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# Application of Self-Learning to Heating Process Control of Simulated Continuous Annealing

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**Abstract**: On the basis of a simulated bright continuous annealing experimental machine, a process control model for heating system was built. The heating model was simplified and self-learning parameters were normalized to enhance the precision of temperature control. By means of the division of temperature layers and the exponential smoothing disposal of the annealing experimental data, the self-learning of the heating model was carried out. Through exponentially smoothing the deviation of self-learning parameters of the heated phase in heating process, dynamic modifications of self-learning parameters and heating electric current were carried out, and the precision of temperature control was confirmed. The application indicated that the process control model for the heating system can control temperature with high precision, and the deviation can be controlled within 8 ℃.

**Key words**: annealing; simulation; annealing machine; process control; self-learning

Experimental machine for simulating continuous annealing is a new kind of annealing equipment in the field of materials processing. The machine is mainly used to simulate the annealing process of cold-rolled strip and to obtain the connection between annealing technology and mechanical properties. The machine is normally 2 or 3 m in length and about 1 m in height, and is heated by electricity. It can adjust the annealing period flexibly, change the annealing parameters in a big scale, and thus, enhance the annealing efficiency greatly. Compared with the method of building experimental annealing line which almost has the fixed annealing technology (with fixed annealing parameters), the machine can reduce the equipment cost and experimental cost greatly. On the background of the high-developed technology of computer, with the quick computing of correlative annealing parameters of process control computer and the quick response and implementing of PLC, the simulated continuous annealing machine can achieve the high precision control of heating current and flux of cooling gas automatically, and ensure the high precision control over temperature of sample. Some groups have excogitated this kind of equipments[1-2].

In the present domestic state that several steel plants have a great need of simulated annealing equipments, the state key laboratory of rolling technology and automation (RAL) of Northeastern University and Baosteel have cooperated together and invented the simulated bright continuous annealing experimental machine, which has the characteristics of high precision of temperature control, a big scale of parameter adjusting, low cost, and so on.

In this study, a processing control model and self-adapting of heating system of the machine were introduced, and the principle and mathematical methods of self-adapting are also fit to the cooling system of the machine.

## 1 Equipment Characteristics

Fig. 1 shows the simple structure of continuous annealing experimental machine. The machine consists of closed furnace main body, holding tension system, electrical heating system, specimen cooling system, protective and cooling gas supply system, cooling water system, vacuum system, control system, and safeguard system, etc.

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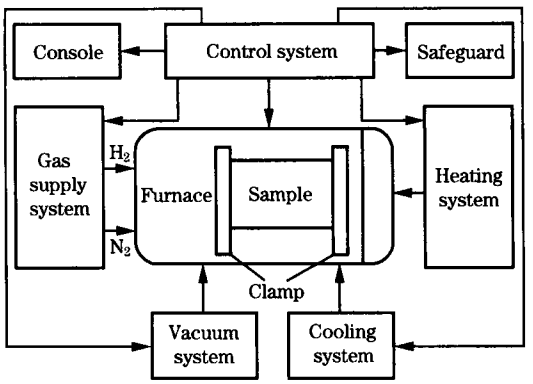


**Fig. 1 Structure of continuous annealing experimental machine**

The experimental machine can be used to simulate annealing process of steel strips, including common straight carbon steel, high strength steel, stainless steel, and silicon steel.

The characteristics of the machine are that it adopts electricity to heat single slice specimen directly, and the heating velocity of specimen can be previously set. After heating, gas jet cooling or spray cooling can be used to cool the specimen with the cooling mediums of nitrogen, hydrogen, or gas inhalator, and cooling velocity can also be previously set. The whole annealing process is carried out in the protective atmosphere mixed by nitrogen and hydrogen, in which the percent of hydrogen is 0—100%, and the dew-point of protective gas can be adjusted. Tension control is also used in the annealing process to control the shape of specimen, and it can be adjusted along with the variation of temperature in annealing process. The machine has advantages such as high thermal efficiency, high precision of temperature control in heating and cooling process, high test efficiency, pretty low cost, and convenient manipulating system.

The automatic control system of the machine is composed of the data collection industrial computer system and PLC system, and PLC system and R-I/O use S7-400 of Siemens in German and ET200M system, respectively. This control system uses CPU-315-2DP high performance digital processor unit, which can quickly communicated with the data collection computer and spots R-I/O through the industrial spot bus PROFIBUS-DP. There is a data collection computer in steel strip continuous console, in charge of the annealing process data collection and monitor. The main purpose of PLC system is to accomplish the basic automatic control and data exchange with the data collection computer. The software of the PLC system adopted the STEP 7 programmable software of SIEMENS in German, and this system can achieve the fast, accurate, and credible real-time control performance. The shortest PID signal treating cycle is 0.1125 ms, providing important assurance of the fast response of this machine.

HMI system uses WinCC6.0 software of Siemens, which communicates with the S7-400PLC through SIMATIC NET software. HMI system is used to input the specimen information (for example, steel grade and thickness), temperature set during the whole annealing process, protecting and cooling gas ratio set (the inclusion of hydrogen and nitrogen), dew-point set, as well as vacuum set, and save and take out the set temperature curve, trend display and each part state of this machine, malfunction alarm, and so on.

## 2 Model of Heating System of Machine

Temperature control is very important in continuous annealing and some control methods were developed[3]. The heating system of the machine heats sample using electricity. In the heating process, the air in the machine is first suctioned to make the machine be vacuum, and then, the machine will be filled up with the protecting gas (the mixing gas of $N_2$ and $H_2$ to prevent the sample from oxidation). In the heating process, a part of electricity energy is used to enhance the temperature of the sample; however, quite a big part of the electricity energy is lost owing to the radiation or the convection between sample and protecting gas, and thus, Eqn. (1) is obtained:

$$P_{sum}=P_{sam}+P_{rad}+P_{con} \quad (1)$$

where, $P_{sum}$ is the total power of electricity; $P_{sam}$ is the power to enhance the temperature of sample; $P_{rad}$ is the power of the radiation; and $P_{con}$ is the power of convection.

The following formula is used to calculate $P_{sam}$

$$P_{sam}=cm\mathrm{d}T/\mathrm{d}t \quad (2)$$

where, $m$ is the mass of sample, kg; $c$ is the specific heat, $J \cdot kg^{-1} \cdot K^{-1}$; and $dT/dt$ is the heating velocity, $K \cdot s^{-1}$.

$P_{rad}$ and $P_{con}$ are calculated by the Stefan-Boltzman formula and the Newton formula[3—5], respectively.

$$P_{rad}=S_{sam}\varepsilon\sigma T_{sam}^4 \quad (3)$$

$$P_{con}=hS_{sam}(T_{sam}-T_{sur}) \quad (4)$$

where, $S_{sam}$ is the surface area of sample, $m^2$; $\varepsilon$ is