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Design and Implementation of Control System for Automatic Spinning Production Line of Chemical Raw Materials

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With the increasing demand for healthy, environmental protection and comfortable spinning products, higher requirements have been put forward on the quality and output of spinning production for chemical raw material. In order to realize the on-site monitoring and remote monitoring of the production process on the spinning production line of chemical raw material, this paper selects the ant colony optimization algorithm (ACO) as control algorithm, and designs the production line control system based on the control scheme of spinning automatic production line for chitosan fiber chemical raw material. The results show that the automatic production line control system for chemical raw materials includes bottom monitoring and remote monitoring. The introduction of ACO algorithm into the parameter optimization of the traditional PID control system can realize the modeling of the coagulation bath control system with the advantages of short rise time and adjustment time, and small overshoot. In terms of the algorithm stability and the difficulty, it can be seen that the ACO algorithm is superior in the parameter optimization.

1. Introduction

The advancement of science and technology has improved people's living standards. Higher requirements have been made for the textiles, and traditional textiles are increasingly being replaced by new textiles that contain new concepts of health, comfort and environmental protection (Al-Hawari et al., 2018). Chitosan fiber is the raw material for dry spinning, as one linear polymer material. Similar to the chemical structure of cellulose, it has certain fiber-forming properties and can be spun into silk. Now it has been gradually applied to textile products in the medical, health and military fields etc. (Gyulai et al., 2016). Compared with developed countries, China has not solved the problem of large-scale industrialization and non-polluting of fiber production. Therefore, there is still a long way to realize the industrialization of pure chitosan fiber production (Qi et al., 2012). Under the guidance of the big environment and national policies, many chemical spinning enterprises seek technological innovation to achieve automation and Informa ionization of the industry, which also puts forward new requirements for process monitoring and intelligent production of production on the production line (Guo et al., 2009; Khenifar-Bessadi et al., 2017).

At present, the production line control system develops in the increasingly diversified, intelligent and large-scale mode. The electromechanical equipment technologies such as intelligent instrumentation and frequency converters for the integrated automation control system of the spinning production line have been mature and widely used (Colledani and Tolio, 2009; Frigerio and Matta, 2015). The control equipment and testing equipment have many functions such as communication and remote transmission, which provide a solid foundation for the comprehensive automation of the spinning production line; also, the real-time database has been successfully applied in chemical spinning production enterprises (Wu et al., 2016). The design of the control system for the automatic spinning line of chemical raw materials provides a feasible solution for the control of the chitosan fibers production line, improving the production quality of chitosan fibers and the stability of the control system (Gyulai et al., 2015, Wu et al., 2017). In this paper, based on the automatic production line control scheme of chitosan fiber chemical raw material spinning, the ant colony algorithm was used as the control algorithm to design the production line control system and then realize the on-site monitoring and remote monitoring of the production line process.

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2. Control system design of spinning production line

2.1 Production process of spinning production line

Chitosan fiber is made by wet spinning of the chitin which removes the acetyl by hot alkali process and then dissolves in the solvent; then, the prepared stock solution is sprayed through a spinneret and solidified by the coagulation bath to form a fiber (Kalinin et al., 2015). The entire automatic production line control system design includes three parts: metering pump control system design, coagulation bath control system design and motor unit control design (Oda et al., 2017). Fig.1 shows the control flow of the stock preparation unit: the fiber-forming polymer is firstly dissolved in the dissolving kettle, then passes through the defoaming kettle and the raw liquid storage tank through the transport pump, and finally is filtered through the filter to the metering pump. In the entire automatic line control, the signals to be detected include control signals, temperature detection signals, liquid level detection signals, and pressure detection signals (Precup et al., 2012).

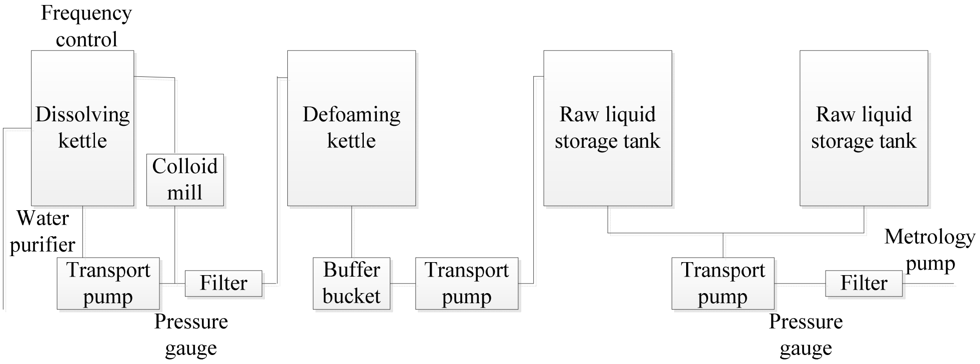

Figure 1: Stock preparation unit control flow

2.2 Control system design of spinning production line

The spinning production line of chemical raw material should ensure the complete control of the entire production process under the normal operation and safe production conditions of the entire production line control system. Therefore, the entire control system is divided into three layers: the bottom control layer, the configuration control layer and the remote monitoring layer. The complete automatic production line control system shall include acceptance indexes such as control point statistics, control requirements and human-machine interface. The core controller PLC has strong anti-interference ability, good stability, good reliability, and strong expansion capability, combination ability and driving capability. Table 1 lists the hardware selection and configuration of the automatic control system on the spinning production line. The types of system hardware systems include PLC controllers, circuit breakers, contactors, switch buttons, cabinets and electronic systems. The automation and informationization of the spinning production process requires real-time monitoring of the production processes on the production line by means of the configuration software MCGS. Fig.2 shows the MCGS configuration monitoring design framework. The overall system structure includes five parts: the main control window, device window, user window, real-time database and operational strategy.

Table 1: Spinning line automatic control system hardware selection and configuration

Number	Category	Product name	Model or order number
01	PLC	EM 221 DI16 1	6ES7 2211BH220XA8
02		EM 221 DI8 1	6ES7 2211BF220XA8
03		EM 231 AI2 thermal resistance	6ES7 2317PB220XA8
04	Breaker	Coagulation bath part breaker	5kW
05	Contactor	Coagulation bath part contactor	7.5kW
06	Switch button	Startup button	—
07		Stop button	—
08	Inside cabinet	Intermediate relay	DC24V 2P/4P
09	Electron	Transformer	AC380V

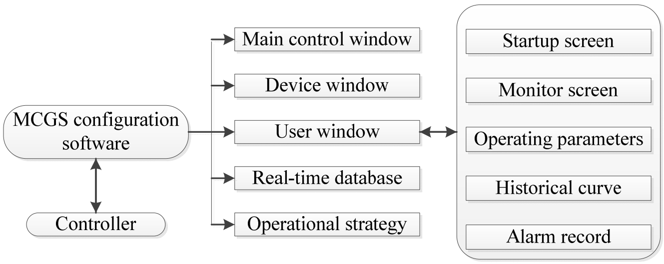

Figure 2: MCGS configuration monitoring design framework

3. Research on intelligent control parameter adjustment strategy of production line

3.1 Traditional and intelligent control algorithms

The traditional PID controller consists of three units: proportion, integral and differential. It has a good optimization and adjustment effect on the given mathematical model. However, due to its time-varying characteristics, the actual production line control system is difficult to be expressed with one certain mathematical model. Therefore, it’s difficult for the traditional PID controller to achieve the expected effect. The intelligent PID control algorithm can be separated from the system mathematical model without relying on accurate mathematical models, so as to be adjusted on line. It has the advantages of both traditional PID control algorithms and the intelligent control algorithms, including strong adaptive ability, and dynamic optimization of parameters.

3.2 Application of ant colony optimization algorithm in production line control system

The group intelligence of the ant colony has significant intelligent characteristics. In the overall optimization process, the time is short and the number of iterations is small. The trajectory of the ant colony system pheromone is shown in formula 1:

$$\tau_{ij}(t+n)= \rho\cdot\tau_{ij}(t)+ \Delta\tau_{ij}(t, t+n) \tag{1}$$

where, ρ is the pheromone and n is the number of iterations.

The ACO algorithm is an inspiring probabilistic group optimization algorithm. The production line control system is a prominent case of the optimization process, and the whole process is dynamic and random. Control parameters such as temperature and concentration of coagulation bath in the preparation of chemical raw materials are crucial to the quality of filament formation. A large number of researchers have applied genetic algorithms, fuzzy control algorithms and neural network algorithms to the combinatorial optimization process. In this section, the selection problem of system control parameters is transformed into the combinatorial optimization problem of ACO algorithm, realizing the control system optimization of the coagulation bath liquid level. Fig.3 shows the block diagram of the production line PID controller system based on the ACO algorithm, in which the relationship between the controller’s control quantity u(k) and the deviation e is shown in formula 2:

$$u(k)=k_p\{e(k)+\frac{T}{T_i}\sum_{j=1}^{k} e(j)+\frac{T_d}{T}[e(k)-e(k-1)]\} \tag{2}$$

where: e(k) is the control deviation, k_p is the proportional coefficient, and Ti and Td are the integral and differential time constants, respectively.

The control law incremental equation of the PID controller is given as:

$$u(k)=kp\{[(k)+e(k-1)]+\frac{T}{T_I}e(k)+\frac{T_d}{T}[e(k)-2e(k-1)+e(k-2)]\} \tag{3}$$

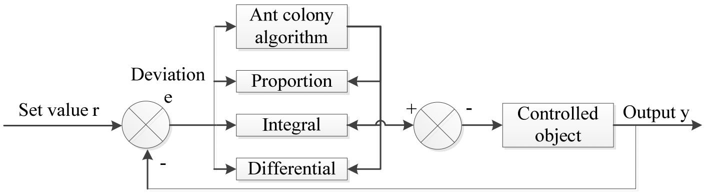

Figure 3: Block diagram of production line PID controller system based on ant colony algorithm

4. Simulation application of production line control system

4.1 Control system simulation of coagulation bath liquid level

Fig.4 shows the control flow of the coagulation bath control unit. The control unit control and detection signals of the whole process include control signals, temperature signals, concentration signals and liquid level signals. Fig.5 shows the interface of the entire spinning line control system, including the operating speed and operating parameters of the machine group. The mathematical model was constructed according to the control flow given in Fig.4, as shown in formula 4:

$$Gs=\frac{K}{T_1T_2s^2+(T_1+T_2)s+1} \tag{4}$$

where: T_1 and T_2 are the time constants of the two liquid reservoirs, respectively, and K is the transfer function.

Fig. 6 shows the hardware block diagram of the coagulating bath liquid level control system. The whole hardware structure includes the controlled object, the PLC controller and the peripheral device, where the controlled object and the PLC controller are transmitted through the sampling device. Fig.7 shows the software structure of the coagulation bath level control system. The entire control system software program includes the PLC program and the touch screen program. The ACO algorithm was applied to the traditional PID controller adjustment method, and the simulation of the coagulating bath liquid level control system was completed by Simulink method (Hou, 2018).

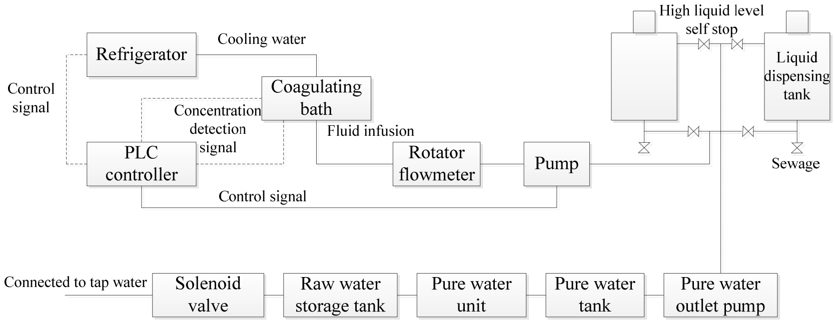

Figure 4: Coagulation bath control unit control process

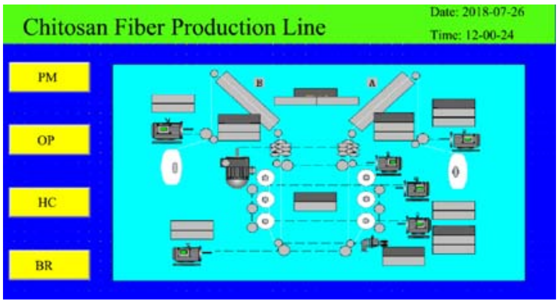

Figure 5: Production line control system interface

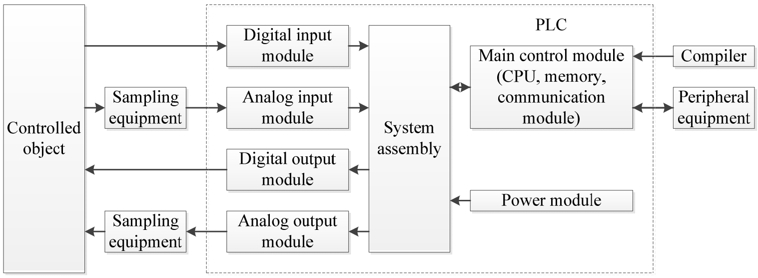

Figure 6: Hardware block diagram of the solidification bath level control system

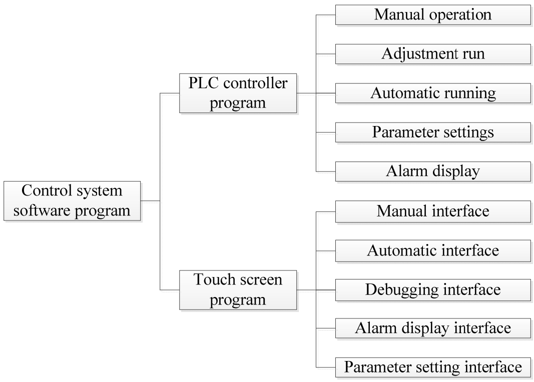

Figure 7: Software structure of the solidification bath liquid level control system

4.2 Comparison of simulation results

Fig. 8-11 shows the PID step response of conventional PID, the PID step response based on ACO algorithm optimization, the PID step response of genetic algorithm optimization, and the fuzzy adaptive PID step response. It can be seen that for the three kinds of intelligent optimization algorithms, the optimized system performance indexes are significantly better than the traditional PID controller. In terms of the stability for the three intelligent optimization algorithms, the rise time and adjustment time of the ACO algorithm are the shortest, and the overshoot is the smallest. Therefore, the optimization parameters of the ACO algorithm are better. In terms of the algorithm difficulty, the ACO algorithm requires a smaller number of iterations, and its objective function value is smaller than that of the genetic algorithm and the fuzzy adaptive algorithm.

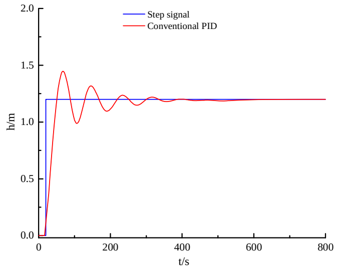

Figure 8: Conventional PID step response

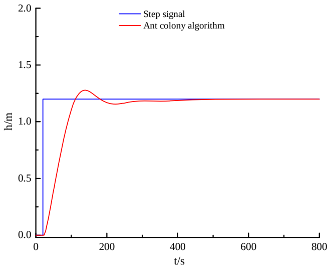

Figure 9: PID step response based on ant colony algorithm optimization

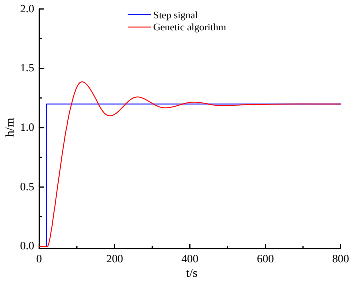

Figure 10: Genetic algorithm optimized PID step response

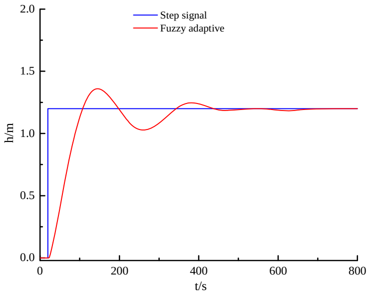

Figure 11: Fuzzy adaptive PID step response

5. Conclusions

In this paper, based on the spinning automatic production line control scheme of chitosan fiber chemical raw material, the ant colony optimization algorithm was used as the control algorithm to design the production line control system. The specific conclusions are as follows:

(1) The intelligent PID control algorithm can be separated from the system mathematical model without relying on the precise mathematical model so as to realize online adjustment. It has the advantages of

both the traditional PID control algorithm and the intelligent control algorithm, including strong adaptive ability, and dynamic optimization of parameters.

(2) The problem of selecting the system control parameters is transformed into the combinatorial optimization problem of the ACO algorithm, which can ensure the optimization of the coagulating bath liquid level control system.

Simulation results show that the system performance indicators optimized by the three intelligent optimization algorithms are significantly better than the traditional PID controller. In the three intelligent optimization algorithms, the rise time and adjustment time of the ACO algorithm are the shortest, and the overshoot is the smallest. From the perspective of the stability and difficulty of the algorithm, the optimization parameters of the ACO algorithm are superior.

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