Research on Temperature and Humidity Decoupling Control of Constant Temperature and Humidity Test Chamber

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Abstract: The temperature and humidity system is a system commonly used in industry and is recognized as one of the most complex systems. Temperature and humidity are important parameters for improving production quality in industrial production. To carry out effective control, factors such as nonlinearity, large hysteresis and real-time change must be considered, and there is mutual coupling between temperature and humidity. Temperature change will lead to humidity, the change of humidity and the same change of temperature will also affect the temperature change. The positional PID control can achieve satisfactory results. In this paper, through the analysis of the temperature and humidity system model, the feedforward decoupling compensation method is adopted for the characteristics of the temperature and humidity control system, which provides an effective way for the modeling and control of the temperature and humidity system. The simulation results show that the feedforward decoupling controller designed in this paper can achieve satisfactory results under various experimental conditions.

1. Introduction
The constant temperature and humidity test chamber is widely used in product development testing and scientific research to provide a constant temperature and humidity test environment for the tested products. When controlling the test environment, the change of temperature will lead to the change of humidity. The change of humidity will also affect the change of temperature. The two parameters are coupled with each other, resulting in deterioration of control quality. Therefore, when controlling the parameters of the constant temperature and humidity chamber, decoupling control is required. In this paper, the decoupling control method is studied from the characteristics of system objects, and the effectiveness of the control algorithm is verified by simulation.

2. The composition and working principle of the constant temperature and humidity test chamber
The schematic diagram of the experimental device is shown in Figure 1. It mainly includes the box body, the constant temperature control system, the constant humidity control system, and the circulation control system\cite{1}.

1. Temperature control system mainly includes two parts: heating system and cooling system.
   (1) Heating system: When the controller receives the heating command, it will output voltage to the solid state relay to make it suck. The voltage is applied to both ends of the heater to start heating up, and the circulation system starts to start, and the heat of the heater is brought to the box through the fan. In the body, the temperature rise process of the constant temperature and humidity test chamber is completed. The controller controls the solid state relay to output 100% power before the
temperature reaches the dead zone value set by the PID; when the temperature exceeds the set dead zone value, the controller performs on-off regulation of the solid state relay by outputting the PFM signal.

(2) Cooling system: When the controller receives the cooling command, the compressor, condenser and evaporator start to start. The low-temperature and low-pressure gas is injected into the compressor to turn it into a high-temperature and high-pressure gas, and the high-temperature and high-pressure gas is condensed into a liquid to discharge heat through the condenser, and the heat in the tank is discharged through the circulation fan, and then absorbed by the refrigerant in the evaporator. The heat turns the low-pressure liquid into a low-temperature low-pressure gas and finally returns to the compressor to achieve the cooling effect, and finally cools the constant temperature and humidity test chamber.

2. Humidity control system mainly includes two parts: humidification system and dehumidification system.

(1) Humidification system: When the controller receives the humidification command, because the heater of the constant temperature and humidity test chamber is equipped with a water tray, the water temperature can be raised by controlling the heating of the heater, and the water temperature rises along with the surface layer of the water tray. High, the water vapor pressure increases, and the difference between the water vapor pressure in the air in the tank increases, which increases the water vapor diffusion and the exchange of fluid. In this way, the superheat of water vapor is significantly reduced, and finally the constant temperature and humidity test chamber is humidified\[2\].

(2) Dehumidification system: When the controller receives the dehumidification command, the air is cooled to below the dew point temperature, so that the water vapor larger than the saturated moisture content is condensed and precipitated, so that the constant temperature and humidity test chamber is dehumidified\[3\].

3. Establishment of test chamber temperature and humidity model
The controlled volume of the test box is: temperature, humidity, temperature controlled by heater and refrigerator; humidity is controlled by heating evaporation tray and air conditioning dehumidification. The control block diagram of the system is shown in Figure 2:
It can be seen from Fig. 2 that the constant temperature and humidity system is a dual input dual output system, and the control object is accompanied by external interference.

The constant temperature and humidity system is a relatively common complex system. It is a nonlinear real-time change system with strong coupling and large hysteresis[4]. Using the mechanism modeling method, a complex coupled real-time nonlinear system model is obtained, which is not conducive to the study of decoupling control. In order to facilitate the control, the system identification method is adopted. Under the open loop, the system step excitation is given to obtain the temperature and humidity response curve. The system model is identified by using multiple sets of unit step curves to obtain the temperature response model of the following system:

\[
T(s) = \frac{0.01813(152s + 1)}{s(87s + 1)} e^{-19s} \cdot C_i(s) + \frac{0.01109}{s(52s + 1)} e^{-75s} \cdot C_h(s)
\]

Humidity response model:

\[
H(s) = -\frac{41.193}{408.09s + 1} e^{-24s} \cdot C_i(s) + \frac{0.1575}{s(27.4s + 1)} e^{-31s} \cdot C_h(s)
\]

In the formula, \(Y_i(s)\) is the temperature control amount, and \(C_h(s)\) is the humidity control amount.

Write it as a matrix:

\[
\begin{bmatrix}
T \\
H
\end{bmatrix} =
\begin{bmatrix}
G_{11} & G_{12} \\
G_{21} & G_{22}
\end{bmatrix}
\begin{bmatrix}
C_i \\
C_h
\end{bmatrix}
\]

The transfer functions in the formula are:

\[
G_{11}(s) = \frac{0.01813(152s + 1)}{s(87s + 1)} e^{-19s}
\]

\[
G_{12}(s) = \frac{41.193}{408.09s + 1} e^{-24s}
\]

\[
G_{21}(s) = \frac{0.01109}{s(52s + 1)} e^{-75s}
\]

\[
G_{22}(s) = \frac{0.1575}{s(27.4s + 1)} e^{-31s}
\]

The control block diagram of Figure 2 can be changed to the following structure:
4. Decoupling controller design

A system based on the strong coupling characteristics between the two in the temperature and humidity control process is also called a temperature and humidity coupling system. If such systems are not decoupled, each loop in the system will interfere with each other during operation, and it will be difficult to obtain an ideal control effect. Therefore, the decoupling of the temperature and humidity coupling system can be realized by decoupling methods such as feedforward compensation decoupling, state feedback decoupling, series compensation decoupling and static decoupling. The decoupler is placed in front of the control object or on the feedback channel in a compensated manner to attenuate or even eliminate the coupling between temperature and relative humidity\(^5\).

From the transfer function of the temperature and humidity control system, their coupling relationship is that the influence of temperature on the relative humidity variable is much greater than the relative humidity on the temperature variable, and the relative humidity changes, the humidity changes much more slowly, and can be compensated completely\(^6\). Whether from theoretical analysis or practical experience, the relative humidity drops by 2%-3% for every one degree Celsius increase in temperature, and such coupling effects are negligible. Therefore, it is completely possible to use single-edge decoupling, temperature and humidity compensation, temperature and humidity variables can be controlled as a single variable\(^7\).

In this paper, the feedforward compensation decoupling method based on the principle of feedforward compensation is selected. The feedforward compensation decoupling is to regard the coupling channel as the disturbance signal of the control object, so as to realize the decoupling of the disturbance signal. The feedforward compensation decoupling system diagram is shown in Figure 4:

\[
\begin{align*}
0)()()() & \equal \frac{sGsGsGsV}{sY} \\
22121 & \equal \frac{1}{s} \\frac{2}{2} P & \equal \frac{1}{s} \frac{2}{2} P & \equal \frac{1}{s} \frac{2}{2} P
\end{align*}
\]

According to the principle of invariance of feedforward control, we can know:

\[
\frac{Y_2(s)}{V_1(s)} = G_{21}(s) + G_1(s)G_{22}(s) = 0
\]  \(8\)
From the above formula, the feedforward decoupler \( G_1(s) \) can be determined as:

\[
G_1(s) = -\frac{G_{21}(s)}{G_{22}(s)}
\]  

(9)

5. Simulation

According to the reference model of the temperature and humidity system, the coupled system is subjected to feedforward compensation decoupling. Under the step signal, the temperature jumps from 0 °C to 60 °C, and the humidity jumps from 0% to 85%. Curves 1, 2 are the set values of relative humidity and temperature, and curves 3 and 4 are the simulated values of relative humidity and temperature respectively. The simulation diagram before decoupling of temperature and humidity system and its simulation results are shown in Figure 5:

![Simulation Diagram](image)

Below we analyze the decoupling effect of the coupling channel between temperature and humidity under the feedforward compensation decoupling:

(1) When the humidification heating amount is \( U_2(s) = 0 \), the heating heating amount \( U_1(s) \) affects the controlled quantity temperature \( Y_1(s) \), the simulation result after decoupling is shown in curve 1 of Fig. 6(a); the control quantity \( U_1(s) \) is the controlled quantity humidity The effect of \( Y_2(s) \), the decoupling simulation results are shown in curve 2 of Figure 6 (a).

(2) When the heating heating amount is \( U_1(s) = 0 \), the effect of humidifying heating quantity
$U_2(s)$ on the controlled quantity humidity $Y_2(s)$, the simulation result after decoupling is shown in curve 1 of Fig. 6(b); the influence of control quantity $U_2(s)$ on the controlled quantity temperature $Y_1(s)$ The decoupling simulation results are shown in curve 2 of Figure 6(b).

![Simulation diagram of decoupling of temperature and humidity system](image)

**Figure. 6 Simulation diagram of decoupling of temperature and humidity system**

It can be seen from the simulation curves in the two graphs in Fig. 6 that the control amount $U_2(s)$ does not affect the controlled quantity $Y_2(s)$, and the control quantity $U_1(s)$ does not affect the controlled quantity $Y_2(s)$; the controlled quantity temperature $Y_1(s)$ is only affected by $U_1(s)$. The controlled humidity $Y_2(s)$ is also only affected by $U_2(s)$. that is, the feedforward compensation decoupling removes the correlation of the temperature and humidity coupling channel, making the system two independent, non-influenced single-entry systems.

By comparing the simulation results of the temperature and humidity system before and after decoupling, the control effects of temperature and relative humidity have been greatly improved. The feedforward compensation decoupling improves the robustness of the temperature and humidity control system and improves the performance of the temperature and humidity control system.

Therefore, the feedforward compensation decoupling can cancel the coupling relationship between temperature and humidity, eliminating the influence of temperature on relative humidity. By changing the different set values of the control object, the feedforward compensation decoupling method can still achieve the control. Decoupling of objects. It is thus verified that the feedforward compensation decoupling method can eliminate the coupling effect of temperature and relative humidity.

**6. Experimental result**

The temperature and humidity test chamber has a temperature of 60 °C and a relative humidity of 85%. The results are shown in Figure 7. Curves 1, 2 are the relative humidity and temperature settings, and curves 3 and 4 are the relative humidity and temperature value. According to China's measurement instrumentation error standard, the temperature is 1% error and the humidity error is 2%. It can be seen from the experimental results that very good control results can be obtained.
7. Conclusion
The temperature and humidity control system of the constant temperature and humidity test chamber is a system with large hysteresis and strong coupling. After decoupling simulation results, it can be known that the positional PID algorithm can achieve good control effect. In the current control system control process, sometimes some oscillations occur. We need to further optimize the controller and optimize the parameters of the controller to reduce the oscillation and make the system more stable.

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