Simulation and Experiment of Plant Factory Environmental Control System Based on Internal Model Control Theory

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Keywords: Internal Model Control, System Simulation, Steady State Conditions, Variable Operating Conditions.

Abstract: Using the relevant theory of internal model control, a multi-variable decoupling internal model control method in which filters are set in the feedback channel, and the process of internal model control is simulated for anti-external disturbance conditions, system response speed conditions, and system stability. Working condition simulation, to check the system's ability to track the output signal in time and overcome external disturbances when working conditions change. In the artificial light source type plant factory, the temperature and humidity field control test was carried out under two conditions: steady-state working condition and variable working condition. The temperature and humidity control test is carried out in the artificial light source type plant factory, which is divided into two situations: steady state working condition and variable working condition. The control effect is illustrated by the actual operation curve. Through the verification test, it is obtained that the supply air flow controls the indoor temperature, the supply air moisture content controls the indoor humidity, and the cold water flow controls the supply air temperature. The internal model controller has stable working performance, and the control system has a good decoupling effect. The fixed value tracking and anti-interference performance can meet the production requirements of the plant factory.

1. Introduction

The allowable range for the internal temperature of the plant factory is $15\ ^{\circ}\mathrm{C} - 35\ ^{\circ}\mathrm{C}$ and the range for the internal humidity is $40\% - 100\%$ Generally, the above two parameters can be maintained within the specified range by adjusting the flow rate of cold water, the flow rate of supply air, and the moisture content of supply air in the plant factory. At the same time, since the energy consumption of a plant factory is not only determined by the temperature and humidity control equipment, but also closely related to the type and usage of artificial light sources. Therefore, under the premise that the artificial light source is determined, the control ability of the temperature and humidity control equipment should be strengthened as much as possible. High plant plant economy. Therefore, according to the operation and control requirements of the plant factory, the purpose and task of the temperature and humidity control system is to maximize the self-balancing ability of the temperature and humidity control system on the premise of ensuring the operation of the plant factory, so that the plant factory is in the best economic operation condition.

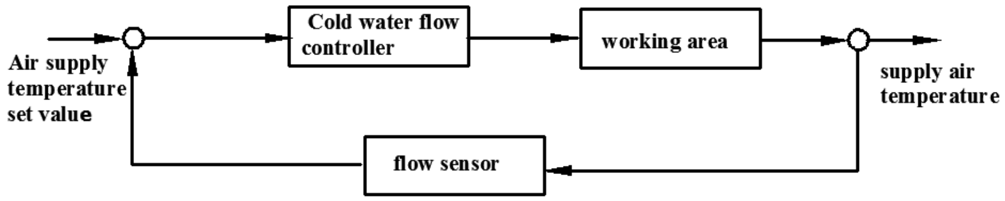
When using internal model control theory to solve the problem of system coupling and time delay, the following conditions need to be met. First, the controlled system must have an accurate mechanism model (a physical model that can describe the structure relatively accurately); second, whether it is a square control structure, or non-square control structure, different decoupling methods are used; the third is to determine the mathematical model of the controlled object, that is, a clear process transfer function is required; the fourth is to carry out a reasonable internal model controller design and filter can be used. Adjust the parameter settings, according to the specific controlled object, to take into account the anti-interference ability, response speed and stability of the controlled system. Therefore, the design of the internal model controller should be based on a clear mathematical model (process transfer function) of the controlled object, that is to say, the accuracy of the system model directly determines whether the design of the internal model controller can be carried out, and the internal model control the controller control performance is determined by the precision of the model parameters [1].

According to the special structure of the artificial light source type plant factory and the high controllability of the system environment, the research on the internal model control of the multivariable system is carried out. Based on the more universal and practical PID control method in industrial systems [2-5], the internal model control strategy is introduced into the temperature and humidity environment control of the artificial light source type plant factory, the design scheme of the internal model controller is given, and the control scheme more suitable for on-site implementation is studied.

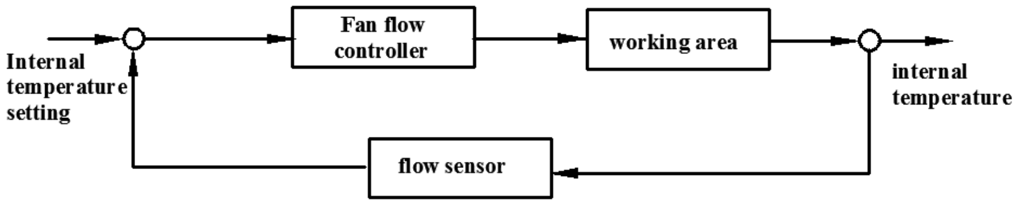
Most of the above environmental modeling theories and control methods are used in natural light or natural light and artificial light source plant factories. Due to the limitations of different types of plant factories in their own structure, materials, functions and use areas, there are great differences in the mechanism analysis of environmental models and environmental control methods. In addition, the existing research on artificial light source plant factories pays too much attention to the use effect of plant factories, and there are few studies on the mechanism analysis of environmental models and related control methods and methods, and the results of effective control are less, which limits the technological innovation and sustainable and healthy development of artificial light source plant factories.

2. Decoupling Control Structure of Temperature and Humidity System

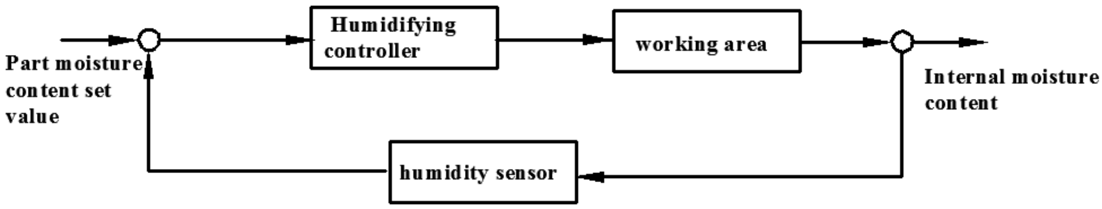
PID control strategy is used to solve the coupling problem of multiple-input multiple-variable (MIMO) system. Combined with the characteristics of system process transfer function, the control structure of MIMO system is determined based on the relative regularization gain matrix and coupling index. Under the premise of stable operation of artificial light source plant factory, the temperature and humidity system is matched, and the matching of air supply temperature and cold water flow, the matching of internal temperature and air supply flow, and the matching of internal moisture content and air supply moisture content are obtained. According to the decoupling matching results, the temperature and humidity control system (MIMO) is decoupled [6], and the temperature and humidity decoupling control loop is established as the supply air temperature control loop, the internal temperature control loop and the internal humidity control loop, as shown in Fig. 1.



(a) Block diagram of air supply temperature control loop.



(b) Block diagram of internal temperature control loop.



(c) Block diagram of internal moisture content control.

Fig. 1 Block diagram of temperature and humidity decoupling control loop.

3. Multivariable Internal Model Controller

The controller and the internal model controller are set in the feedback channel to regulate the operation of the system together to obtain a dual-controller internal model control system [6], as shown in Figure 2.

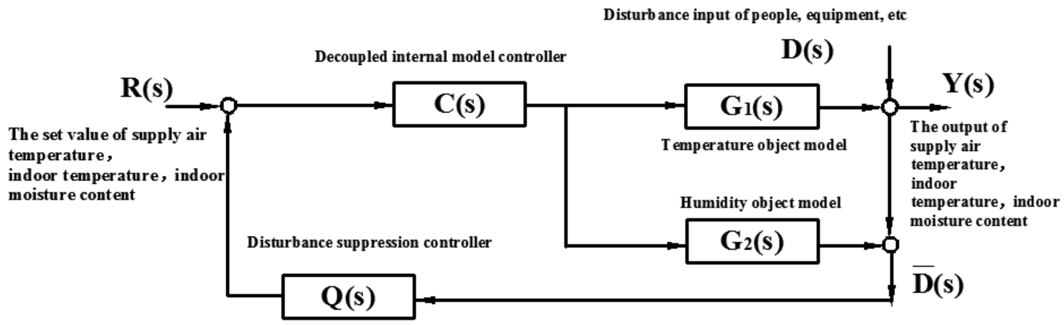


Fig.2 Dual-controller type multivariable decoupled internal model control.

Let $Q(s)$ be the controller set on the feedback channel,

$$\begin{cases} C(s) = G(s)_{m-}^{-1} F(s) \\ Q(s) = G(s)_{m-}^{-1} F_Q(s) \\ F(s) = \dfrac{1}{(\lambda s + 1)} \\ F_Q(s) = \dfrac{1}{(\lambda_Q s + 1)} \end{cases} \quad (1)$$

Among them, λ_Q —the adjustable parameter of the feedback channel filter; $R(s)$ is the set input quantity, $Y(s)$ is the output quantity, $D(s)$ is the disturbance quantity, $C(s)$ is the internal model controller, $G(s)$ is the transfer function of the controlled object, $G_m(s)$ is the object model, $U(s)$ is the input quantity, and $E(s)$ is the deviation quantity, $\widetilde{D}(s)$ is the feedback semaphore.

4. Simulation and Verification of Decoupled Internal Model Controller

The calculated optimal parameters of the system are applied to the simulation module. After the system runs stably, the simulation research of the internal model control system for temperature and humidity control is started. Through the simulation operation of the environmental controller, the coupling problem and time delay problem of the temperature and humidity environment are solved. Under the closed-loop control state, the timely tracking of the output signal of the system and the ability to overcome external interference are tested under the condition of changing working conditions. Therefore, the simulation process is divided into anti-external disturbance condition simulation, system response speed condition simulation, system stability condition simulation. According to the decoupling method of the temperature and humidity control system and the design method of the internal model controller matrix, the *Matlab / Simulink* M tool is used to model the temperature and humidity control system [7]. Figure 3 shows the internal model control simulation model of the temperature and humidity control system.

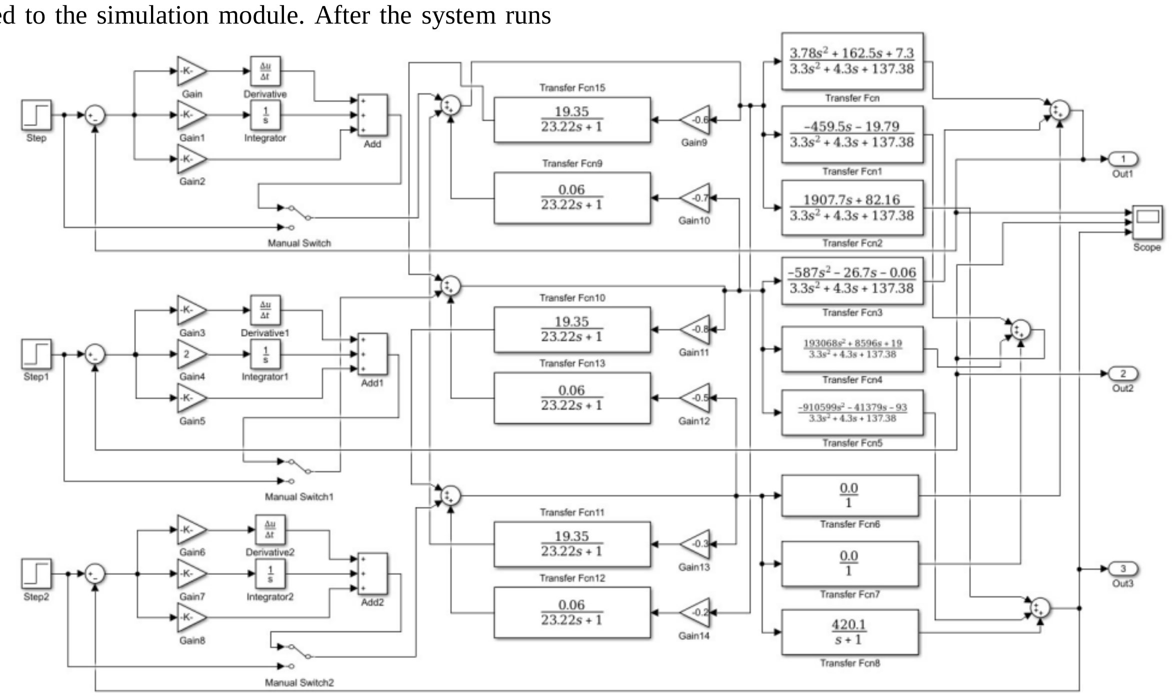


Fig. 3 Internal model control simulation model of temperature and humidity control system.

① Simulation of anti-external disturbance conditions

In order to more accurately reflect the anti-interference ability of the internal model controller, some unavoidable working processes of the artificial light source type plant factory in actual work are taken as the interference signal of the control system, for example, the heat exchange caused by the entry and exit of personnel, the heat dissipation of the equipment in the factory, etc., refer to the relevant information [11], set the disturbance analog quantity to be added to the system every 600 seconds, and the temperature disturbance range is ± 2 ℃. The simulation curve of the step response of the modulo controller is shown in Figure 4.

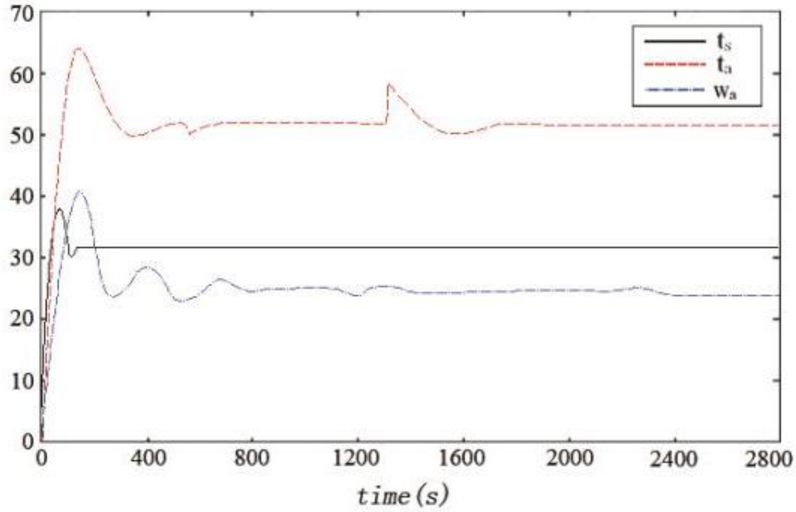


Fig. 4 Step response curve of external disturbance resistance condition.

Analyzing the step response curve in Figure 4, the mutual coupling phenomenon has been eliminated between the various loops of the temperature and humidity control system, and the output response curves of the indoor temperature loop and the indoor moisture content loop have regular intermittent fluctuations, and the supply air temperature The curve of the loop is very smooth. The above shows that when the temperature loop is subjected to external regular interference signals, the internal temperature control has a regular negative adjustment, indicating that the temperature is very sensitive to external interference. At this time, the parameters of the internal model control are not to achieve the effect of eliminating temperature and humidity coupling. At the same time, the moisture content loop in the inner area fluctuated regularly. After about 600 seconds of time delay, the response curve gradually smooth; it shows that the internal model controller is superior to the temperature anti-interference ability in the disturbance of indoor moisture content.

② Simulation of system response speed conditions

Under the premise that the regular interference signal of the temperature loop remains unchanged, the system response speed of the internal model control system is simulated and verified by adjusting whether the target object and the control model match and adjusting different filter parameters.

(a) When the object matches the model, under the premise of external interference signals, the system output response curve of the temperature and humidity internal model control system is shown in Figure 5. Adjust the filter parameters separately, so that $\lambda_1 = 20, \lambda_2 = 50$, $\lambda_3 = 60$, the supply air temperature loop and the indoor moisture content loop have smooth curves without overshoot, indicating that under the action of the internal model controller, the two loops are decoupled; Under the interference of the external regular interference signal, the curve quickly recovered and smoothed, indicating that under the adjustment of the internal model controller, the response of the control temperature output was faster and the control ability was stronger.

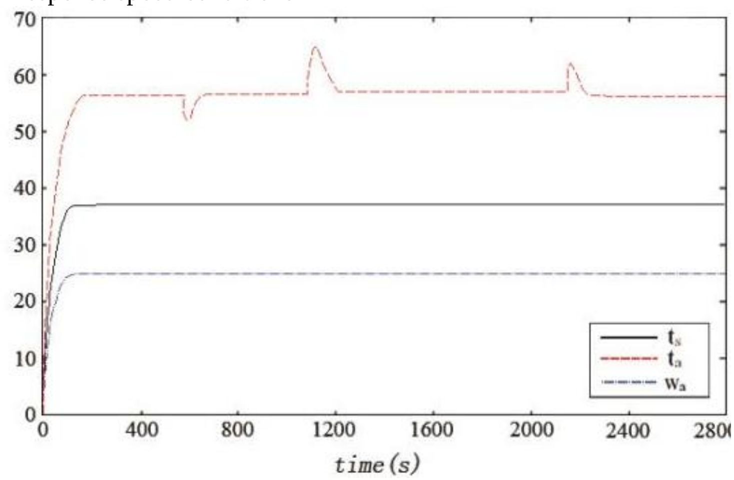


Fig. 5 Output response curve of internal model control system when object and model are matched.

(b) When the object does not match the model, under the premise of external interference signals, the system output response curve of the temperature and humidity internal model control system is shown in Figure 6. Adjust the filter parameters separately, so that $\lambda_1 = 20, \lambda_2 = 50$, $\lambda_3 = 60$, the supply air temperature loop and the indoor moisture content loop have smooth curves without overshoot, indicating that under the action of the internal model controller, the two loops are decoupled; Under the interference of the external regular interference signal, the output curve quickly returns to the set value, and the curve recovers smoothly, and under the action of the filter, when the interference signal appears for the second time, the degree of change of the curve is smaller than before, indicating that the internal model Under the adjustment of the controller, the ability to suppress external disturbances is also taken into account.

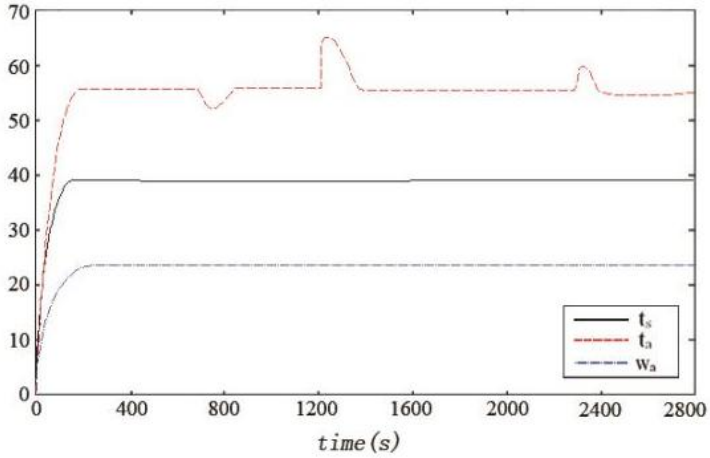


Fig. 6 Output response curve of internalmodel control system after model mismatch.

③ Simulation of system stability conditions

The control effect of internal model controller with different λ_Q values, and the output response curve of temperature internal model control system with different λ_Q values are shown in Fig. 7. The function of setting a filter on the feedback channel is to suppress the interference of external signals. Under the premise of having external regular interference signals, the temperature loop sets the time delay of the temperature control loop as 60 s when $\lambda_Q = 5$, $\lambda_Q = 30$, and $\lambda_Q = 60$, respectively. When $\lambda_Q = 5$, the temperature output response value can quickly track the set value when the regular signal disturbance occurs, but there is a negative modulation; when $\lambda_Q = 30$, the temperature output response is mediated by the feedback filter, and the anti-interference effect is better than the output response when $\lambda_Q = 5$. When $\lambda_Q = 60$, the temperature output response curve is basically consistent with the output response curve when $\lambda_Q = 30$, indicating that under the control of the feedback filter, increasing the filtering parameters has little effect on suppressing the disturbance.

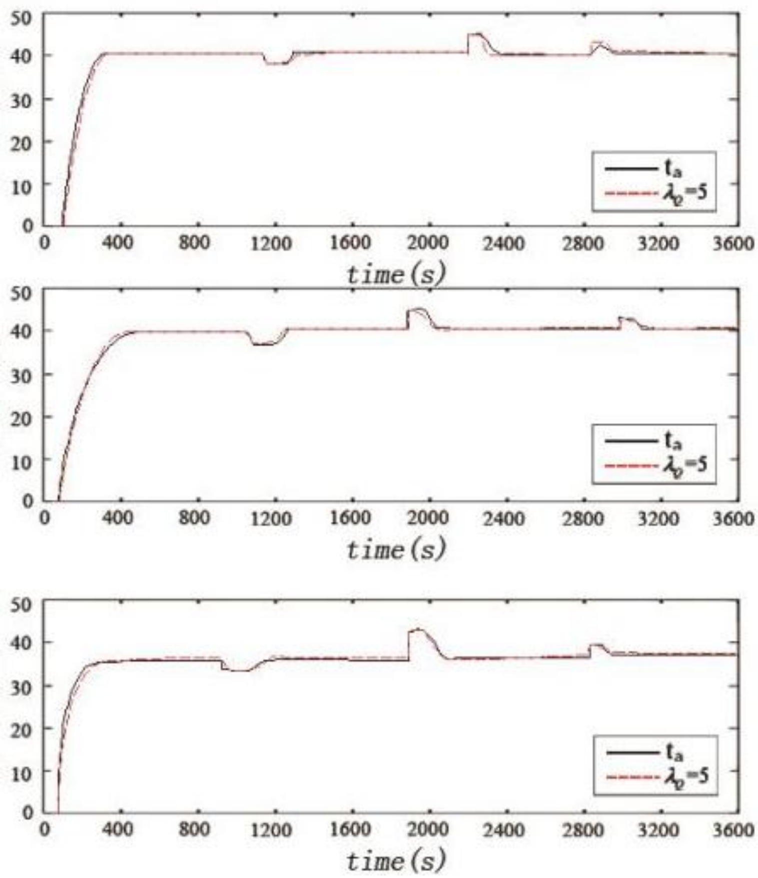


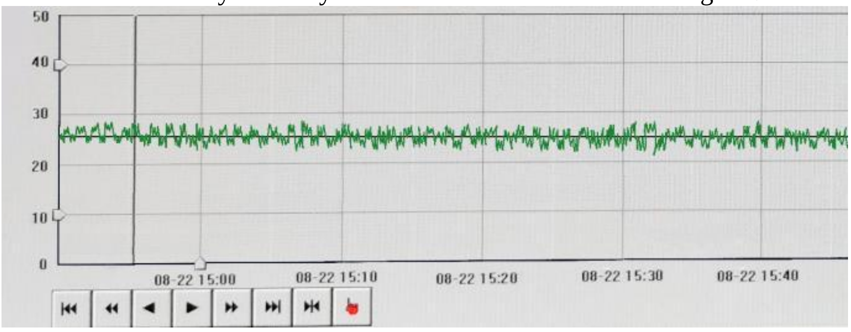
Fig. 7 Temperature internal model control system output response with different λ_Q .

5. Verification Test

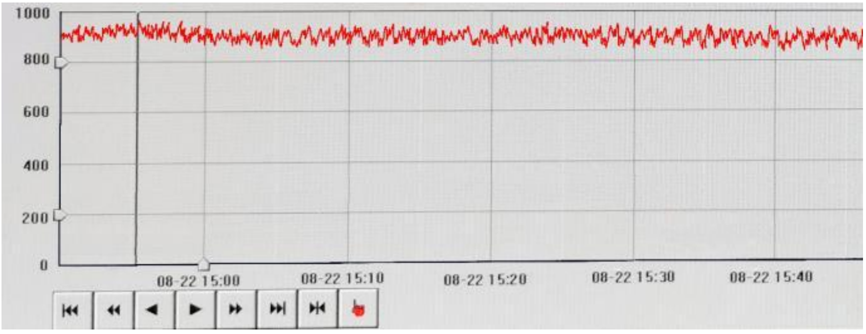
The effectiveness of the control system of the temperature and humidity system is verified by the actual operation effect of the plant factory [8-11]. In order to ensure the experimental effect, in the test, the actual operating state work is divided into two cases: I working condition (steady state) and II working condition (variation). Among them, I working condition (steady state) is shown in Figure 8; II working conditions (changes) are shown in Figure 9 and Figure 10. In working condition I (steady state), after the artificial light source is running and the air treatment equipment is running stably, the change rule of the system's set value, input value, and output value is verified by the response time and curve change to verify the control ability of the system. In case of II working condition (change) , first, after the artificial light source is running and the air treatment equipment is running stably, manually change the system setting value, study the changing law of input value and output value, and verify the control of the system through the response time and curve change The second is that after the artificial light source is running and the air treatment equipment is running stably, the system is fully put into autonomous operation, and when the system setting value changes (that is, from the light source on stage to the light source off stage, or from the off stage to the on stage), the system starts the automatic optimization, studies the change rule of the input value and the output value, and verifies the control ability of the system through the response time and curve change. The graph is from the actual screenshot of the MCGS6.2 software. The color of the curve represents the setting value, input quantity and output quantity. Specifically, "black" is the setting value, "red" is the input quantity, and "green" is the output.

5.1 working condition (steady state)

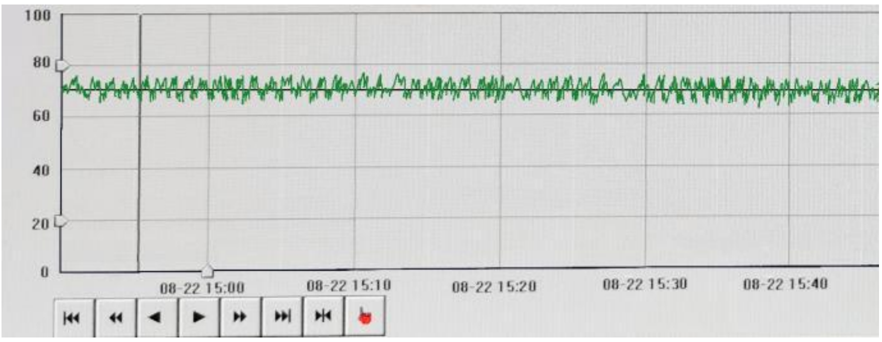
When the system is in a steady state, the set value of the internal ambient temperature of the plant factory is 26 ℃, the set value of the supply air temperature is 23 ℃, and the set value of the internal humidity of the plant factory is 70%. The cold water flow rate of the fan coil unit is 0.21 kg/s, the air supply flow rate of the fan coil unit is 926 m 3 /h, and the measured value of the moisture content of the supply air is 11.4 g/kg. Since the set value of the internal temperature is higher than the set value of the supply air temperature, the combined effect of the fresh air and the return air increases the supply air volume. The set value of the internal humidity is high, and the humidification valve increases the opening degree to humidify the air supply. When the air flow rate of the fan coil unit and the cold water flow rate of the fan coil unit are constant, the outlet temperature of the air supply unit is higher. From the change curves of internal temperature, internal humidity, and supply air temperature, it can be seen that after the system reaches stability, there is a certain overshoot and fluctuation, which is consistent with the characteristics of the system. Figure 8 shows that the verified control system works continuously for 40 minutes, and the measured values of supply air temperature, internal temperature, and internal humidity of the system are basically stable, and the fluctuation is small, indicating that the control effect is good.



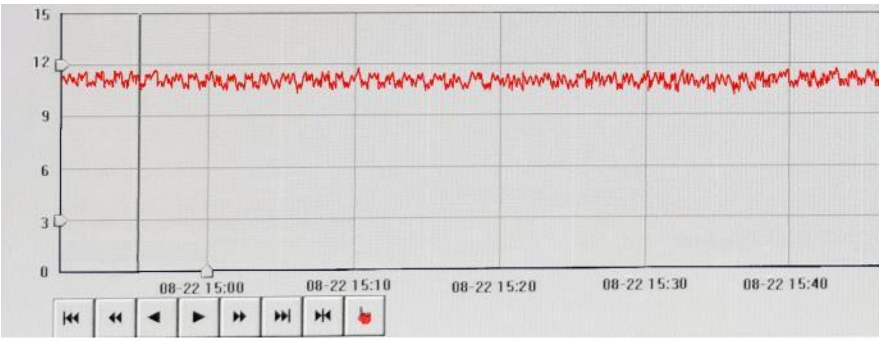
(a)Set value and output value (internal temperature).



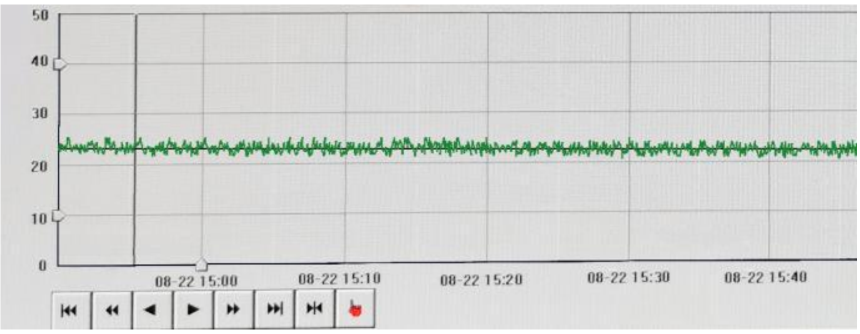
(b)Input value (air output)



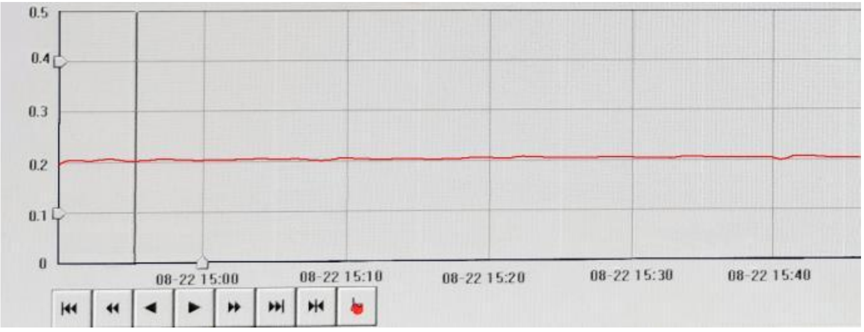
(c)Set value and output value (internal humidity).



(d)Input value (moisture content of air supply).



(e)Set value and output value (supply air temperature).



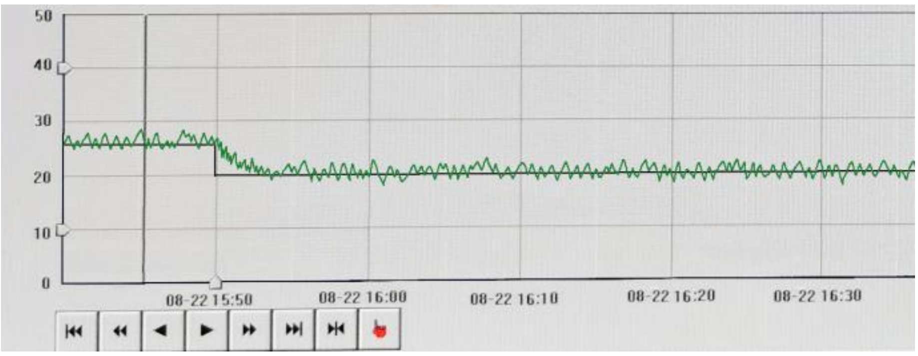
(f)Input value (refrigerating output).

Fig. 8 Control effect at steady-state operating point.

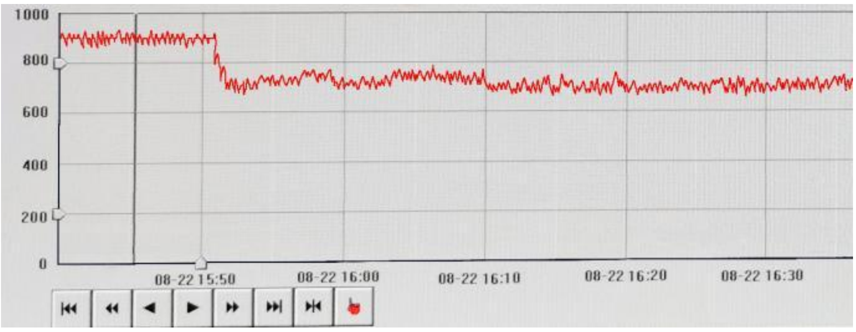
5.2 working condition (change)

1) When manually changing the set value, the system controls the effect.

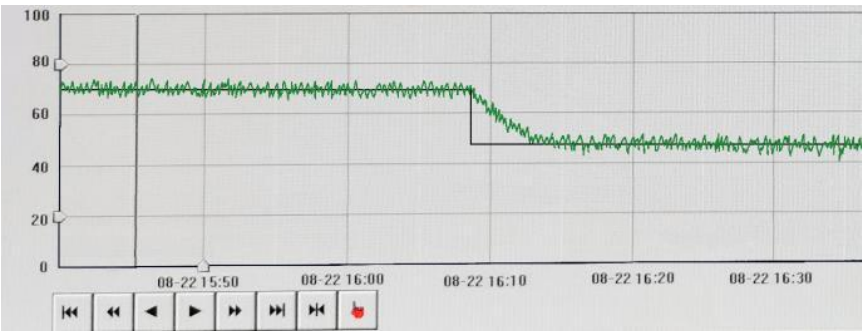
After the plant factory system runs stably, the initial setting values are: the internal ambient temperature setting value is 26 ℃, the supply air temperature setting value is 23 ℃, and the internal humidity setting value of the plant factory is 70%. Through the control interface of MCGS6.2 software, manually change the set values of supply air temperature, internal temperature and internal humidity in turn. Change the set value of the internal temperature of the plant factory to 20 ℃, and the output value of the internal temperature will be 19.9 ℃ after 3 minutes; after reaching a new steady state, change the set value of the supply air temperature to 18 ℃, and send it after 4 minutes. The wind temperature output value is 17.8 ℃; after reaching the steady state again, the internal humidity setting value is changed to 48%, and the internal humidity output value is 48 ℃ after 7 minutes. After the internal temperature setting value is lowered, the air flow rate of the fan coil unit decreases from 926m 3/h to 720m 3/h. The moisture content is appropriately increased; after the air supply temperature setting value is lowered, the cold water flow rate of the fan coil unit decreases, from 0.21kg/s to 0.17kg/s. In order to keep the internal humidity unchanged, the air supply volume of the fan coil unit increases increase. After the internal humidity setting value is lowered, the moisture content of the supply air also decreases, from 11.4g/kg to 8.3g/kg. In order to keep the internal temperature unchanged, the supply air flow rate of the fan coil unit also increases slightly. During the whole operation process, the system runs stably. The supply air flow of the fan coil controls the indoor temperature, the moisture content of the supply air controls the indoor humidity, and the cold water flow of the fan coil controls the supply air temperature. The change of a single control quantity has a greater impact on other process loops. Small. The curve in Figure 9 shows that the control system has a good decoupling effect, and has good setpoint tracking and anti-disturbance performance.



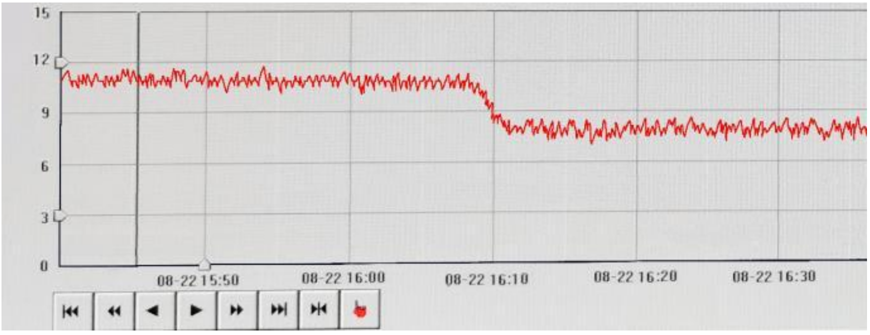
(a) Set value and output value (internal temperature).



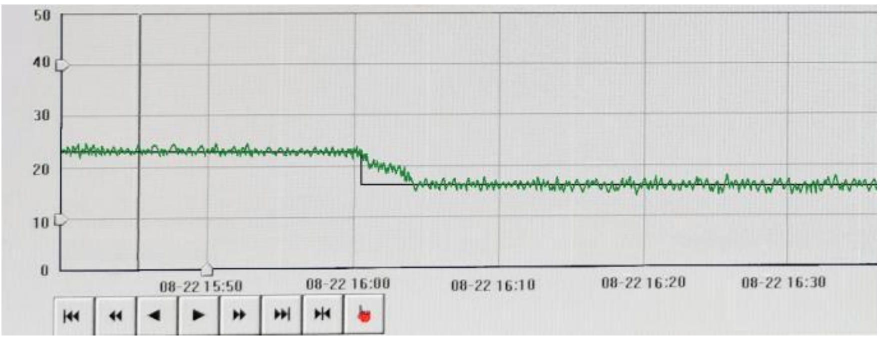
(b) Input value (air output).



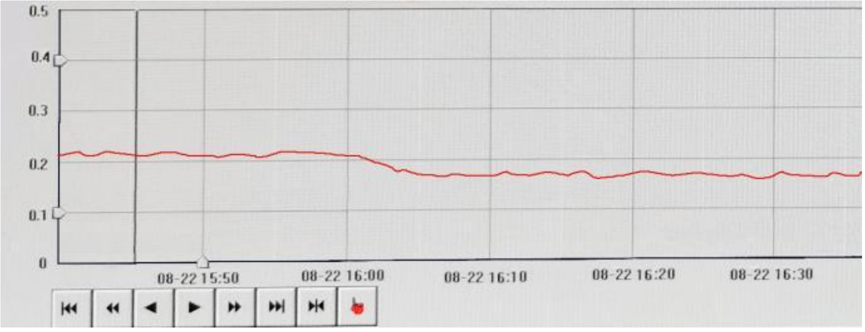
(c) Set value and output value (internal humidity).



(d) Input value (moisture content of air supply).



(e) Set value and output value (supply air temperature).



(f) Input value (refrigerating output).

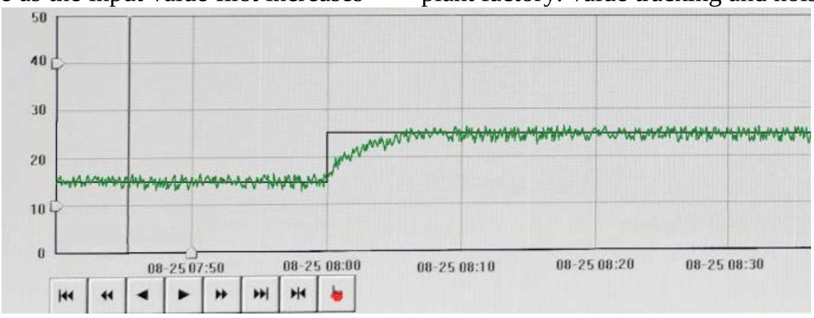
Figure 9 Control effect when manually changing the set value.

2) When the working conditions are automatically optimized, the system control effect.

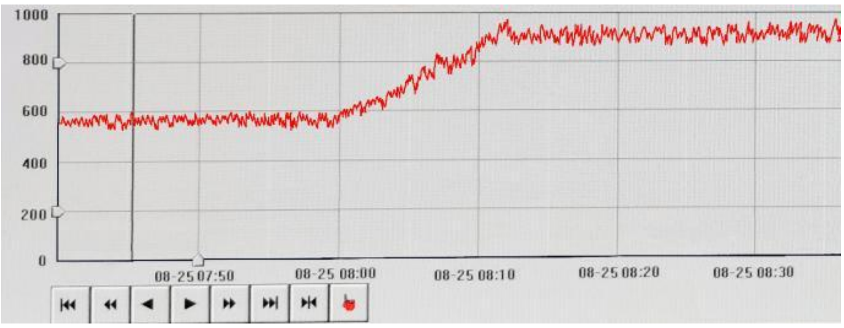
In the plant factory when the light source is turned off, the set value of the internal ambient temperature is 16 ℃, the set value of the supply air temperature is 13 ℃, and the set value of the internal humidity of the plant factory is 50 % ; when the light source is on, the set value of the internal ambient temperature is 26℃, the supply air temperature is set to 23 ℃, and the internal humidity of the plant factory is set to 70%. When the operating time of the system reaches 8:00, the working state of the system is automatically adjusted from the light source off state to the light source on state. At this time, the set values of the internal temperature, internal humidity and supply air temperature change at the same time. The internal temperature of the output value reached the set value of the system after 6 minutes; the supply air flow of the input value increased from 580m 3/h to 900m 3/h, an increase of 55.2%, and reached the relative value after 12 minutes. stable state. After 15 minutes, the internal moisture content of the output value reached the set value of the system; the input value of the supply air moisture content increased from 6.9g/kg to 12g/kg, an increase of 73.9%, and after 14 minutes, it reached the set value. relatively stable state. After 14 minutes, the output value of the supply air temperature reached the set value of the system; the input value of the cold water flow rate increased from 0.15kg/s to 0.24kg/s, an increase of 60%, and reached a relatively stable state after 14 minutes. The change curve of the supply air volume as the input value first increases and then remains relatively stable. The change curve of the supply air moisture content and supply air temperature first increases and then decreases, and finally remains relatively stable.

In the optimization process, the air supply volume increases, the air supply temperature increases, and the artificial light source is turned on, when the internal temperature first reaches the set value after 6 minutes of operation, the internal humidity and supply air temperature have not reached the set value. In order to ensure that the internal humidity and supply air temperature reach a stable state as soon as possible, the supply air volume continues to increase, and the supply air temperature and supply air moisture content also continue to increase. After 10 minutes of operation, the internal humidity and supply air temperature reach the set value. However, it is unstable, and the curve appears overshoot. The reason is that at this time, the supply air temperature and the supply air moisture content of the input volume have reached the maximum value. After 14 minutes of operation, the internal humidity and supply air temperature have reached the set value, and the system enters a relatively stable operation state.

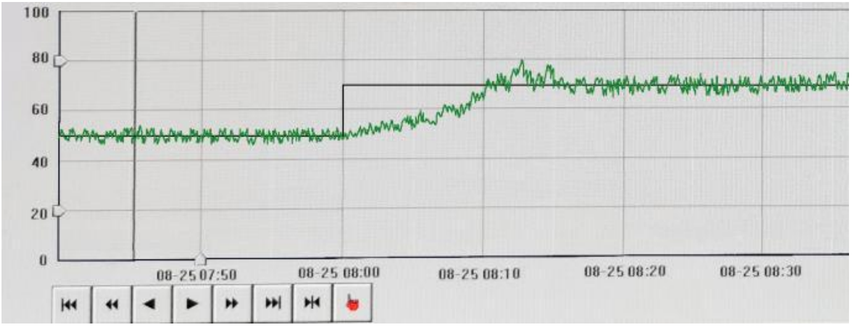
Figure 10 show that the designed temperature and humidity control system has strong adaptability in the environment of automatic optimization of variable working conditions, which can make the temperature and humidity regulation of the plant factory work in the optimized working area, and improve the setting of the plant factory. value tracking and noise immunity.



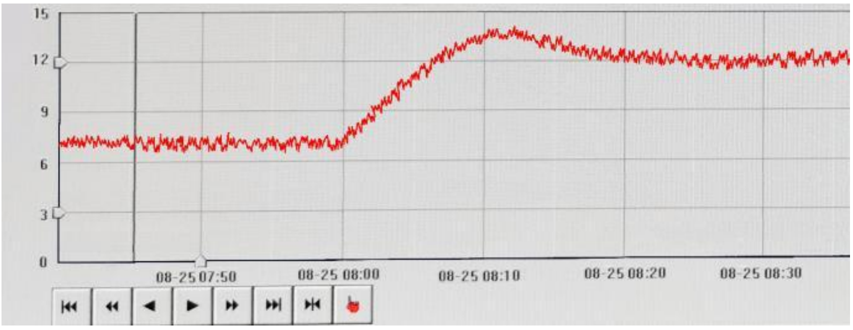
Set value and output value (internal temperature).



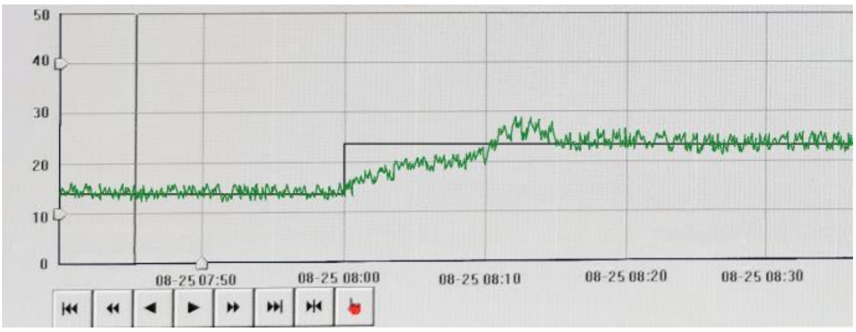
Input value (air output).



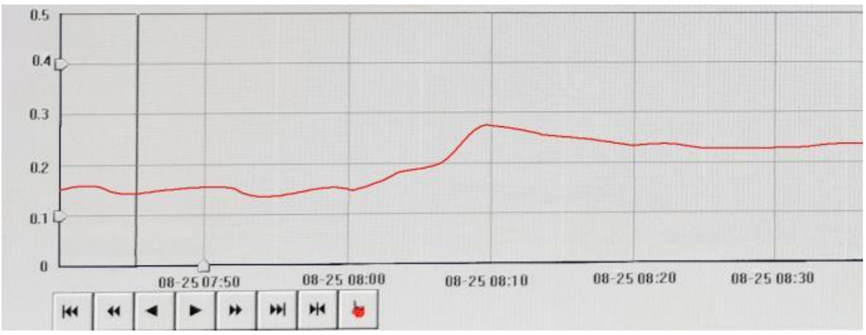
Set value and output value (internal humidity).



Input value (moisture content of air supply).



Set value and output value (supply air temperature).



Input value (refrigerating output).

Fig. 10 Control effect in automatic optimization of operating conditions

6.Conclusion

In the closed-loop control state, the process of internal model control is simulated for anti-external disturbance conditions, system response speed condition simulation, and system stability condition simulation to verify the timely tracking of the output signal of the system and the ability to overcome external disturbances when the operating conditions change. The ability to interfere, to meet the test requirements. The temperature and humidity control test is carried out in the artificial light source type plant factory, which is divided into two situations: steady state working condition and variable working condition. The control effect is illustrated by the actual operation curve. Through the verification test, it is obtained that the air supply flow of the surface cooler controls the indoor temperature, the moisture content of the supply air controls the indoor humidity, and the cold water flow of the surface cooler controls the supply air temperature. The influence is small, the control system has good decoupling effect, and has good set value tracking and anti-disturbance performance, which can meet the production requirements of plant factories.

Acknowledgements

Heilongjiang Institute of Technology's 2020 Provincial Undergraduate Universities Basic Scientific Research Business Expenses Special Fund Project: Mechanism Analysis and Control Technology Research on Crop Breeding Environment in Plant Factories (2020-KYYWF-0519).

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