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Application Research on Foam Glass Kiln Temperature Control Model and Strategy

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Abstract: Foam glass production process is a typical nonlinear, large time delay, large inertia, strong cross-coupling, time-varying and complex control object. In this study, a new temperature control strategy is proposed by analyzing the working mechanism of the kiln and the temperature control problem in it. In the application, the Optimized Fuzzy Neural Network (OFNN) is applied to model the foam glass kiln and its weights and threshold value of the neural network are optimized by the Clonal Selection Algorithm (CSA) of the immune system theory. The structure of the controller is modified at any time in the process of production according to the temperature output error and its aim is to achieve the most stable temperature control of the foam glass production process in the kilns. The application of the model in the control system is successful and effective to improve the glass product quality.

Key words: Clonal selection algorithm (CSA), optimized fuzzy neural network (OFNN), foam glass, kiln, temperature control

INTRODUCTION

Foam glasses which feature high strength, thermal and sound insulation properties and exhibit good moisture-proof and fire-proof abilities, are new constructional materials used in the internal and external wall of buildings. Peoples prepared the environment-protection foam glasses using waste glasses or fly ash as raw materials with other additives (Fernandes *et al*., 2009; Bernardo *et al*., 2005; Ducman and Kovacevic, 1997; Bernardo *et al*., 2007; Spiridonov and Orlova, 2003).

In the foam glass production, the firing process can be divided into the following four stages: Preheating, foaming, shaping, annealing. Accurate temperature control of all stages is the key problem to the production of foam glass and the quality of products is depended on the correct and reasonable temperature control technology. Therefore, how to choose a temperature control strategy is an important part of foam glass production.

PID control strategy is the early one developed for industrial processes control in the linear systems. It is simple, reliable, easy to implement and it can eliminate the steady-state error. It can meet the performance requirements in most practical cases. And so far, about 90% of the control loop structure is still PID (Li *et al*., 2005).

Foam glass production process is a typical nonlinear, large time delay, large inertia, strong cross-coupling, time-varying and complex control object. A single PID control strategy has been unable to meet the control requirements. Therefore it is important to design an integrated intelligent control strategy to compensate for the lack of a single control strategy to solve complex control problems. In this work, a clonal selection algorithm based multi-layer optimized fuzzy neural network prediction model of foam glass kiln is established to estimate the production condition. In the control process, according to the temperature of the output error of the blank, different controller structures will be adopted to ensure the temperature stabilization with the purpose of improving the rate of qualified products.

OPTIMIZED FUZZY NEURAL NETWORK MODEL DESCRIPTION

The pre-production data are used to model the foam glass kiln with fuzzy neural networks at first and then use the clonal selection algorithm to optimize the network weights and thresholds. With the use of this model as a forecast model for the control system, the controller structure is changeable according to the output error of the temperature of the billet mold at any time in the production process. This aims to achieve the best control effect of the foam glass production kiln system.

The most useful property of the Fuzzy Neural Network (FNN) is the ability to arbitrarily approximate linear or nonlinear mappings through learning. Meng and

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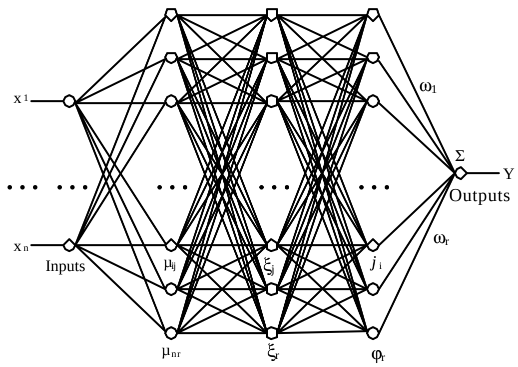

Fig. 1: Model description of the fuzzy neural network

Yang (2010) said, a fuzzy diagonal regression neural networks recurrent forecast model is proposed based on analyzing influential factors of passenger traffic volume and the experimental results show that the simulation system has well application prospect and the promoted value. In which the FNN is trained by MPSO to implement the optimization of FNN parameters. The short term load forecasting accuracy is improved in Guizhou power system which average percentage error is not more than 1.2%. Zuo (2009) proposed a fault-tolerant control method based on fuzzy neural networks was presented for nonlinear systems. We obtained the basis data set for model training and verification set through valid data filtering and the FNN model in this study includes five layers is shown in Fig. 1.

Where:

- Each node in layer 1 represents an input of the current values of the electric heaters placed at the top, bottom and both sides in the foam glass kiln
- Each node in layer 2 represents a member ship function which is in the form of Gaussian

$$\mu_{ij}(x_i) = -(x_i - c_{ij})^2 / 2\sigma_{ij}^2, i = 1, \cdots, n, j = 1, \cdots, r \tag{1}$$

In which, μ_{ij} is the membership function of the input variable; σ_{ij} is the centre of the Gaussian membership; c_{ij} is the width of the Gaussian membership:

- Each node in layer 3 represents a possible rule for fuzzy rules

$$\xi_j = e^{-\sum_{i=1}^{n}(x_i - c_{ij})^2} / 2\sigma_{ij}^2, j = 1, \cdots, r \tag{2}$$

- Each node in layer 4 represents the then

$$\varphi_j = \xi_j / \sum_{k=1}^{r} \xi_k, j = 1, \cdots, r \tag{3}$$

- Layer 5 represents the output variable of the temperature of the billet mold as a weighted summation of incoming signals

Recently, clonal selection theory in the immune system has received the attention of researchers and given them inspiration to create algorithms that evolve candidate solutions by means of selection, cloning and mutation procedures. The Clonal Selection Algorithm (CSA) in its canonical form and its various versions are used to solve different types of problems and are reported to perform better compared with other heuristics (i.e., genetic algorithms, neural networks, etc.) in some cases, such as function optimization and pattern recognition (Ulutas and Kulturel-Konak, 2011).

In this study, a special Gaussian mutation is used to collect more priori information which was coded into CSA. And the size of the search space is decreased and the convergence speed of the algorithm is increased at the same time. The flow chart was shown in Fig. 2. The steps of CSA algorithm are defined as follows:

Step 1: **Initialization:** Randomly initialize an antibodies population (Abi) with a number (p) of antibodies and determine its affinity with each element of the population and then define an empty antibodies memory library (Abm). All individuals in the algorithm are used in real-coded

Step 2: **Selection:** Select a number (s) of the best highest affinity elements to compose a selected antibodies population (Abs) from Abi and update the Abm with the best highest affinity antibodies at the same time

Step 3: **Cloning:** Individuals in Abs generate the clonal expansion to a number of c to compose a new antibodies population (C)

Step 4: **Gaussian mutation:** Mutate all the individuals in C with the randomly selected number of genetic locus of genes to compose a new antibodies population (C^*)

The achieve method is shown in the following equation 4:

$$L_i^{'} = L_i + r(u_i^{max} - u_i^{min})N(0,1) \tag{4}$$

where, L_i and L_i are the genetic locus values of before and after mutation; μ_i^{max} and μ_i^{min} are the maximum and minimum values of the independent variable of the genetic

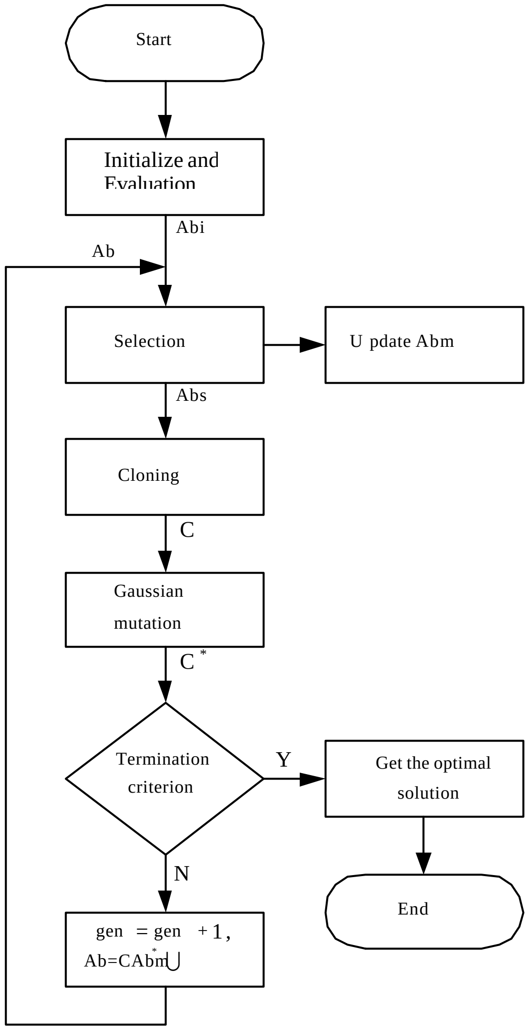

Fig. 2: CSA algorithm process

locus. They are derived from prior experience; N(0, 1) is a random number subject to the standard normal distribution; r is the expansion radius of mutation operation.

Step 5: Repeat step 2 to step 4 until a termination criterion is met.

Figure 3 shows the compared results of the model outputs and the actual measurements. It can be seen from the results that the model can reflect the characteristics of the control object better. Fig. 4 shows the error of the model outputs and the actual measurements. Obviously the error of the system is between -3°C and +3°C and it can fully meet the temperature control accuracy of foam glass production process.

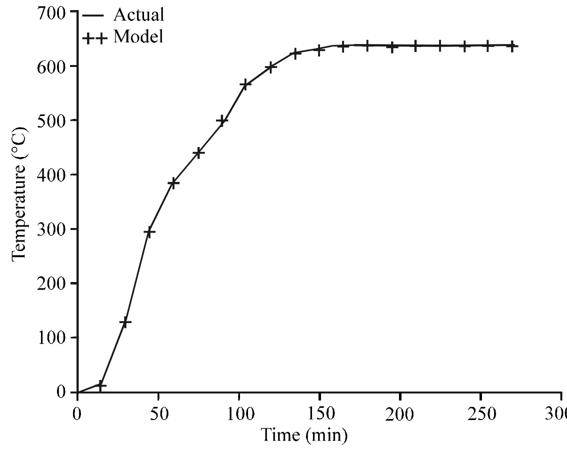

Fig. 3: Compared results

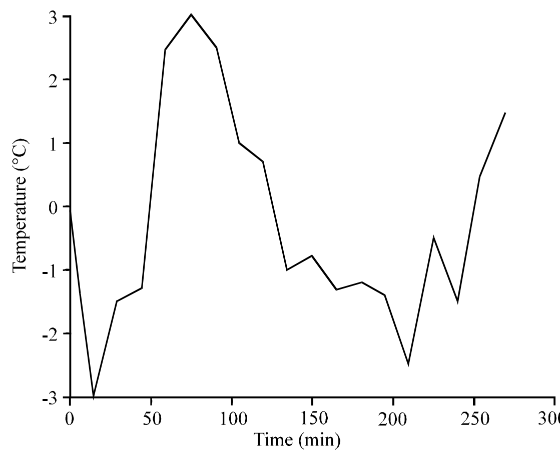

Fig. 4: Error of the model outputs and the actual measurements

TEMPERATURE CONTROL STRATEGY DESIGN

Single and changeless control strategy is no longer applied in the controller design. The structure of the controller is modified at any time in the process of production according to the temperature output error and its aim is to achieve the best optimal control of the foam glass kiln.

At the start time of the system, we take the Bang-Bang control strategy to heat up the billet mold with the shortest possible time: When e>0, the controller output the maximum μ_{max} to make temperature rise rapidly; when e<0, the controller output the minimum μ_{min} to make temperature drop smoothly.

When the temperature error is less than a given range with the control process on, if the control strategy is still using would make the overshoot too large. This is not feasible. So, when $|e|\leq 10°C$ it takes the OFNN controller

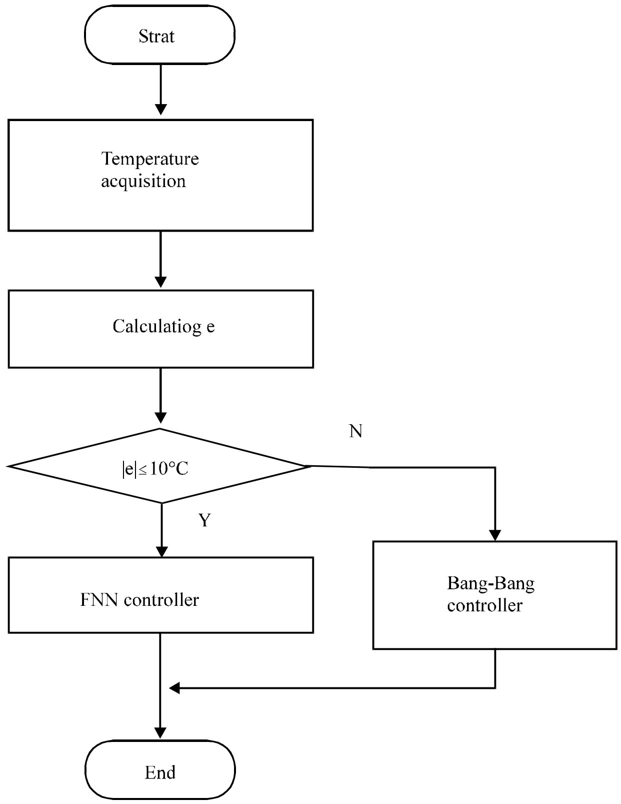

Fig. 5: Controller switching process

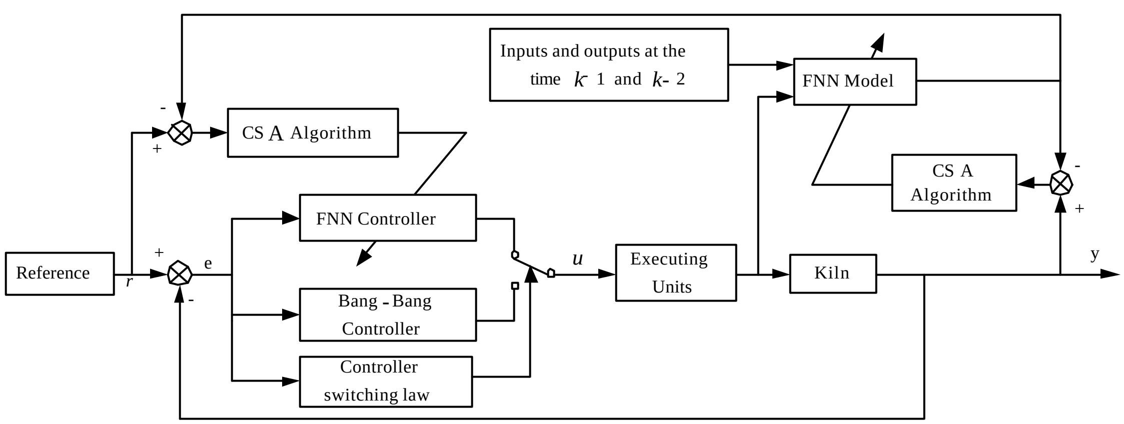

Fig. 6: Block diagram of the control system

to calculate out the accurate output with little temperature error; on the contrary, $|e|>10°C$, we switch back to the Bang-Bang controller. Fig. 5 shows the controller switching process.

The control strategy is written in C language saving in the industrial PC to calculate out the input current according to the real-time field data and the results sent to PLC will be converted to the corresponding control signal. The executing units will receive the signal to complete the control requirements. Fig. 6 shows the block diagram of the control system.

APPLICATION RESEARCH

The electric heaters are placed at the top, bottom and both sides in the foam glass kiln in order to make the mold evenly heated by adjusting the input current of the four heating wires to control the temperature of the production bay. Fig. 7 shows the components of the system includes foam glass kiln, temperature acquisition units, executing units, PLC and industrial PC.

System configuration software is Turing Control v7.3. The user interface including the temperature parameters real-time monitoring of each kiln room, limit alarm, data reports, historical curve, etc. Fig. 8 shows the interface of control system is stable and reliable. Fig. 9 shows the screenshot of real-time curve at No.7 temperature measurement point within a certain period of time. The the foaming process of foam glass producing. It can be seen from the figure, the temperature trend of the entire production line is very close to the technological requirements temperature curve, indicating that the curve is basically stable and the temperature error is controlled within 3°C.

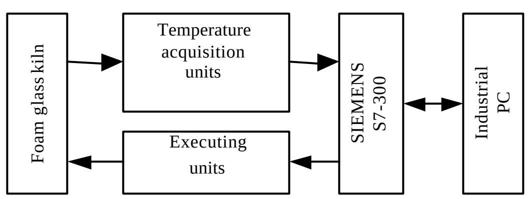

Fig. 7: System structure

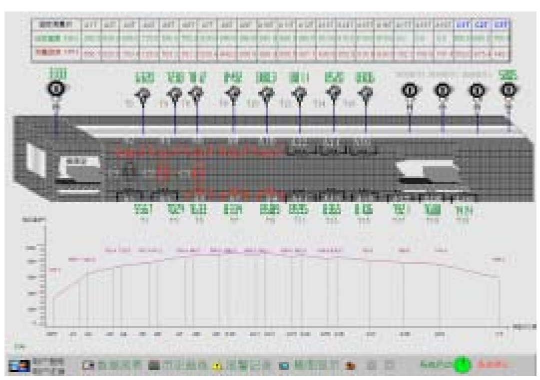

Fig. 8: Configuration software interface

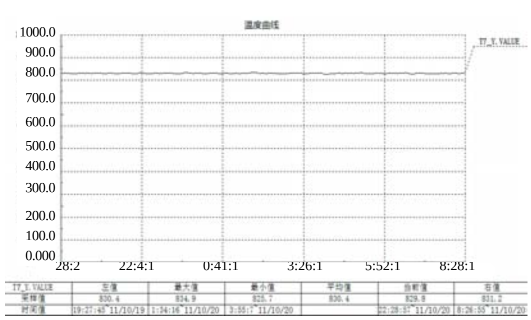

Fig. 9: Screenshot of real-time curve at No.7 temperature measurement point within a certain period of time

CONCLUSION

In this study, a new temperature control strategy is proposed by analyzing the working mechanism of the kiln and the temperature control problem in it. In which the OFNN is trained by CSA to implement the optimization of OFNN parameters. The structure of the controller is modified at any time in the process of production according to the temperature output error and its aim is to achieve the best optimal control of the foam glass kiln system.

The application of this control systems shows that the production process is stable, reliable and it can meet the process requirements. The heating process is smooth, almost no vibration and the temperature error of the heating wire maintained within 3°C. The strategy which reducing the energy consumption, the production time and the scrap rates, has good control effect to make the product quality greatly improved and the revenue for the company greatly increased.

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