Study on Control Scheme of Quartz Fiber Prefabricated Rod Production Line

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Abstract: PSOD process has serious hysteresis phenomenon and belongs to the large hysteresis system. On the basis of analyzing the working mechanism of the system, the PID control, Smith predictive control and fuzzy control are combined to control the system. Simulation results show that the proposed method has better dynamic performance than the traditional PID control method, regardless of the given input or interference. The conclusion is valuable for the safe operation and control of time-delay systems.

1. INTRODUCTION

At present, the preparation methods of fiber prefabricated rod mainly include electrofusion preparation, gas refining preparation, artificial chemical synthesis preparation and high frequency plasma deposition preparation (PSOD). The PSOD process uses clean and dry compressed air or argon plasma as the heat source, without the introduction of external impurities. The quartz glass produced by this process has low hydroxyl content and high purity. It not only ensures the performance of quartz glass, but also reduces the content of hydroxyl. This method is one of the main processes for the preparation of high purity silicon materials [1-3].

Due to the poor thermal conductivity of quartz glass in the process of PSOD, the measurement signal of deposition temperature has some hysteresis. After leaving the feeder, the powder needs to go through a period of free fall in the material channel to reach the deposition position. Since the control quantity can only act on the controlled object after a period of time, and the output of the control system can only feed back to the input end after a period of time, the control system belongs to a time-delay system, and all these lag factors increase the difficulty of system adjustment.

2. STRUCTURE AND PRINCIPLE OF THE SYSTEM

The schematic diagram of PSOD process is shown in figure 1. The high-frequency plasma generating equipment generates high-frequency magnetic field, and the high-frequency magnetic field ionizes the working gas and generates high-temperature plasma flame. The temperature can reach 3000-4000°C. The high quality quartz glass prepared by this process is fully vitrified, uniform in texture and high in deposition efficiency.
The quality of quartz products is directly affected by the operating accuracy, deposition temperature and feeding accuracy of the deposition lathe[4]. However, restricted by the adverse conditions such as high temperature, strong light and high-frequency signal interference in the deposition workshop, the important parameters such as deposition temperature and deposition amount during the deposition process cannot be measured directly, and the deposition temperature can only be indirectly reflected through the generator power. Through the operator entering the operation room regularly and measuring the deposition amount at a certain position with vernier caliper, and adjusting the process parameters through experience value, the product quality cannot be guaranteed and the production efficiency is low.

The deposition lathe, as the carrier of the center tube of the deposition foundation required by the PSOD deposition process and the execution part of the product shaping, is an important equipment to ensure the geometric specifications of quartz products[5-6]. The quartz glass can be deposited layer by layer through the interaction of longitudinal, transverse, vertical and rotational motion. The running track and speed of the lathe are directly related to the technological position, geometric specifications and single layer deposition of quartz material, which is one of the important factors affecting the quality of quartz deposition. The lathe is controlled by four servo control systems, which control the running track and speed accuracy in each direction.

The structure of the hardware system of the deposition temperature control system is shown in figure 3-6. The system is composed of omron CJ2 series PLC, voltage regulator, power supply, plasma generator, temperature measuring instrument and other units. PLC is the control core of the whole system, its role is: 1. send PWM pulse signal to the voltage regulator to control the output of the voltage regulator, to achieve the plasma generator power control, so as to achieve the regulation of the deposition temperature; (3) the realization of the control algorithm, according to the selected control strategy to achieve the corresponding control function, that is, according to the temperature signal transmitted by the temperature measurement instrument, using the corresponding control algorithm, through the PLC program to achieve the closed-loop control of the deposition temperature. Voltage regulator is the control unit of deposition temperature, which receives PWM pulse signal sent by PLC, adjusts output voltage, and realizes the control of deposition temperature. The deposition process can be detected by infrared thermometer.

3. RESEARCH OF CONTROL METHOD

Four methods are used to control the system.

3.1 PID control

PID control method is simple, economical, practical and easy to realize. These characteristics make it widely used in industrial control. However, PID control is often difficult to achieve good control effects for large lag systems, systems that cannot obtain accurate mathematical models or systems with random interference[7].

PID control is conducted according to proportion, integral and derivative of system input and output deviation. The control principle structure of the system is shown in figure 2.
In the figure 1, r is the system input; E is deviation; U is the control signal; Y is the system output. The mathematical expression of PID control is shown in equation 1.

\[ U = K_p (e + \frac{1}{T_i} \int e dt + T_d e) \]  

(1)

Here, Kp is proportional coefficient, Ti is integral time coefficient, Td is differential time coefficient.

3.2 Smith Estimation Control

The basic idea of Smith predictive control method is as follows: the dynamic characteristics of the system under the action of basic disturbance are estimated in advance, and then the time delay is compensated by Smith estimator, so that the delayed modulator is reflected to the regulator in advance, and the regulating action is acted in advance, so as to offset the influence caused by large time delay[8]. Thus the overshoot of the system is reduced, the stability of the system is improved, and the rapidity of the system is improved. Smith estimated control structure is shown in figure 3.

In the figure, r is the system input; \( C(s) \) is master controller; q is system disturbance; \( P(s) \) is the actual physical model of the controlled object; \( \hat{P}_0(s) \) is the non-delay part of the system model; \( e^{-\sigma} \) is the time-delay part of the system model; Y is the output of the system; \( \tilde{y} \) is the output of the model; \( y_0 \) is the output of the model without delay; e is the error; \( e_f \) is the error between system output and model output; \( y_f \) is the feedback quantity of the system. As can be seen from the figure, the structure of Smith estimator is divided into two parts: the master controller and the estimator. The main controller generally adopts PID control, and the estimator is composed of the model without delay and the delay part in series. Therefore, the complete model of the controlled object is:

\[ \hat{P}(s) = \hat{P}_0(s)e^{-\sigma} \]  

(2)

Smith predictive control divides the mathematical model of the controlled object into two parts, namely, the delay-free model and the time-delay model. When there is no modeling error, \( \hat{P}(s) = P(s) \), \( e_f \) is zero, the feedback quantity of the system \( y_f \) is the output of the model without time delay. At this point, the influence of time delay is completely eliminated, and the whole system can be regarded as a
hysteresis free system. The main controller can adjust the parameters according to the time-delay-free model so as to improve the control accuracy of the system.

From the above analysis, it can be seen that the Smith estimation controller relies on the mathematical model of the system and needs to know the precise model of the controlled object. But the industrial process is often very complex, it is difficult to obtain the precise mathematical model of the controlled object.

3.3 Fuzzy control

The biggest advantage of fuzzy control is that it does not need the precise mathematical model of the controlled object, and the control rules are designed according to experts' experience and knowledge. In engineering application, the control effect of fuzzy control is often better than that of traditional PID control for the control of complex systems such as large lag, time varying and non-linear.

According to the above analysis, the PID control structure is simple and easy to implement, but it is helpless for the system with large time delay. Smith control is an effective control method for large time delay systems, but it is excessively dependent on accurate mathematical models and has poor robustness. Fuzzy control has high robustness and can solve the control problem of large time delay system through expert experience. Therefore, we can make use of the advantages of the three control modes to form a composite controller to control the time-delay system.

3.4 Compound control

According to the advantages and disadvantages of the three control methods described above, the composite control method takes its advantages and introduces Smith predictive compensation control on the basis of switching between fuzzy control and PID control. The composite control consists of four parts, namely, modal selection, PID controller, fuzzy controller and Smith estimator, whose control structure is shown in figure 4.

The composite control method is simulated, and its simulation structure is shown in figure 5.

Add an input to the system with an initial step of 10, a disturbance of 20% step is added to the system at 1800 second. The comparison of simulation results is shown in figure 6 and figure 7. Figure 6 shows the simulation result of traditional PID control, Figure 7 shows the simulation result of compound control.
It can be seen from the simulation results that the composite control method is obviously superior to the traditional PID control method in both tracking performance and anti-interference performance.

4. CONCLUSION

In this paper, PID control, Smith predictive control and fuzzy control are combined to control the PSOD system. Simulation results show that the proposed method has better dynamic performance than the traditional PID control method, regardless of the given input or interference. The response speed using this control method is very fast, and the system has a strong anti-interference ability.

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