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STRIP TEMPERATURE CONTROL MODEL AND APPLICATION OF CONTINUOUS HEATING FURNACE[1]

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Abstract

Temperature control of cold rolled sheet annealing plays an important role in the product characteristics. Usually, there are two kinds of temperature control model used in the heating furnace , furnace temperature control and strip temperature control. As the control object of the later is strip temperature, the accuracy rate is better . In this article, dynamic speed model and preheating track control based on strip temperature control model are explained, which are applied in the strip temperature control of Baosteel NO.4 continuous annealing line. The result of different strip temperature control models is compared. It is concluded that new strip temperature control model can not only improve the response of temperature magnificently, but also decrease strip temperature fluctuation, it is suitable for cold rolled automobile sheet production.

Keywords: Temperature control model; Continuous annealing; Heating furnace.

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1 INTRODUCTION

The heating furnace of cold rolled continuous annealing process line is to heat up strip from room temperature to annealing goal temperature, so the temperature control plays an important role in product characteristics. There are many kinds of heating method for strip, among which radiant heat is of special importance because of its high efficiency, good surface quality and moderate cost. In order to heat strip, radiant tubes are usually arranged both sides along the strip pass. The burner of radiant tube includes main burner and ignition burner ,in which gas is ignited and keep combustion . The called "push - pull" combustion system (shown in Figure 1) is usually adopted. To save energy, the air is drummed into radiant tube by blower and preheated by the combustion exhaust gas. The combustion air and gas flow is controlled by cross-limiting control loop to make sure air-fuel ratio stable. In addition, this method can also bring temperature regulation more precise and low exhaust emission.

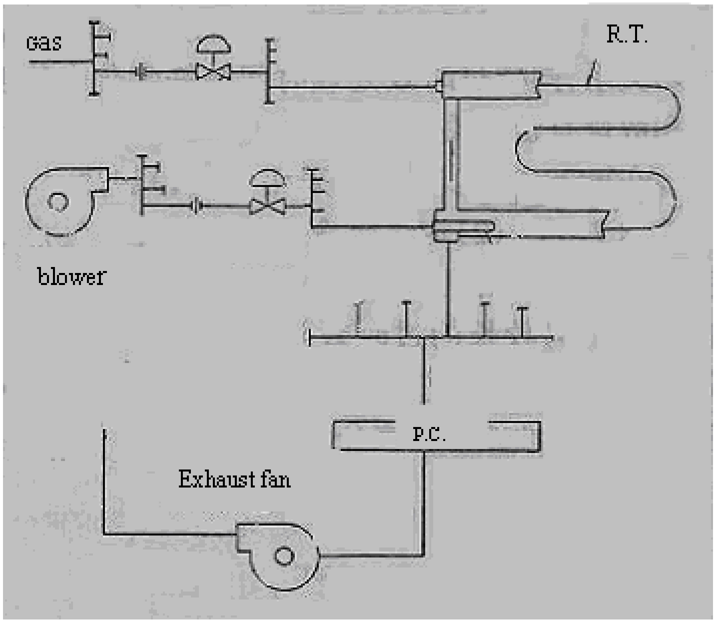

Fig.1. Combustion system diagram of continuous annealing heating furnace.

2 TEMPERATURE CONTROL METHOD OF HEATING FURNACE

In general, there are two kinds of temperature control model used in the heating furnace:

(1)Furnace temperature control model: furnace temperature setting is given by operator to control the combustion.

(2) strip temperature control model: manipulated variable (such as gas flow, etc) setting is given by the computer system to control strip temperature.

As we known, the actual furnace temperature is the goal in furnace temperature control model. In order to reduce the deviation from preset furnace temperature, a multi-variable predictive control algorithm is adopted considering two factors of entrance strip temperature and strip second flow in heating furnace. However, the control object is not direct strip temperature, but furnace temperature, the transforming relationship between furnace temperature and strip temperature is affected by many factors, for example, furnace structure, material, hearth rolls, and so on, so the accuracy rate of strip temperature can hardly reach what we expect .

In another temperature model, strip temperature is taken as the target, control data is predicted (such as gas flow, etc.) and set to instrument to control strip temperature. This kind of temperature control object is direct strip, and more scientific, so high robustness and control precise are obtained .

In strip temperature control model, two control methods are often adopted during the heating furnace design. The first is static control method, in which the strip temperature is derived and caculated through radiant heat transforming function, it can be applied in a long time steady state of strip thickness, running speed and strip temperation. In order to control strip temperature in all stable and unstable state of furnace, the dynamic control method is developed. It is also known as the manipulated variables (such as gas flow , etc) and control variables (strip temperature) auto-regressive moving average model (ARMA). Dynamic control method is based on dynamic furnace heat balance principle and relationship of hearth roll-strip heat exchange, the output variable is gas flow. To improve the robustness of the method, the generalized predictive control technology is introduced.

Here the generalized predictive control[1] is estabolished on the theory of least squares curve-fitting method. A cost evaluation function J is designed, the most appropriate gas flow setting can be determined when J reaches the minimum value.

$$J = \sum_{j=N1}^{N2} \rho(j)\{r(t+j) - y(t+j)\}^2 + \omega \sum_{k=1}^{NU} \Delta u'(t+k-1)^2 \quad \rightarrow \min$$

Of which:

ω: weight of manipulated variable variation;
r: target strip temperature;
y: actual strip temperature;
Δu ': variation of manipulated variable;
N1: response delay time
N2: max predicted time;
NU: at some point from current point;
ρ (j): weight of strip temperature deviation

Furthmore, some measures have been taken to increase the accuracy rate of strip temperature control in continuous annealing process line, dynamic speed control and preheating track control based on the above strip temperature control have been applied in Baosteel NO.4 cold rolled continuous annealing furnace.

2.1 Dynamic Speed Control

Dynamic speed adjustment model is suitable to improve the temperature response when the target temperature or strip thickness changes. Through predictive calculation, the reasonable little speed change is found, which does not affect the stability of production, It is beneficial to make the strip temperature closer to target in time.

Set: DTS: the variation of target strip temperature ;

TSot (k): target strip temperature;

DSS (k): the absolute value of the strip temperature variation caused by TH × VS changes;

DSS: the value of the strip temperature variation caused by TH × VS changes;

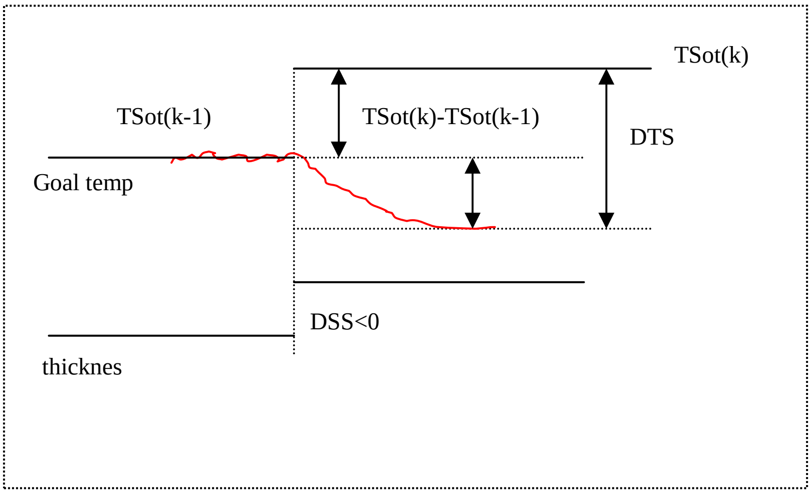

Fig.2 strip temperature under target strip temperature and strip thickness both change

DTS can be predicted by the function as follow:

$$DTS = [TSot(k) - TSot(k-1)] - DSS(k)$$

$$= [TSot(k) - TSot(k-1)] - (-DSS)$$

$$= [TSot(k) - TSot(k-1)] + DSS$$

According to DTS calculation value, line will be speed up and down.

When $\alpha < DTS < \beta$, then Vs = Va

VS: the set value of current line speed;

Va: the actual value of current line speed ;

α, β for the practical experience data

When DTS> β line will be decelerated;

When DTS <α line will be accelerated.

To minimize the impact to the stability of the production, it is necessary to treat smoothly between theoretic optimal speed setting Vs and the current speed Va after caculating Vs. So a smooth speed transition can be obtained and Then, the current optimal speed setting Vset will be determined finally.

$$Vset = Va + Gv * (Vs - Va);$$

Where, Vset for current optimal speed setting ;

Vs for theoretic optimal speed setting;

Va for current speed;

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Gv for the smooth coefficient

Figure 3 and Figure 4 illustrate the heating time comparison of different speed control models in the same strip size 1.0mm * 1417mm, the same speed 200mpm and stable operation of temperature from 811 □ to 840 □. The heating time is 4 minutes and 54 seconds without speed control model; but the time is only 2 minutes 28 seconds, nearly half of the former with speed control model.

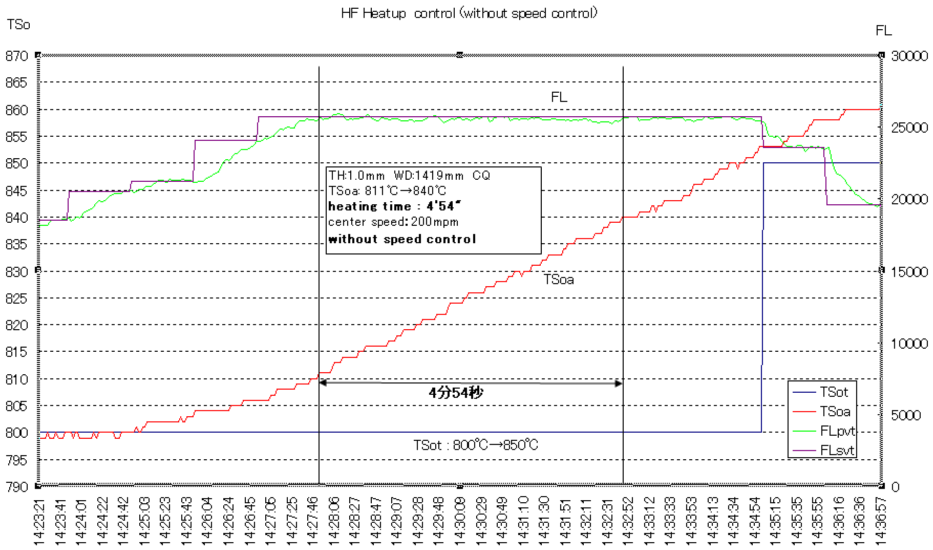


Fig. 3 Heating up without strip speed control.

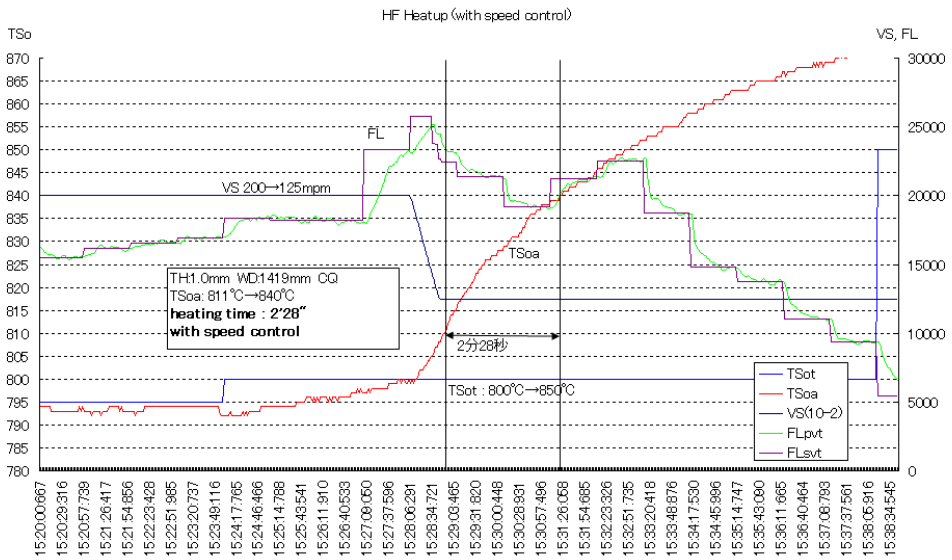


Fig. 4 Heating up with strip speed control.

2.2 Preheating Control

Different thickness and width coils run continuously in the heating furnace by welding. Usually we ignore the changes of front and back coils size and temperature in the heating furnace, put the following coil annealing temperature as the target control temperature. The coil will be heated up or down sharply, this results in large temperature fluctuation in welding beam transition, especially in the front coil tail and back coil head . When there is larger change in the size and temperature of front and back coils , the annealing temperature fluctuation in the welding beam transition is often beyond technical range, resulting in coil characteristics failure inevitably.

The goal of preheating control is to establish a moderate furnace and strip temperature model taking into account the changes of front and back coils size and temperature and technical range in the heating furnace.

Tout = f(*TF, Tsi, TH, VS,s)*

Of which, Tout: strip predictive temperature in the exit of heating furnace
TH: thickness
VS: strip running speed in the heating furnace
TF: furnace temperature
Tsi: strip temperature in the entry of heating furnace
s: model parameter

Based on predicted strip temperature fluctuation value of the following coil ,and considering front and back coils goal temperature, and the upper and lower limits, the reasonable target strip heating track near welding beam can be determined. For instance, coil heating track can be designed if the conditions occur as following:

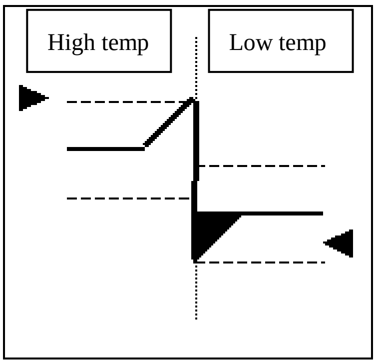
High temperature material (front coil) upper limit - low temperature material (back coil) lower limit □ strip temperature variation□high temperature material (front coil) upper limit - low temperature material (back coil) goal,

Then set:

The target temperature of high temperature material transition part = high temperature material (front coil) upper limit

The target temperature of low temperature material transition part = high temperature material (front coil) upper limit - strip temperature variation

Preheating control is adopted to heat up the front coil in advance to ensure moderate temperature fluctuation of all coil parts, not only coil center but also transition part near welding beam of coil, to meet with coil annealing requirements.



In diagram，

Predicted temperature values: ▲indicate

Strip temperature upper and lower limits: dotted lines indicate

Fig.5 Preheating control model diagram

The following examples show the comparison of transition part temperature fluctuation with/without preheating control.

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Table 1 Comparison of transition temperature with/without preheating control

Item	Without preheating		With preheating	
	Fig.6	Fig.7	Fig.8	Fig.9
Thickness , mm	0.8 → 0.9	0.7 → 0.8	0.8 → 1.0	0.8 → 1.0 → 0.8
Goal temperature, ℃	840 → 820	840 → 820	825 → 790	850 → 840 → 850
Actual temperature , ℃	842 → 813	835 → 807	835 → 789	868 → 833 → 861
Temp. fluctuation , ℃	2 → - 7	-5 → - 13	10 → - 1	18 → - 7 → 11
Remarks	Little thickness & temp change, The following coil temperature low obviously	The following coil temperature lower than -10℃	Big thickness fluctuation, the following coil temperature OK	Big thickness fluctuation, the following coil temperature OK

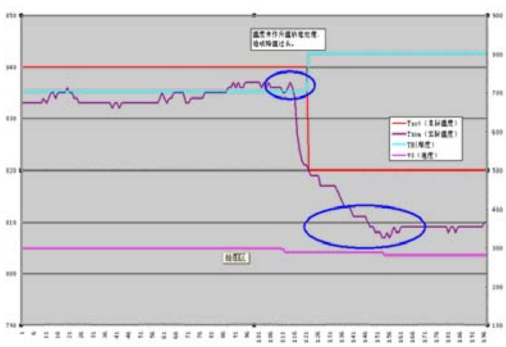

Fig .6 Without preheating temperature control 1

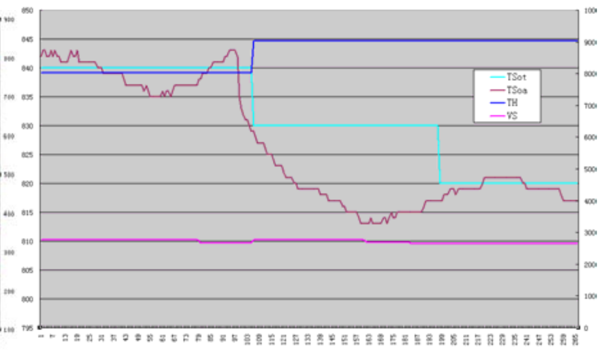

Fig .7 Without preheating temperature control 2

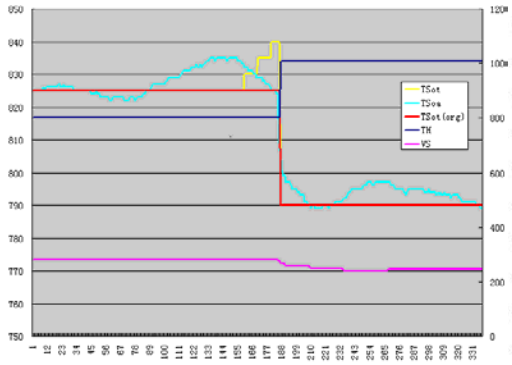

Fig. 8 With preheating temperature control 1

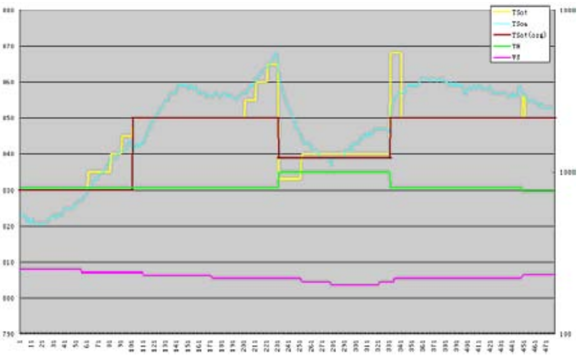

Fig .9 With preheating temperature control 2

Note :Tsot :target strip temperature (it is technical goal temperature without preheating control; or model goal temperature in welding transition part with preheating control)

Red line in Fig.6 & Fig.8; blue line in Fig.7, brown line in Fig.9.

Tsot(org) : Target strip temperature track (only for preheating control),

none in Fig.6 Fig.7; yellow line in Fig.8 Fig.9.

Tsoa : Actual strip temperature,

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purpe line in Fig.6 Fig.7; blue line in Fig.8 & Fig.9.

TH：Thickness，blue line in Fig.6 & Fig.7 & Fig.8, green line in Fig.9

3 THE APPLICATION OF STRIP TEMPERATURE IN HEATING FURNACE

Baosteel No.4 cold continuous annealing line has put into operation since March 2005. Continuous and stable production has been received after optimizing the temperature control in heating furnace. The strip temperature at any point of coil is less than ±10 □ from aim temperature , furthermore, the deviation of coil average temperature and target temperature is less than 5 □.

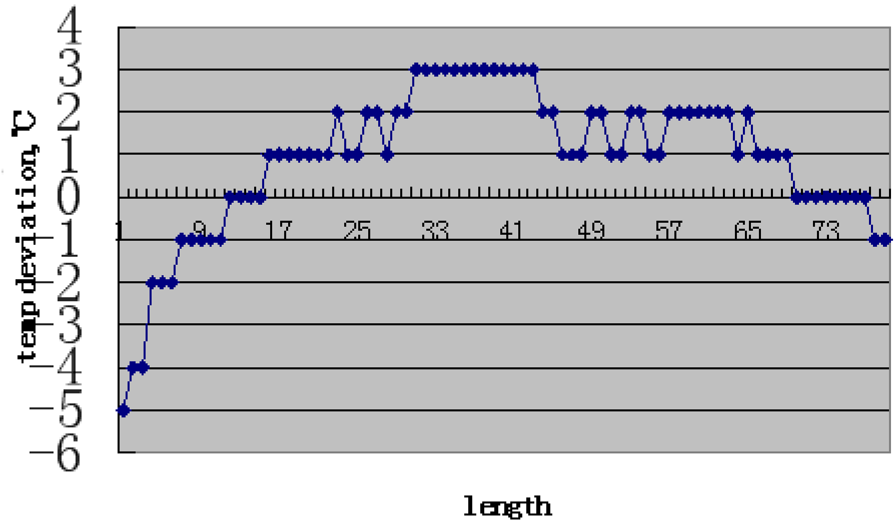

Fig.10 Coil annealing temperature deviation in heating furnace.

4 CONCLUSION

(1) The strip temperature model in heating furnace directly control strip annealing temperature by regulating the gas flow, so the control accuracy rate is high. The response of the strip temperature can be improved obviously by adding dynamic speed control based on the normal temperature control model.

(2) It is proved that preheating track control in welding beam transition part can decrease the coil temperature fluctuation when strip size and goal temperature change. It is beneficial for the whole coil characters stable, so this new control model is more suitable for cold-rolled automobile sheet annealing.

REFERENCES

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