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Research on Multivariable Decoupling Internal Model Control System of Temperature and Humidity Environmental Factors in Plant Factory

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Abstract: In the practical application of artificial light source type plant factories, the temperature and humidity environment is a dynamic environment with strong coupling and strong time delay. In the face of complex and changeable situations, the control strategy after the decoupling of the temperature and humidity dynamic environment model system needs to be control loop for effective control. This paper will use the relevant theory of internal model control to study the temperature and humidity control system, design an environmental controller to solve the coupling problem and time delay problem of the temperature and humidity environment, and simulate the process of the internal model control under the closed-loop control state. The timely tracking ability of the output signal of the inspection system under the changing working conditions will lay a theoretical foundation for the implementation and verification of the next temperature and humidity on-site control.

1. Introduction

In industrial process control, internal model control, as an advanced control strategy [1], is a special form of robust control. It has clear control parameter standards, fast closed-loop response, strong anti-interference ability, and few system adjustable parameters. It can meet the dynamic and static performance of the system, the system has good stability, and is convenient for on-site implementation and application. The premise of using the internal model control is that 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 internal model controller can be designed, and the control performance of the internal model controller is determined by the accuracy of the model parameters [2].

However, in practical applications, the temperature and humidity environment is a dynamic environment with strong coupling and strong time delay [3]. In the face of complex and changeable situations, it is necessary to effectively control each control loop. This paper will focus on solving the following problems: One is to solve the coupling problem between the various loops of the system through the design and use of the decoupling controller, that is, to eliminate or reduce the mutual interference between the various loops, so that the sub-loops that are relatively independent or interfere within a controllable range are decomposed. Make the system stable [4]; the second is to solve the time delay problem between the system and the three loops through the design and use of the decoupling controller, that is, each loop has different characteristics due to different input and output parameters. The problem of time lag, when there is interference signal or the working condition changes, reduces the system reaction time and makes the system robust [5]. In order to make the artificial light source type plant factory temperature and humidity control system more universal and practical, on the premise that the process function of the control system is clearly defined, this paper will use the relevant theory of internal model control to study the temperature and humidity control system and design the environment. The controller solves the coupling problem and time delay problem of the temperature and humidity environment. Under the closed-loop control state, the process of internal model control is simulated to test the ability of the system to track the output signal in time under the changing working conditions, which is the next step of temperature and humidity. Field implementation and verification lay the theoretical foundation.

2. Internal Model Control Research

2.1. The Basic Structure of the Internal Model Control System

$R(s)$ 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 controlled object transfer function, $G_m(s)$ is the object model, $U(s)$ is the input quantity, $E(s)$ is the deviation quantity, and $\widetilde{D}(s)$ is the feedback signal quantity. $C(s)$ and $G_m(s)$ are the core of the internal model control system, and the basic structure of the internal model control system is shown in Figure 1.

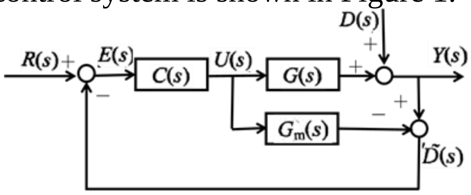

Figure 1: IMC system block diagram.

From Figure 1, when the closed-loop system is stable, the system equations of input quantity $U(s)$, output quantity $Y(s)$, feedback quantity $\widetilde{D}(s)$, and deviation quantity $E(s)$, see formula (1):

$$\begin{cases} U(s) = \frac{C(s)}{1+C(s)[G(s)-G_m(s)]}[R(s)-D(s)] \\ Y(s) = \frac{C(s)G(s)}{1+C(s)[G(s)-G_m(s)]}R(s) + \frac{1-C(s)G_m(s)}{1+C(s)[G(s)-G_m(s)]}D(s) \\ \widetilde{D}(s) = [G(s)-G_m(s)]U(s) + D(s) \\ E(s) = R(s) - Y(s) \end{cases} \tag{1}$$

When the closed-loop system is stable, the system response transfer function of the input quantity $R(s)$ and disturbance quantity $D(s)$ is set, as shown in formula (2):

$$\begin{cases} G_r(s) = \frac{C(s)G(s)}{1+C(s)[G(s)-G_m(s)]} \\ G_d(s) = \frac{1-C(s)G_m(s)}{1+C(S)[G(s)-G_m(s)]} \end{cases} \quad (2)$$

2.2. The Closed-loop Output of the Stable System

1) When $G(s) = G_m(s)$, that is, the object matches the model, the system output can be simplified to:

$$Y(s) = C(s)G(s)R(s) + \big(1 - C(s)G_m(s)\big)D(s) \quad (3)$$

Let $C(s) = G^{-1}(s) = G_m^{-1}(s)$, and $C(0) = G_m^{-1}(0)$, then we get from equations (2) and (3):

$$Y(s)=\begin{cases} G_r(s)R(s)+G_d(s)D(s)=R(s) & (设定值扰动) \\ 0 & (外部干扰扰动) \end{cases} \quad (4)$$

2) When $G(s) \neq G_m(s)$, that is, the object does not match the model, and the closed-loop characteristic equation of the system is required to be $1 + C(s)[G(s) - G_m(s)] = 0{:}\,1$; ①Assume $G(s)$ is a minimum phase system. If the model has a non-minimum phase, that is, $G(s)$ contains a pure time-delay term, it will cause the design to be physically impossible to achieve $C(s)$; ② Assume $G(s)$ is a non-minimum phase system, that is, $G(s)$ contains a time-delay link and has a right-half-plane zero, and a filter is introduced to ensure the robustness and stability of the closed-loop system, and we get:

$$\begin{cases} C(s) = C_{m-1}^{-1}(s)F(s) \\ F(s) = \frac{1}{(1+\lambda s)^n} \end{cases} \quad (5)$$

where,$C_{m-1}^{-1}(s)$ —minimum phase, and contains only S the left half-plane zeros of the plane;
$F(s)$— Low-pass filter;
λ— Filter time constant;
n—Filter order.

In addition, the selection of *n* should be large enough to ensure the rationality of the internal model controller; λ as an adjustable parameter of the filter, it directly determines the response speed and robustness of the system. The actual system response and use characteristics, that is, to make a balance between stability, tracking ability, and robustness, generally select reasonable λ through system simulation.

2.3. Sensitivity Function and Sensitivity Complementary Function

The sensitivity function $\varepsilon(s)$ expresses the error $R(s)$ relationship $D(s)$ between and, Equation (1) is obtained,

$$\varepsilon(s)=\frac{E(s)}{R(s)-D(s)}=\frac{Y(s)}{D(s)}\frac{1-C(s)G_m(s)}{1+C(s)[G(s)-G_m(s)]} \quad (6)$$

$\varepsilon(s)$ reflects the influence of external disturbance on the output. The smaller the function value, the better the feedback control system.

The complementary sensitivity function $\eta(s)$ expresses the relationship between $R(s)$ and $Y(s)$, and $\eta(s)+\varepsilon(s)=1$, we get,

$$\eta(s)=\frac{Y(s)}{R(s)}=\frac{C(s)G(s)}{1+C(s)[G(s)-G_m(s)]} \quad (7)$$

$\eta(s)$ reflects the influence of the input on the output. The closer the $\eta(s)$value is to 1, the better the tracking of the control system. Because $\eta(s)+\varepsilon(s)=1$, in the control system, at that time , the system output $\eta(s)\to 0$, $,\varepsilon(s)\to 1\, Y(s)$obtained good tracking performance; at that time , the system output $\eta(s)\to 1$, $,\varepsilon(s)\to 0.\, Y(s)$obtained good noise suppression capability, which are obviously contradictory. Therefore, in the internal model control, when the object is matched with the model, formula (8) is used as the reference basis for the system to balance the response speed and robustness when the internal model controller is designed.

$$\begin{cases}\tilde{\varepsilon}(s)=1-C(s)G_m(s)\\ \tilde{\eta}(s)=C(s)G_m(s)\end{cases} \quad (8)$$

2.4. Internal Model Controller Design

①Let $G_m(s)=G_{m+}(s)G_{m-}(s)$, $G_{m+}(s)$be the $G(s)_m$zero point and time delay of the right plane $G_{m-}(s)$in all planes in the middle, and Sbe $G_m(s)$the minimum phase in the middle;

②Adopt formula (4.5) to design the internal model controller; at the same time, when the object is matched with the model, $\eta(s)=G_{m+}(s)F(s)$.

To sum up, when the object matches the model, λ is the time constant; when the object does not match the model, if $G_m(s)$ is the minimum phase system, λ is the main time constant, and the value of λ is large enough, λ determines the output response of the system.

3. Research on Multivariable Decoupling Internal Model Control

(1) Transfer function of target matrix after decoupling of $MIMO$ system

In a $MIMO$ system, assuming that $G(s)=G_m(s)$,

$$\mathrm{G(s)}=\mathrm{G_m(s)}=\begin{bmatrix}g_{11}(s) & \cdots & g_{1n}(s)\\ \vdots & \ddots & \vdots\\ g_{n1}(s) & \cdots & g_{nn}(s)\end{bmatrix} \quad (9)$$

In formula (9), $g_{ij}(s)=g_{ij0}(s)e^{-\tau_{ij}s}$ is a regular rational fraction, and τ_{ij} is a non-negative constant. When the system is decoupled, $G(s)$ must satisfy the stable and non-singularity properties, that is $\det G(0)\neq 0$.

The closed-loop $H(s)$ matrix of the MIMO system is

$$H(s)=\frac{G(s)C(s)}{1+[G(s)-G_m(s)C(s)]} \quad (10)$$

It can be obtained by formula (9) and formula (10)

$$C(s)=G^{-1}(s)H(s) \quad (11)$$

Therefore, let $H(s)=G(s)C(s)=\mathrm{diag}\{h_{ij}(s)\}$,

$$H(s) = G(s)C(s) = \mathrm{diag}\{\tilde{g}_{ii}(s)c_{ii}(s)\} = \mathrm{diag}\left\{\frac{\det G(s)}{G^{ii}(s)}c_{ii}(s)\right\} \tag{12}$$

Among them, $G^{ij}(s)$—the corresponding $g_{ij0}(s)e^{-\tau_{ij}s}$ algebraic cofactor of $g_{ij}(s)$— The univariate object element corresponding to each loop.

MIMO After the system is decoupled, $g_{ij}(s)$ the form of transfer function plus time delay may not be satisfied, and $c_{ii}(s)$ although it is theoretically feasible, the actual operation is unstable, and it is even physically impossible to achieve, so it is necessary to carry out time delay analysis, non-minimum Phase section analysis.

(2) Time delay analysis

In a $MIMO$ system, the time delay τ_i of $C(s)$ must satisfy $(c_{ji}(s)) \geq 0, j \in J_i$, where $J_i = \{j \in n | G^{ij}(s) \neq 0\}$,

$$\tau(c_{ii}(s)) \geq \tau\left(G^{ii}(s)\right) - \tau_i \tag{13}$$

In formula (13), In formula (13), $\tau_i = min_{j \in J_I} \tau\left(G^{ij}(s)\right)$, indicating the minimum range of the diagonal element delay τ_i in $C(s)$.

Satisfying $h_{ii}(s) = \tilde{g}(s)c_{ii}(s)$ in $H(s) = G(s)C(s)$, the minimum range of $H(s)$ element delay τ_i is,

$$\tau\left(h_{ii}(s)\right) \geq \tau\left(det\, G\,(s)\right) - \tau_i \tag{14}$$

When the system runs stably after the decoupling of the $MIMO$ system, the following conclusions are obtained:

①Diagonal $C(s)$ element delay, $\tau\ (c_{ii}(s)) \geq \tau(G^{ii}(s)) - \tau_i$;

② $H(s)$ Diagonal element delay, $\tau\left(h_{ii}(s)\right) \geq \tau\left(det\, G\,(s)\right) - \tau_i$.

(3) Non-minimum phase analysis

In the $MIMO$ system, set $H(s) \neq 0$, if $\eta_z\left(H(s)\right) > 0$ means that $H(s)$ has $\eta_z\left(H(s)\right)$ zeros $s = z$; $\eta_z\left(H(s)\right) = 0 H(s)$ has no poles and zeros.

When the system runs stably after the decoupling of the $MIMO$ system, the following conclusions are obtained:

① $C(s)$ The number of non-minimum phase zeros of diagonal elements, $\eta_z\left(c_{ij}(s)\right) \geq 0, j \in J_i, z \in C^+$;

② The $H(s)$ number of non-minimum phase zeros of diagonal elements, $\eta_z\left(h_{ii}(s)\right) \geq \eta_z\left(det\, G\,(s)\right) - \eta_i(z), z \in Z_G^+$.

4. Research on Multivariable Decoupling Internal Model Controller

In the $MIMO$ system, it can be known that $G_{m+}(s)$ is not the only form, so first assume that $G_{m+}(s) = e^{-\tau s}\prod_{i=1}^{n}\frac{z_i - s}{z_i + s}$, τ is the time delay, z_n $(z_i, i = 1,2,\cdots,n)$ are all non-minimum phase zeros in $G(s)$.

Low pass filter $F(s)$

$$F(s) = diag\left\{\frac{1}{(\lambda_i s+1)^n}\right\} \tag{15}$$

Formula (15), i— The first i control loop;

λ— Filter time constant;
n— Filter order.

From the research of $H(s) = G(s)C(s) = diag\{\tilde{g}_{ii}(s)c_{ii}(s)\} = diag\left\{\frac{det\,G(s)}{G^{ii}(s)}c_{ii}(s)\right\}$ and internal model controller, the core of internal model controller design is to determine the transfer function of each coupling loop. In order to ensure the strong anti-interference ability and stable operation of the temperature and humidity environment system controlled by the controller, according to the time delay analysis and the minimum phase analysis, each coupling loop $h_{ii}(s)$ and the diagonal element $c_{ii}(s)$ and non-diagonal element $c_{ji}(s)$ of the internal model controller are finally determined.

$$h_{ii}(s) = e^{-[\tau(det\,G(s))-\tau_i]s}\prod_{z\in Z_G^+}\left(\frac{z-s}{z+s}\right)^{\eta_z(det\,G(s)-\eta_i(z))}F_i(s) \quad (16)$$

$$c_{ii}(s) = h_{ii}(s)\tilde{g}_{ii}^{-1}(s) \quad (17)$$

$$c_{ji}(s) = \frac{G^{ij}(s)}{G^{ii}(s)}c_{ii}(s), i \neq j \quad (18)$$

Formula (16), $F_i(s)$— $i$the internal model filter of the first loop.

At this time, there is only one control system. In $F(s)$ order to meet the anti-interference adjustment and maintain the stability of the dynamic system, a perfect compromise solution needs to be obtained in theoretical design. However, in the process of practical significance, due to the industrial engineering Complexity, perfect match between model and object is impossible. Therefore, 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.

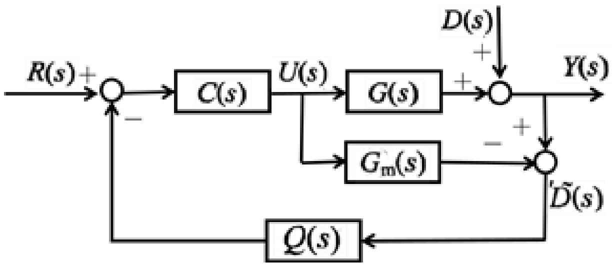

Figure 2: Dual-controller type multivariable decoupled internal model control.

Let $Q(s)$ be the controller set on the feedback channel, by formula (1) and formula (3), we can get

$$Y(s) = \frac{C(s)G(s)}{1+Q(s)[G(s)-G_m(s)]}R(s) + \frac{1-C(s)Q(s)G_m(s)}{1+C(s)Q(s)[G(s)-G_m(s)]}D(s) \quad (19)$$

When $G(s) = G_m(s)$, when $C(s)$ is determined, the system disturbance is suppressed by adjusting $Q(s)$,

$$Y(s) = C(s)G(s)R(s) + \big(1 - C(s)Q(s)G_m(s)\big)D(s) \quad (20)$$

According to formula (5) and formula (15), respectively $C(s)$, $Q(s)$, $F(s)$, $F_Q(s)$, are obtained as

$$\begin{cases} C(s) = G(s)_{m-}^{-1}F(s) \\ Q(s) = G(s)_{m-}^{-1}F_Q(s) \\ F(s) = \frac{1}{(\lambda s+1)} \\ F_Q(s) = \frac{1}{(\lambda_Q s+1)} \end{cases} \quad (21)$$

Wherein, λ_Q—the adjustable parameter of the feedback channel filter;

In typical PID control, the transfer function of the system target object is $(s) = \frac{K}{Ts+1}e^{-\tau s}$, then it can be known from equation (21).

$$\begin{cases} C(s) = \frac{Ts+1}{K(\lambda s+1)} \\ Q(s) = \frac{(Ts+1)(\lambda s+1)}{K(\lambda_Q s+1)} \end{cases} \quad (22)$$

When $G(s) = G_m(s)$, $Y(s) = \frac{K}{\lambda s+1}e^{-\tau s}R(s) + \left(1 - \frac{e^{-\tau s}}{\lambda_Q s+1}\right)D(s)$ can be obtained by formula (20), which can be obtained, which λ is in a monotonous increase or decrease relationship with the response time; the decrease λ_Q can enhance the anti-interference ability, which λ_Q is in a monotonous increase or decrease relationship with the suppression of disturbance. The expression for the filter of the system:

$$F(s) = diag\left\{\frac{1}{(\lambda_i s+1)^n}\right\} \quad F_Q(s) = diag\left\{\frac{(\lambda_i s+1)^n}{(\lambda_{iQ} s+1)^n}\right\} \quad (23)$$

5. Design and Simulation of Decoupled Internal Model Controller for Temperature and Humidity Control System

5.1. Design of Decoupling Internal Model Controller for Temperature and Humidity Control System

According to the environmental physical parameters and environmental test parameters of the dynamic system at the steady state operating point [7], as shown in Table 1.

Table 1: Parameter values of temperature and humidity environment system of plant factory artificial light source (A).

	parameter name	parameter symbol	Environment status and parameter values					
Environment initial setup	time point		August 21st 9:00	August 23 at 9:00	August 25 at 9:00	August 21st 21:00	August 23 at 21:00	August 25th 21:00
	growth state		one leaf stage	two-leaf stage	trefoil	one leaf stage	two-leaf stage	trefoil
Stable operating point measurement	Thermometer constant	γ	$\gamma = 0.0646\text{kPa}/\ ^oC$					
	Air supply capacity coefficient	k_s	$k_s = 1.21\left(\text{kJ}/(m^3 \cdot\ ^oC)\right)$					
	Air density	ρ_a	$\rho_a = 1.199(\text{kg}/\text{m}^3)$					
	constant air pressure	c_{ap}	$c_{ap} = 1.009\left(\text{kJ}/(\text{kg} \cdot\ ^oC)\right)$					

	specific heat cold water specific heat	C_w	4.18kJ/(kg · °C)					
	cold water density	ρ_w	1000kg/m^3					
	Fresh air ratio	$\frac{q_x}{q_s}$	30%					
	specific heat of air	C_a	1.0kJ/(kg · °C)					
	fan coil unit specific heat	C_f	0.39kJ/(kg · °C)					
	The temperature difference between the inlet and outlet water of the fan coil	Δt	-3℃					
	amount of cold water	q_w	0.51m^3/h					
	Work area volume	V	20.16m^3					
	leaf area index	LAI	4.35e-6	3.23e-5	7.07e-5	4.35e-6	3.23e-5	7.07e-5
	leaf temperature	$\sum t_p$	26.2	27.1	27.9	19.4	18.2	15.2
	Fan coil inlet air temperature	t_{s1}	22	20	20	13	13	13
	Fresh air temperature	t_x	14	13	14	10	10	11
	Regional air humidity	W_a	11.89	11.35	12.09	12.42	11.71	11.65
	Air volume	q_s	5.22	5.18	5.22	5.62	5.58	4.94
	Supply air temperature	t_s	26	26	26	16	16	16
	Supply air moisture content	W_s	11.53	11.38	11.53	12.91	12.75	10.62
Calculate the value	internal temperature	t_a	23.77	23.79	23.79	15.86	16.2	12.89
	Internal humidity	RH_{in}	61.87	59.82	62.95	57.72	55.12	65.83
Validate the value	internal temperature	t_a	25.4	26.0	27.2	20.1	18.5	14.6
	Internal humidity	RH_{in}	63.6	62.1	64.7	60.2	58.4	69.2
temperature	absolute error	$\lvert t_a \rvert$	1.63	2.21	3.41	4.24	2.3	1.71
	Relative error	%	6.86	9.29	14.33	26.73	14.20	13.27
humidity	absolute error	$\lvert RH_{in} \rvert$	1.73	2.28	1.75	2.48	3.28	3.37
	Relative error	%	2.80	3.81	2.78	4.30	5.95	5.12

The transfer function model of the temperature and humidity control system of the artificial light source type plant factory is:

$$\begin{bmatrix} t_s \\ t_a \\ W_a \end{bmatrix} = \begin{bmatrix} \frac{19.35}{23.22s+1}e^{-1.92s} & \frac{0.06}{23.22s+1}e^{-1.92s} & 0 \\ \frac{18.28}{(23.22s+1)(421s+1)}e^{-1.86s} & \frac{0.17s+7.3}{(23.22s+1)(421s+1)}e^{-1.86s} & 0 \\ 0 & \frac{4.16}{420s+1}e^{-42s} & \frac{1}{420s+1}e^{-42s} \end{bmatrix} \begin{bmatrix} q_w \\ q_s \\ W_s \end{bmatrix}$$

Among them, t_s , t_a , W_a are the supply air temperature (℃), the internal temperature (℃), and the internal moisture content (g/kg);

q_w ,q_s ,W_a are the cold water flow rate (kg/s) and the supply air flow rate (m^3/h), respectively, and the supply air moisture content (g/kg).

$$G(s) = \begin{bmatrix} \frac{19.35}{23.22s+1}e^{-1.92s} & \frac{0.06}{23.22s+1}e^{-1.92s} & 0 \\ \frac{18.28}{(23.22s+1)(421s+1)}e^{-1.86s} & \frac{0.17s+7.3}{(23.22s+1)(421s+1)}e^{-1.86s} & 0 \\ 0 & \frac{4.16}{420s+1}e^{-42s} & \frac{1}{420s+1}e^{-42s} \end{bmatrix}$$

By formula (16), formula (21),$h_{ii}(s) = e^{-[\tau(det\,G(s))-\tau_i]s} \prod_{z\in Z_G^+} \left(\frac{z-s}{z+s}\right)^{\eta_z(det\,G(s)-\eta_i(z))} F_i(s)$

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

Get the internal model controller matrix of the temperature and humidity control system $C(s)$.

$$C(s) = \begin{bmatrix} \frac{(23.22s+1)(0.17s+7.3)}{(3.3s+137.38)(\lambda_1 s+1)}e^{-52.23s} & \frac{-0.06(23.22s+1)(421s+1)}{(3.3s+137.38)(\lambda_2 s+1)}e^{-48.36s} & 0 \\ \frac{-19.79(23.22s+1)}{(3.3s+137.38)(\lambda_1 s+1)}e^{-52.23s} & \frac{19.35(23.22s+1)(421s+1)}{(3.3s+137.38)(\lambda_2 s+1)}e^{-48.36s} & 0 \\ \frac{82.16(23.22s+1)}{(3.3s+137.38)(\lambda_1 s+1)}e^{-52.23s} & \frac{-93.15(23.22s+1)(421s+1)}{(3.3s+137.38)(\lambda_2 s+1)}e^{-48.36s} & \frac{420s+1}{\lambda_3 s+1} \end{bmatrix}$$

5.2. Simulation of Decoupling Internal Model Controller of Temperature and Humidity Control System

According to the decoupling method of the temperature and humidity control system and the matrix design method of the internal model controller of the system, the *Matlab*/ *Simulink*M tool is used to model the temperature and humidity control system. The model controller is simulated [4][6][8]. Among them, the simulation model of the temperature and humidity control system before decoupling is shown in Figure 3; the simulation model of the internal model control of the temperature and humidity control system is shown in Figure 4-6.

1) Simulation of temperature and humidity control loop decoupling model

According to general experience, the value of the system response characteristic is taken for simulation. For the closed-loop system of temperature and humidity control, when the three system loop channels of internal temperature, internal moisture content, and supply air temperature are respectively input, when the step input is $r_1 = 0,\ r_2 = 1, r_3 = 2$, the step response curve of the system output is shown in Figure 4; when the step input is $r_1 = 1$,$r_2 = 1$, $r_3 = 2$, the step response curve of the system output is shown in Figure 5. When changing a step input, the supply air flow is increased. When changing the reference input value of the internal temperature channel and keeping other input quantities such as cold water flow and supply air humidity unchanged, the system temperature and humidity output also increases. There are obvious disturbances. Therefore, the temperature and humidity control system does not use the decoupling method to control the mutual influence of system parameters, and the coupling problem of temperature and humidity will not be solved.

Figure 6 is the simulation model of the internal model control of the temperature and humidity control system. When the step input is $r_1 = 1, r_2 = 2, r_3 = 3$ the step response curve of the system output is shown in Figure 7; when the step input is $r_1 = 0,\ r_2 = 1,\ r_3 = 2$ the step response curve of the system output is, Figure 8. At the same time, changing the step input of the three channels, that is, reducing the supply air flow, reducing the cold water flow, and reducing the supply air moisture content. From the simulation results, the response curves of the three channels do not cross, indicating that the various loops of the system The response output between the two is not affected by the input quantity, and the control system eliminates the coupling effect.

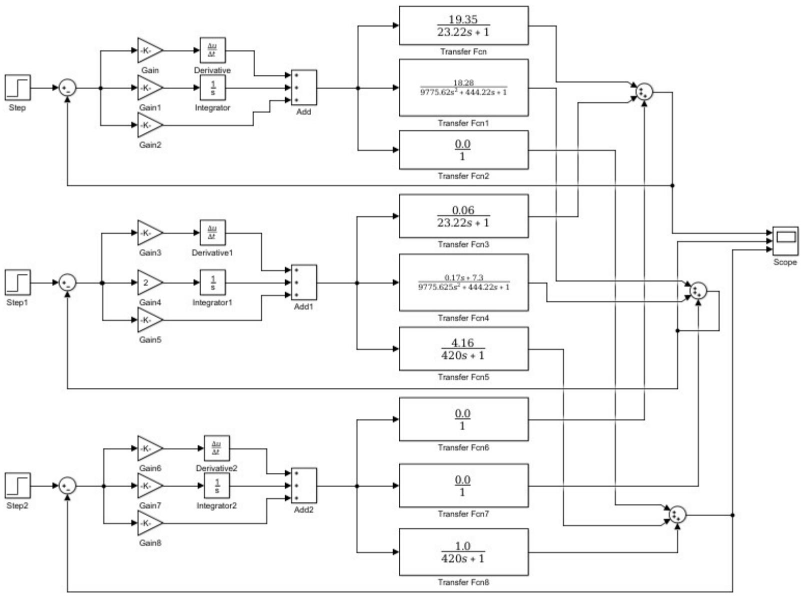

Figure 3: Simulation model of temperature and humidity undecoupled control system.

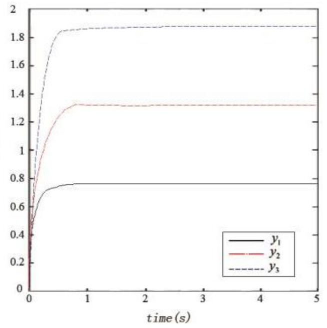

Figure 4: Tep input（$r_1 = 0$，$r_2 = 1$，$r_3 = 2$）, the step response curve of the system output.

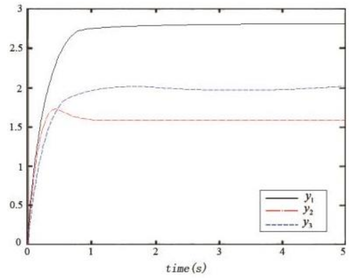

Figure 5: Tep input（$r_1 = 1$，$r_2 = 1$，$r_3 = 2$）, the step response curve of the system output.

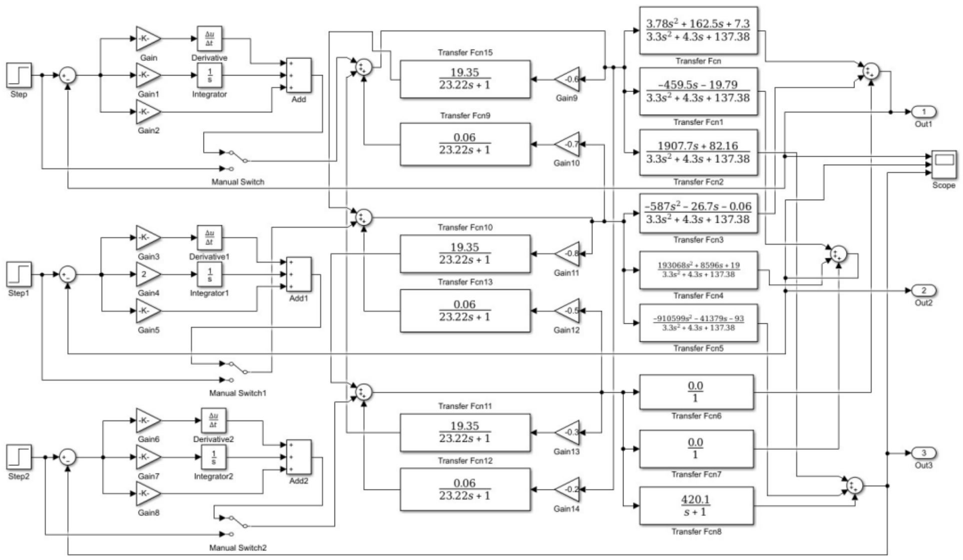

Figure 6: Internal model control simulation model of temperature and humidity control system.

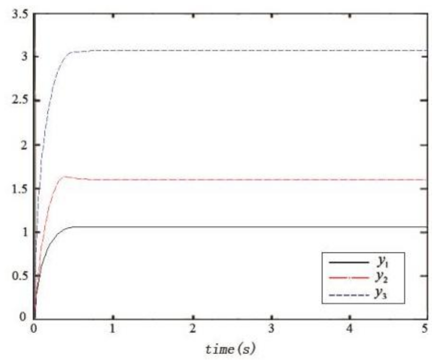

Figure 7: Tep input（$r_1 = 1$，$r_2 = 2$，$r_3 = 3$）, the step response curve of the system output.

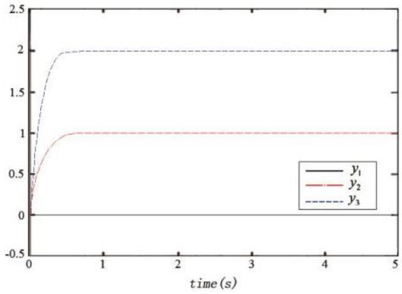

Figure 8: Tep input ($r_1 = 0$, $r_2 = 1$, $r_3 = 2$), the step response curve of the system output.

6. Conclusion

On the premise that the process function of the control system is clarified, the relevant theory of internal model control is used to study the temperature and humidity control system, and an environmental controller is designed to solve the coupling problem and time delay problem of the temperature and humidity environment. Decoupling control requirements, discuss the time delay terms of each element in the decoupling controller and the constraints of the number of non-minimum phase zeros, and propose a multivariable decoupling internal model control method with filters in the feedback channel. According to the decoupling method of the temperature and humidity control system and the matrix design method of the internal model controller of the system, the M tool is used to model the temperature and humidity control system. The simulation results show that in order to verify the control effect of the internal model controller, the environmental physical parameters and environmental test parameters of the dynamic system at the steady-state operating point are used.

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