Research on Temperature Control of Single Crystal Furnace Based on Neural Network

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Abstract: Silicon material has excellent semiconductor characteristics. It is the raw material of electronic devices, photovoltaic power generation and other industries. The growth of silicon mainly includes Czochralski method and zone melting method, among which monocrystalline silicon grown by Czochralski method is the most popular in the market. The growth environment of monocrystalline silicon is very complex, which requires very high temperature and precise control. The current development of monocrystalline silicon towards large diameter and high quality requires higher temperature control in the furnace. However, the single crystal furnace used for the growth of monocrystalline silicon has the characteristics of large lag, and cannot adapt to the growth of large diameter monocrystalline silicon. Therefore, in order to ensure the sTable growth of monocrystalline silicon, the requirements for temperature control in the furnace are higher.

1. Introduction

In recent years, China's silicon industry has developed rapidly. As an important part of non-ferrous metal industry, silicon industry's main products are as follows: organic silicon, industrial silicon, monocrystalline silicon and polycrystalline silicon. The semiconductor properties of silicon materials are very good, especially monocrystalline silicon, which is an important material of electronic devices, semiconductor chips and photovoltaic power generation industries. The downstream of silicon industry has been applied in various professional fields such as aerospace, electronic communications, national defense and military industry and new energy. For example, mobile phones, LCD TVS, Tablet computers, cars, spaceships, and satellites and so on all use silicon as one of the raw materials. There are generally two ways to grow silicon: the straight-pull method and the zone melting method. Most silicon integrated circuits on the market use the single-crystal silicon grown by the straight-pull method. Currently, 98 percent of electronic components are made of silicon, and about 85 percent of these components are made of single crystalline silicon sheets. At present, the world is advocating new energy and renewable energy technology, solar energy technology is one of the most important technology. China is the world's largest energy consumer. The current energy consumption structure of China is shown in figure 1.

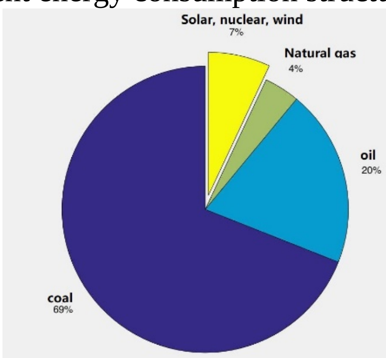

Figure 1 China's energy consumption ratio

As can be seen from figure 1, the largest energy consumption in China is non-renewable resources such as coal, and the environmental pollution is very large, and the proportion of new energy consumption is very low.

During the growth of monocrystalline silicon, the thermal field temperature of monocrystalline furnace has a great influence on the quality of crystal

The failure of the whole process may result in the failure of the whole process. The silicon raw material is heated by electric heating in single crystal furnace. At present, most single crystal furnace at home and abroad adopts PID control to control its heating. PID control is one of the most commonly used closed-loop system control technologies in industrial production. PID controller has the following characteristics:

(1) PID control of the control objects can be more than one kind, algorithm stability is strong, and the control objects of no Parameters and internal structure are not very sensitive.

(2) The principle of the algorithm is simple. PID control is mainly to determine the three parameters P, I, D, and these parameters mainly rely on the controlled object and experience of many experiments. PID control is very dependent on the controlled object, and has certain limitations. Its parameters will change due to different controlled equipment and working environment, so it is quite difficult to set parameters. The growth furnace of monocrystalline silicon is a system of great hysteresis and inertia, which leads to the difficulty in establishing the mathematical model of monocrystalline silicon furnace.

2. Research status of intelligent temperature control

The traditional PID temperature control system has a simple structure and good adaptability, which has been widely used in industrial control. However, due to the increasing requirements on temperature accuracy and response speed during production [14], the traditional PID control cannot meet the current requirements for temperature control in silicon production. Now a lot of researchers are starting to study intelligence

PID control algorithm to control the temperature, PID control algorithm and intelligent algorithm are combined, the advantages of the two together to solve some nonlinear, complex temperature control problems. Here is a summary of some common intelligences PID control algorithm and temperature control system combined control method.

(1) The combination of fuzzy control and neural network control makes use of the self-learning advantages of neural network Time setting parameters of the control system make the control effect better, with the characteristics of good control effect, strong adaptive ability and high control accuracy [15].

(2) Genetic algorithm PID control. It mainly USES the control system to find the best parameter value, It can effectively improve the control response speed, reliability and stability of the system [16].

(3) Neural network PID control. Neural network can infinitely approximate any nonlinear system, and can automatically adjust system parameters by using self-learning ability to achieve the optimal control effect [17].

Although these intelligent PID control algorithms have the effect that traditional PID control cannot achieve when dealing with some complex control systems, they also have some shortcomings. For example, the genetic PID control algorithm has a large amount of computation, and the stability of the nonlinear system is not high. BP neural network algorithm is very weak.

The signal processing is not very sensitive, and the fuzzy controller cannot eliminate the static difference of the system, so in the production practice, the best control algorithm is selected according to the requirements of the system.

The control object studied in this paper is the temperature control device of single crystal furnace, which belongs to the large hysteresis and nonlinear control system, and the neural network PID control adopted in this paper just solves the relevant problems, and applies to the production according to the actual production situation of the factory.

3. Neural network PID control and MATLAB simulation

In this chapter, the neural network PID control algorithm is introduced in detail, and the engineering software MATLAB is used to simulate and compare the traditional PID and neural network PID, so as to achieve the purpose of optimization algorithm.

3.1 MATLAB simulation test of network PID

3.1.1 Temperature control simulation model

Single crystal furnace is a complex control system, which heats the whole thermal field by energizing the graphite heater. As shown in FIG. 4.2, when the temperature of liquid surface of silicon melt is stable, the power of the heater increases by 4KW, and the liquid surface temperature of the melt slowly increase after about 20 minutes.

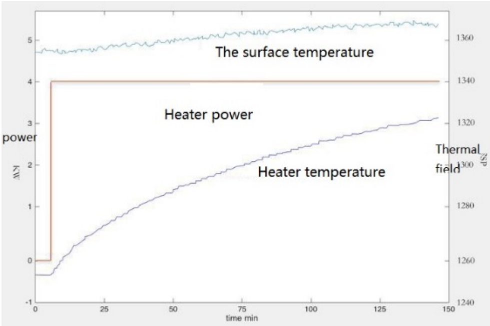

Figure 2 temperature hysteresis diagram of molten fluid surface of silicon

Figure 2 shows that the heating system of single crystal furnace is characterized by large hysteresis and inertia [27]. The transfer function of liquid surface temperature and power is:

$$G(s) = \frac{K}{Ts+1}e^{-\tau s} \tag{1}$$

K is expressed as percentage of the coefficient on type, tau is delay time constant, T for the inertial time constant. In this paper,

Equation (4.31) is selected as the mathematical model of monocrystalline silicon heating control system, and the neural network PID and PID control algorithm are compared and verified from the aspects of the system's self-adaptability, tracking characteristics and dynamic characteristics.

3.1.2 Simulation and analysis of temperature control system

The heating system of single crystal furnace is characterized by large hysteresis and inertia [14]. Therefore, large values of delay time (I -) and inertia time (T) in the mathematical model of the heating system in equation (4.31) are selected for simulation. Let the delay time I - =20s, the inertia time T=60s, and the proportionality coefficient be 1, then we can get:

$$G(s) = \frac{1}{60s+1}e^{-20s} \tag{2}$$

Where, the sampling period $T_c = |4 = 5\,s$, respectively for neural network PID control algorithm and PID control

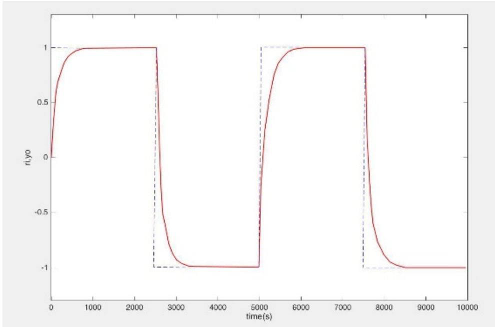

Figure 3 square wave response diagram of PID control

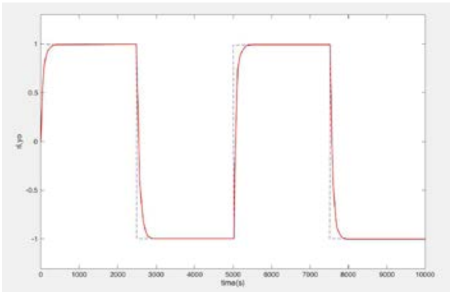

Figure 4 square wave response controlled by neural network PID

The proportional coefficient KP in PID control is 0.5, the integral coefficient ki is 0.006, the differential coefficient kd is 0.008, the input weight vector in neural network PID control is win1 =[0.1,0.1,0.1;-0.1,-0.1,-0.1], the output weight

The weight vector is wou1 = [0.1,0.1,0.1], and the learning efficiency is ri = 0.15. The ordinate in the simulation diagram represents the expected value ri and the actual output of yo of the controlled object, the dashed line represents the expected value, and the solid line represents the actual output. In figure 4.3

It can be seen that after about 1000s, the PID control algorithm realizes the square wave of the control object

Tracking; When square wave is converted into high and low level, the PID control algorithm needs about 1000s time to stabilize the tracking of rectangular wave. In FIG. 4.4, it can be seen that the PID control algorithm of neural network realizes the tracking of the other wave in about 350s, and when high and low level conversion occurs, it needs about 350s to stabilize the square wave tracking of the control object. By comparing the above two square wave response graphs, it can be seen that neural network PID control algorithm has better capability in waveform tracking than traditional digital PID control algorithm.

Step simulation experiments were carried out on neural network PID control algorithm and PID control algorithm respectively. Step response of PID control and step response of neural network PID control were shown in figure 4.7 and figure 4.8 respectively.

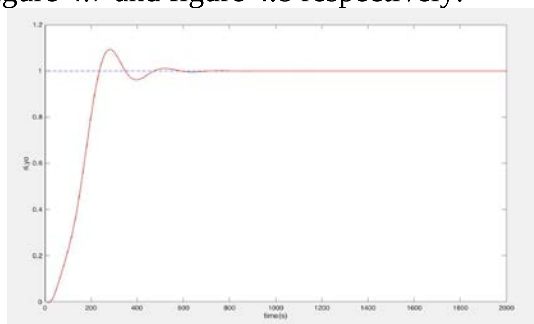

Figure 5 PID control step response diagram

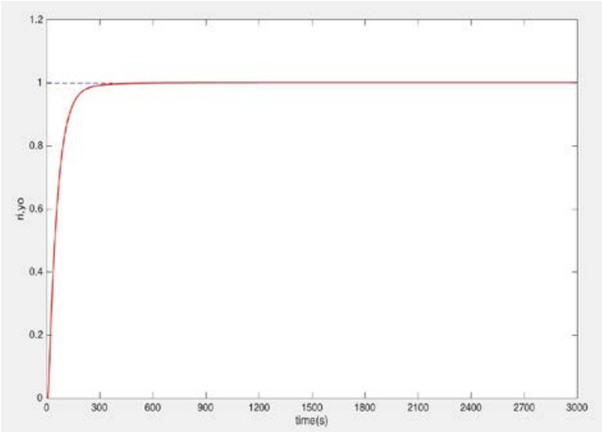

Figure 6 step response diagram of neural network PID control

In figure 5, the step response curve of PID control increases rapidly in the first few hundred seconds, reaching the step value between 250s and 350s. However, the output of the controlled object is unsTable and fluctuates greatly [14], and the sTable tracking of the step signal is completed after roughly 1000s. In figure 6, it can be seen that the response curve of neural network PID control is not as fast as that of PID control in the first 250s, but the output of yo to the controlled object continues to rise steadily. After about 450s, the goal of sTable tracking step signal is achieved, and the time to achieve stability is almost half of that of PID control.

4. Reduce thermal field sp value to detect temperature stability

The quartz crucible is at the position of 50 (mm), the quartz crucible is at the position of 50 (mm), the pressure in the single crystal furnace is 19.0 (Torr), the power of graphite heater is 90.0 (KW), the crucible is converted to 15 (RPM), and the set value of sp in the thermal field is reduced from 1330.0 to 1270.0. The test curve of this condition is shown in figure 7

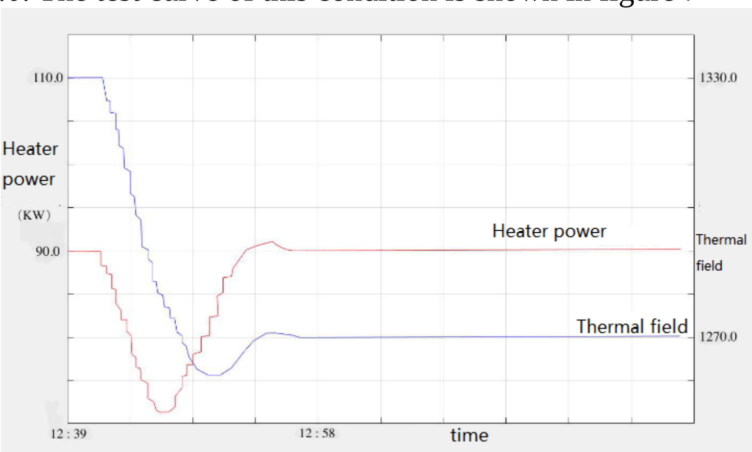

Figure 7 in the change of sp value of thermal field from 1330.0 to 1270.0, heating

The power was reduced to 72 (KW), and then followed up slowly to the set value of 90 (KW), and the sp value of thermal field followed up slowly to the preset value of 1270.0. It took about 15 minutes for the temperature to stabilize, which was a fast response.

Without adding silicon raw material in the single crystal furnace, the test results of heating, insulation and cooling of heater are shown in Table 1. The Table shows the time, actual temperature and preset temperature of the whole heating and cooling process.

Table 1 experimental data

time	Vacuum in furnace	Pa	Actual temperature ℃	Set temperature ℃	phase
8 : 10	6.9×10^{-1}		57.0	66.1	
8 : 50	2.2×10^{-2}		297.0	320.0	
9 : 30	8.3×10^{-3}		524.2	524.0	Vacuum heating stage
10 : 30	4.8×10^{-3}		834.0	834.0	
12 : 40	1.5×10^{-2}		1017.2	1017.0	
14 : 05	2.7×10^{-2}		1330.1	1330.0	
14 : 45	3.9×10^{-2}		1330.0	1330.0	
15 : 23	5.7×10^{-2}		1330.0	1330.0	
15 : 58	4.3×10^{-2}		1330.0	1330.0	
16 : 39	4.2×10^{-2}		1330.0	1330.0	
17 : 05	4.1×10^{-2}		1330.0	1330.0	Heat preservation stage
17 : 45	3.8×10^{-2}		1330.2	1330.0	
18 : 50	3.3×10^{-2}		1330.0	1330.0	
19 : 40	2.6×10^{-2}		1330.0	1330.0	
20 : 27	2.2×10^{-2}		1330.1	1330.0	
21 : 09	1.8×10^{-2}		1330.0	1330.0	
21 : 49	1.5×10^{-2}		1313.2	1313.0	
22 : 50	5.7×10^{-3}		1249.8	1250.0	
23 : 50	3.8×10^{-3}		1124.7	1125.0	Cooling phase
24 : 50	2.4×10^{-3}		997.0	997.0	
1 : 25	1.7×10^{-3}		904.0	904.0	

The group of experiments show that the neural network PID control algorithm can basically meet the design requirements of the control, due to a lot of environmental factors in the furnace, resulting in some small fluctuations in the measured temperature, but the temperature accuracy of the control meets the requirements of the system.

5. Conclusion

To solve the problem that the traditional PID control temperature effect in single crystal furnace is not ideal, this paper applies the neural network PID control algorithm to the heating system of single crystal furnace, and obtains a better control to meet the production requirements.

The main research work is as follows:

(1) The structure and hot field components of single crystal furnace are studied.

(2) The heat transfer and heat transfer of monocrystalline silicon in the thermal field were studied, and the crystal was built

The growth characteristics of crystal were studied.

(3) The principle of PID is introduced, and the common PID algorithm is elaborated, from the algorithm improvement, know the advantages and disadvantages of PID combined with other algorithms.

(4) The principle and characteristics of neural network are systematically studied, and PID control and neural network calculation are also given

The combination of method is analyzed in detail.

(5) Matlab tool is used to compare PID control algorithm and neural network PID control

algorithm in terms of accuracy, response speed and tracking speed, and draw the conclusion that neural network PID control algorithm is superior to PID control algorithm.

(6) The modular control heating system of single crystal furnace is studied to ensure the accurate control of single crystal furnace temperature.

(7) Identify the mathematical model of single crystal furnace heating system, and from the location of crucible, thermal field temperature, crucible

The feasibility of the algorithm is verified by the field test of the rotating speed.

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