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Dynamic furnace temperature setting research on combustion system of rolling mill reheating furnace

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Abstract

The setting of furnace temperature in combustion system of reheating furnace at rolling mill is an important parameter in the production process. Variety of some factors such as furnace heating capacity, steel thermal stress, production rhythm etc. directly affects the setting of furnace temperature, it is an industry problem. This article analysis about how the above mentioned factors affect the furnace temperature setting, and mainly focus on dynamic setting strategy of furnace temperature so as to fit fluctuation of production rhythm through theoretical analysis on the energy balance of billet heat transfer in the furnace. This strategy has been verified by production and experiment, and matches with the related data.

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Keywords: Combustion system, reheating furnace, dynamic setting of furnace temperature, production rhythm

1. Foreword

The temperature setting at rolling walking beam furnace is closely related by some factors such as furnace heating capacity, steel thermal stress, production rhythm etc., how to reasonably solve their relationship is an industry problem. In actual production, as these factors often change, it's difficult to guarantee the billet along the most optimal curve heating. This article set these above factors' influence as constraint conditions, and through theoretical analysis on the energy balance of billet heat transfer in the furnace, it improved the temperature setting method from traditional static to dynamic, that can get a better temperature setting curve.

2. Affect furnace temperature setting's constraint conditions

Furnace temperature settings request to draw an ideal billet heating curve to meet with the requirements of production and technology, and then calculate the furnace temperature distribution. The conditions which judge a heating curve whether ideal can be generally considered with[1] :

(1) Meeting technological conditions. Mainly include: The thermal stress can't damage the steel material; The furnace temperature can't exceed the effective heat capacity of each heating zone; The highest temperature can't exceed the upper limit..

(2) The fuel consumption is least on the heating process, the billet thermal integral on heating time is minimum.

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Its mathematical description is:

$$\sigma_T = \frac{T_b - T_c}{1.05} a_l E \le \sigma_{\max} \tag{2—1}$$

$$\varphi\sigma_0\left(T_f^4 - T_b^4\right) \le \eta Q_0 \tag{2—2}$$

$$T_f \le T_{\max}^f \tag{2—3}$$

$$J = \min\int_0^t MC_p T_s d\tau \tag{2—4}$$

Here, σ_T is steel thermal stress; $\sigma_{\max}$ is maximum allowable stress; a_l、E are steel thermal expansion coefficient, modulus of elasticity; T_b、T_c、T_s are billet's surface temperature, central temperature and average temperature; φ is total heat exchange factor in furnace; σ_0 is Stefan-Boltzmann constant, 5.67×10^{-8} W/(m^2·K^4); Q_0 is the maximum heat capacity at unit furnace length; η is furnace's thermal efficiency; J is the billet's thermal change; M is billet weight; C_p is specific heat capacity of steel; τ is time; t is the whole heating time.

T_s is difficult to directly measure in general. Usually, we got that by numerical simulation method at the help of mathematical model on billet heating process.

Furnace temperature setting use some solution method such as optimizing one by one, genetic algorithm and so on, at the help of billet heating process mathematical model, set (2-4) as objective function, set (2-1)、(2-2)、 (2-3) as restraint conditions, through regulate every zone's temperature to search the best setting to conform the billet's ideal heating curve[2], the key work is analysing the restraint of technological conditions that effect the furnace temperature setting.

3. Analyzing the effect of constraints on the furnace temperature setting

This chapter will detailed analyse the constraints at setting furnace temperature which showed by equation (2-1) ~ (2-3).

3.1 The constraints of steel thermal stress on furnace temperature setting

For some higher heating requirements steel (such as alloy steel, stainless steel and so on), we should consider the damage of thermal stress at low temperature region, so as to avoid bringing a large temperature difference. If the billet is heated with top and bottom surfaces, its thickness is H , the temperature distribution curve similar to a parabola [3], that the surface heat flux can be expressed:

$$q = \frac{4\lambda(T_b - T_c)}{H} \tag{3—1}$$

The main heat flux at billet's heating in furnace is radiation, so that we can estimate the maximum permissible temperature setting of furnace T_f by equation (2-1), (3-1):

$$T_f \le \sqrt[4]{\frac{4.2\lambda\sigma_{\max}}{\varphi\sigma_0 a_l EH} + T_b^{\,4}} \tag{3—2}$$

3.2 The constraints of heating zone's heating capacity on furnace temperature setting

The furnace temperature can only be regulated at the range of the heating capacity. If the billet's surface temperature at entrance is T_i, at outlet is T_{i+1} , the maximum furnace temperature enable can also be estimated by equation (2-2) :

$$T_f \le \sqrt[4]{\frac{\eta Q_0}{\varphi\sigma_0} + T_i^2 T_{i+1}^2} \qquad (3-3)$$

3.3 The constraints of steel grade and discharging temperature on furnace temperature setting

The maximum furnace temperature for general steel is usually 100~150℃ below the solidus line at iron carbon equilibrium diagram, equal to or slightly higher than the discharging temperature[4].So that, the furnace temperature must be limited according to the steel initial rolling temperature. Usually, the highest temperature is been set about 50℃ above the discharging temperature at high temperature zones, about 30℃ above at soaking zone.

4. Dynamic setting of furnace temperature

The main heat flux at billet's heating in furnace is radiation, every zone's energy balance equation can be simplified as:

$$\rho C_p\left(\frac{\partial T}{\partial \tau} + V\frac{\partial T}{\partial x}\right)H = 2\varphi\sigma_0\left(T_f^4 - T_s^4\right) \qquad (4-1)$$

Here, V is the billet's mean walking speed . If the furnace is at steady continuous production process, and the heating curve along the length of the furnace is consistent with the standard curve, the temperature is only changed by position, not change by time, $\frac{\partial T}{\partial \tau} = 0$, $\frac{\partial T}{\partial x} = Const$. If the billet's width is W , the output of furnace is $U = \rho VHW$, that the relationship between the furnace temperature with the billet temperature at varied of output can be describe as following [5]:

$$\frac{U}{U_0} = \frac{T_f^4 - T_s^4}{T_{f0}^4 - T_{s0}^4} \qquad (4-2)$$

Here, U_0/U is the rated/actual output of heating furnace,, T_{f0}/T_s is the furnace temperature setting at rated/actual output, T_{s0}/T_s is the billet surface temperature at rated/actual output,. So that, base on the heating curve of rated output, we can deduce the dynamic setting of furnace temperature to adapt varied output:

$$T_f = \sqrt[4]{\frac{U}{U_0}(T_{f0}^4 - T_{s0}^4) + T_s^4} \qquad (4-3)$$

The table below is the furnace temperature setting for each heating zone calculated by this method at varied output and cold charging for heating a low alloy structural steel.

Table 1 Furnace temperature settings at varied production rhythm

		The first heating zone	The second heating zone	The third heating zone	The soaking zone
Standare heating 200 t/h	Fur temp	820	1130	1230	1215
	Billet outlet temp	595	878	1160	1200
	Billet average temp	476	816	1082	1193
Slow heating 160 t/h	Optimized fur temp	789	1075	1204	1212
Rapid heating 240 t/h	Optimized fur temp	866	1179	1257	1220

From this table, we can find out that each zone's furnace temperature setting will increase when rhythm is accelerated, and the low temperature zone increase more than high temperature zone.

5. The comparative analysis for the experimental and theoretical results deviation

In order to verify the accuracy of the temperature setting strategy, we tested the billet heating process, track and record the whole process' data changes in furnace, the trend curve is showed as figure 1.

At actual testing experiment, the output is 172t/h, and the furnace temperature settings of each zone are reduced by 32℃、13℃、8℃、5℃ than rated output of 200t/h. These values have -14℃、-9℃、-8℃、3℃ differ compared with actual measured values. These are in the allowable range. So the method this article described has an effective application in furnace temperature setting at actual production.

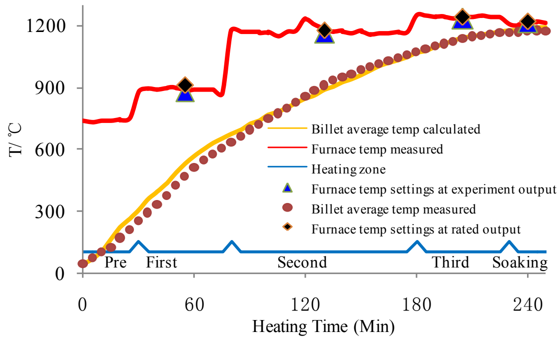

Figure 1 The trend curve of furnace and billet temperature measured on billet heating

6. The actual application effect

Rolling delay can be seen as a special kind of production rhythm. This temperature setting strategy in this article is applied to multiple regenerative walking beam furnace, the effect is obvious. Figure 2 is the variation trend of a heating zone's temperature setting at varied production rhythm by applied this setting method above.

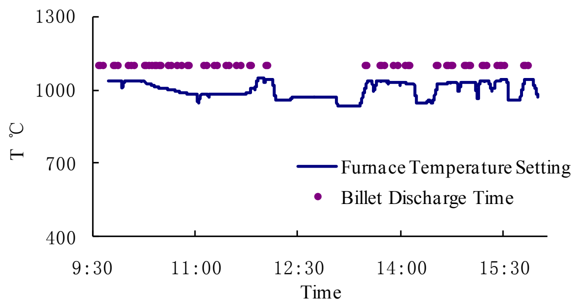

Figure 2 The furnace temperature setting curve at varied production rhythm

We can find out from this figure, the furnace temperature setting is changed with the production rhythm.

7. Conclusion

In the actual production, the furnace temperature setting is closely related with some factors, especially the production rhythm changes, output fluctuation have a greatly influence. In this article, through the analysis and derivation on energy balance in the billet heating process, the furnace temperature setting method is replaced from traditional static to dynamic, and realize a dynamic practical setting strategy, its actual effect is obvious, the production process according to the statistics, compared with static, dynamic setting of furnace temperature can reduce steel energy consumption 5%~15%.

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