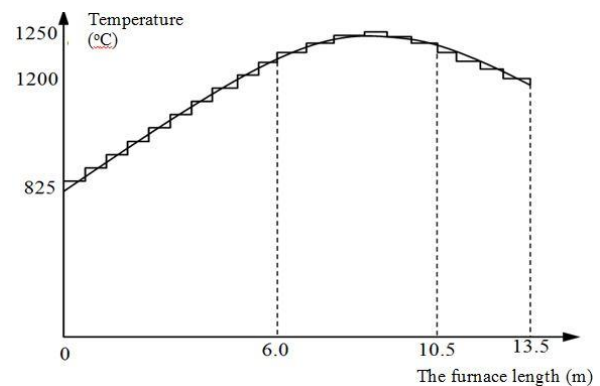


Fig7: The temperature characteristic

Simulating heat ranges of a baked object in MATLAB/Simulink is depicted in Fig.8 and Fig.9 shows characteristics of these heat ranges.

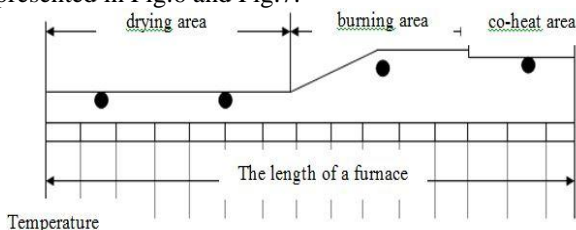


Fig 6: The diagram of the furnace

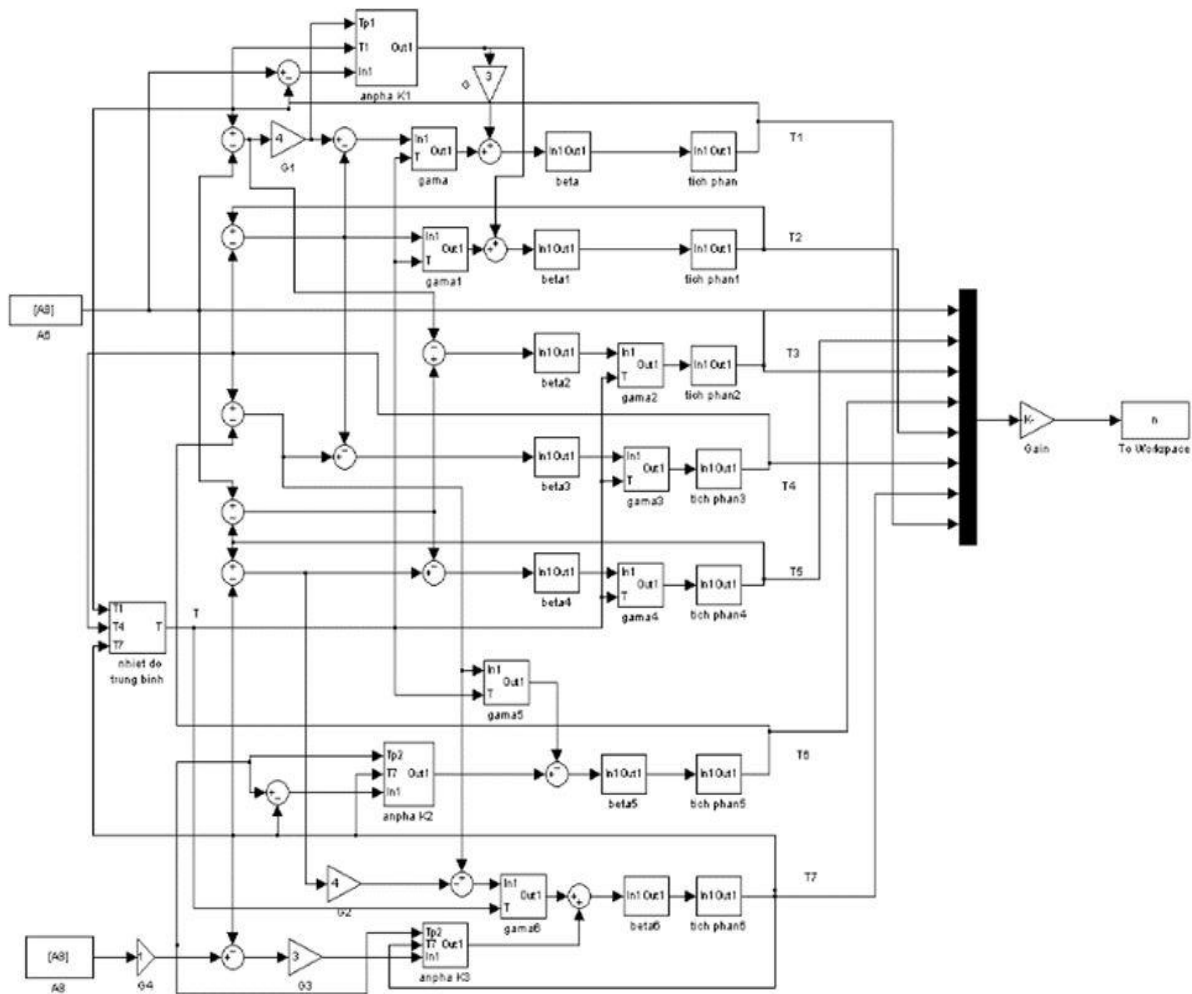


Fig 8: The diagram of a baked object in MATLAB/Simulink

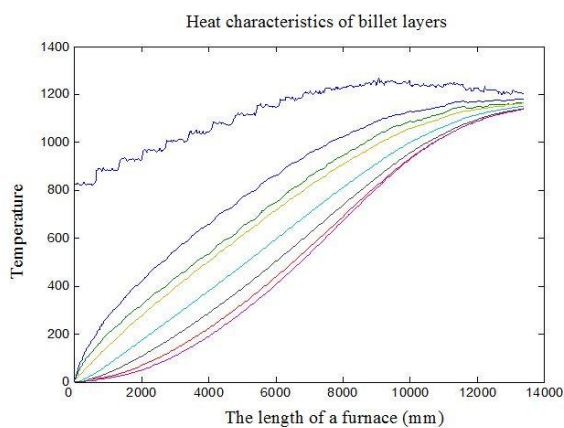


Fig 9: Heat characteristics of billet layers

Simulation results perform the judiciousness of algorithm, so it can find convenient to determine the heat distribution inside steel and calculate to control temperature in the furnace.

IV. CONCLUSIONS

This paper has proposed a model for calculating the temperature distribution in the baked objects based

on the furnace temperature. The time for slabsto be transferredin the furnace with 3 different temperature areasisconvertedto the preset temperature of stable state furnaces. After that, based on the calculation model is to define the distribution of temperature ranges of baked objects in 3 areas above. Furthermore, a temperature observation in steel slabs is designed. In other word, building algorithm is a process solving nonlinear partial differential equations. The authors have designed and simulated this systemon MATLAB/Simulink with various objects. Experimental results show that thesystem meets the quality requirements and enables to improve control quality inThai Nguyen steel milling factory.

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