A New Strip Temperature Control Method for the Heating Section of Continuous Annealing Line

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Abstract—**Because of the imperfect feature of the current model and control, and frequent changes of the strip type and size, the current strip temperature control mode is not normally used in Baosteel's three annealing lines. It affects the quality stability of products, energy consume, and equipments life. The new developed strip temperature control method for heating furnace of continuous annealing line has been applied in Baosteel 1550 CAL. It has reached 2℃ as steady state precision and 10 minutes as dynamic response time.**

Keywords–**Continuous annealing line Strip temperature control Predict control Intelligent control**

I. INTRODUCTION

Continuous annealing line, rear process of cold rolling, takes an important role in improving the performance of cold rolling products. After Nippon Steel Kimitsu Works built the first continuous annealing line in Oct. 1972, it has been applied and extended all over the world for its high productivity, low cost, high quality and diversification advantages. The continuous annealing line continuously heats and colds the strip to make the internal crystal suffered renewal, recrystallization, growth, and carbide precipitation in order to improve the reprocessing performance of the strip. Among the factors affecting the material performance, the strip temperature is the key one. So how to accurately control the strip temperature at the outlet of each furnace is the most effective method to guarantee the product quality.

A continuous annealing process consists of preheating, heating, soaking, cooling, re-heating and final-cooling furnaces. The heating section plays a decisive role in these furnace sections. But it is also the hardest to control, for the thermal inertia of the strip is great and the specification and speed change frequently. So the strip temperature control is always the focused research in the past years.

II. COMMONLY USED STRIP TEMPERATURE CONTROL MEHTODS

There are two commonly used strip temperature control methods for the heating section of continuous annealing line at present: classical control method and advanced control method.

The classical control method [1][2] (see Fig. 1) consists of strip temperature regulator, furnace temperature regulator, coal gas flow regulator and preset furnace temperature (feedforward). Each regulator adopts PID control and the preset furnace temperature uses mathematic model or table form. This control mode has clear control structure and is easy to debug, but PID control is not suitable for great inertia and large delay links. Further more, the common preset can't solve the large-scale temperature fluctuations caused by the frequent change of the strip specification. When the strip specification changes frequently, it will result in burners being frequently on-off. Thus, it not only will cause the furnace temperature fluctuation and energy waste, but also will shorten the life of the radiation.

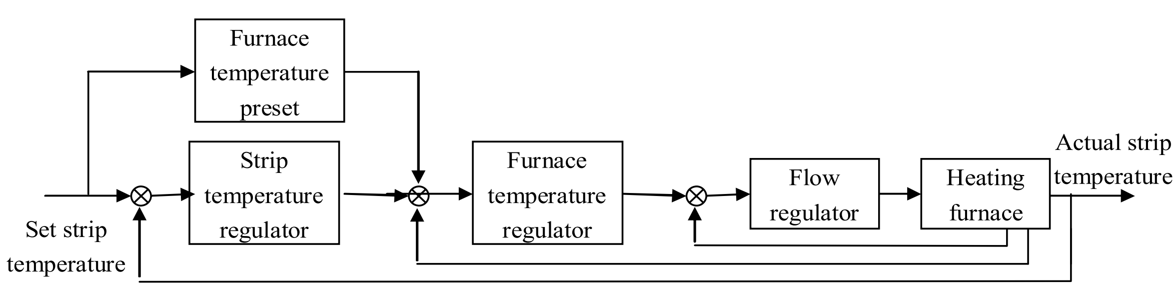

Figure 1. Classical strip temperature control method

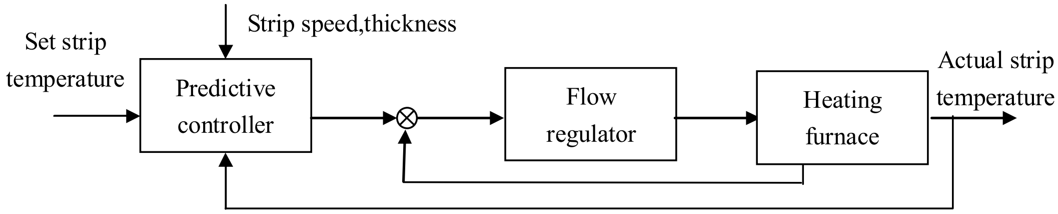

Figure 2. Advanced strip temperature control method

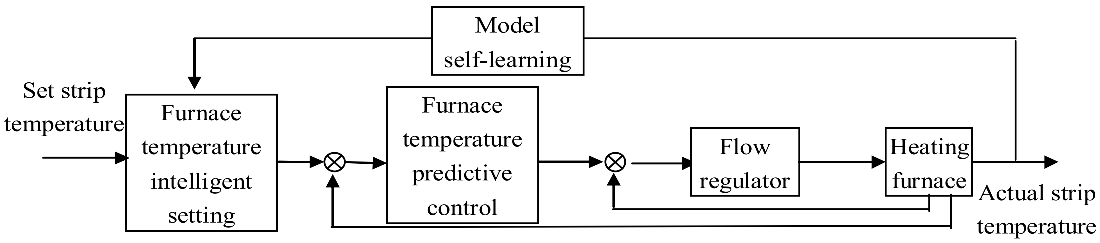

Figure 3. Intelligent predictive control

The advanced control method [3][4], showed as Fig. 2, combined the preset furnace temperature and strip temperature control into a linear predictive control, which introduces strip speed factor and strip thickness factor. The advanced control method reduces the control layers in structure, but makes the design of the predictive control extraordinarily complex.

This two control methods are used in Baosteel, but neither of them meets the needs of the production. So the strip temperature control in the heating section of continuous annealing line is always controlled by man in practice manufacture.

III. INTELLIGENT PREDICTIVE CONTROL METHOD

As the competition grows among the iron and steel corporations, the delivery cycle is shortened day by day. And the continuous annealing line also tends to multi-specification and small batch production. But this needs to change the preset values (strip width, strip thickness and the accepted reference value of temperature), and the line speed changes accordingly, but the temperature of the heating furnace must maintain at a certain temperature. For the large delay and great inertia of the heating furnace and frequently change of the strip specification, the classical control and advanced control do not work well. Researches find out that considering the features of the continuous annealing line and combining artificial intelligent method with advanced predictive control method is an effective way, called intelligent predictive control coming from classical control method. See Fig. 3, the intelligent predictive control method contains three parts: furnace temperature intelligent setting, furnace temperature predictive control and model self-learning.

A. Furnace temperature intelligent setting

Furnace temperature intelligent setting contains three modules:

- Strip temperature preset: This module calculates the setting strip temperature in the future according to the specification and target temperature of the strip and next strip, and then presets the strip temperature on the basis of the process requests and a set of rules, which are summed up from the actual production data according to the experience of operators and process engineers.
- Load distributions of each furnace zone: A furnace section usually have several furnace zones, each zone may set different furnace temperature. This depends on the thickness, speed and target temperature of the strip. The optimizing goal is energy-saving and convenient in adjusting.
- Furnace temperature calculation: The steady-state mathematical model of strip temperature and furnace temperature based on the principle of heat transfer shows as below:

$$T_s = f\left(T_f, H, V, U\right) \tag{1}$$

T_s: strip temperature;

T_f: furnace temperature;

H: strip thickness;

V: strip speed;

U: self-learning parameter.

B. Furnace temperature predictive control

Predictive control, the normal way people used to deal with uncertainty problems, contains three parts: predictive model, rolling optimization and feedback correction. The rolling optimization in a limited time can reduce the influence of errors from predictive model and disturbances from outside. Although global optimization cannot be obtained, this rolling optimization has a strong robustness and fit the actual control better than the one-off optimization of mathematical model, as no model can describe the objects accurately in industry control. With the predictive control technology, the furnace temperature control can solve the great inertia and large delay effectively, and predict the coming status change by the strip trace information at the same time. This can help us to adopt control method ahead of time in order to achieve the anticipate aim and have a good control effect.

C. Model self-learning

The model self-learning not only can increase the precision but also plays a closed-loop role at the same time. We can figure out the actual model parameter $\tilde{U}$ from the actual strip temperature, furnace temperature, strip thickness and strip speed. After smoothing processing, the new model parameter is:

$$U_{new} = \alpha U_{old} + (1-\alpha)\tilde{U} \tag{2}$$

α : learning speed coefficient.

IV. OPERATING ACHIEVEMENTS

At present, Baosteel has three continuous annealing lines（2030,1420,1550）in production, and this technology has been applied at 1550 continuous annealing line. After a period of time, it has achieved the anticipated goal and received a very good control effect. When the time is ripe, we will popularize it to the other lines.

The step response is a measure for control system. Figure 4 indicates the process of a strip temperature from 720 °C to 780 °C, in which the overshooting is only 5 °C and the dynamic response time is 10 minutes.

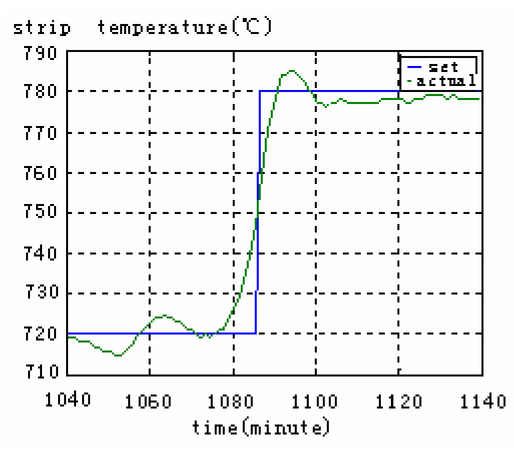

Figure 4. Step response of strip temperature

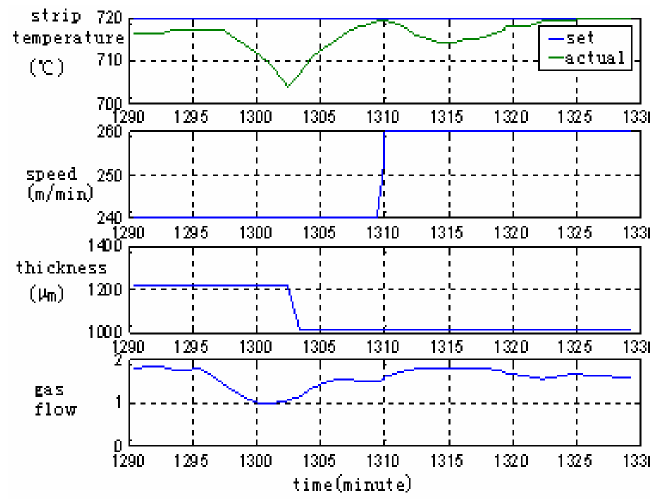

Figure 5. Anti-disturbance ability

The Anti-disturbance ability is another measure for control system. To the furnace of continuous annealing line, the main disturbance is the change of speed and thickness. Change of speed is unforeseeable, but alternation of thickness can be forecasted. Fig. 5 shows the Anti-disturbance ability of the strip temperature. When the thickness changes 200μm, the strip temperature fluctuation is only 15 °C after a 12 minutes adjusting process and we can clearly see the control goes into effect before the thickness changes. When the speed varies 20m/min, the fluctuation is only 6 °C with a 10 minutes adjusting process.

V. SUMMARY

Combining advanced control theory with operating experiences of fieldworks, a new strip temperature control technology of the continuous annealing line has been applied successfully in 1550 continuous annealing line of Baosteel. Though this technology is only applied in continuous annealing line, its principle is also suitable for other cold-rolled processing line such as hot galvanized, electric galvanized, and electrical steel and so on, especially for electrical steel as this system provides a ±2 °C temperature accuracy while common control system only ensure ±5 °C. On the other hand, in the past control models have not been fully applied for continuous annealing line because of the state of the practical product (varying in steel type and frequent changes of steel specification) and the status of customary operation (prefer manual operate). But this integrated intelligent control system would be the first choice for the furnace temperature model in the future as this is based on the mechanism of thermal technology, control theory and with the guidance of production and operating experience.

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