Switching Controller for Enthalpy Difference Laboratory Temperature Based on Fuzzy Control and PID Control

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***Abstract*—The enthalpy difference laboratory is an experimental device for measuring refrigerating and heating capacity of Air conditioner. However, the temperature system of enthalpy difference laboratory has the characteristics of nonlinearity, hysteretic nature and time variation. Therefore, it is difficult for general control method to meet the control requirements of enthalpy difference laboratory. In this paper, We designed a DCS system that embeds controller of complex algorithms based OPC Technology as the system architecture of the enthalpy difference Laborator. And, we designed control algorithm based fuzzy and PID switching to control the temperature of the enthalpy difference lab. By designing the fuzzy control part and the PID control part of the switching controller, and selecting the reasonable and stable switching index to switch the controller to complete the designed of switching controller. The switching controller perfectly combines the advantages of the PID controller and the fuzzy controller. It can be seen by simulation that the performance of switching controller was significantly higher than that of PID controller and the fuzzy control of the enthalpy difference lab control. Switching control can achieve the requirements of control enthalpy difference laboratory.**

***Index Terms*—Enthalpy difference laboratory, OPC, DCS, Fuzzy control, PID control, Switching controller**

I. Introduction

With the development of the air-conditioning industry, the competition is becoming increasingly fierce. The performance index of air conditioning has become an important indicator of increasing competitiveness. But the air conditioning performance can not be measured directly, it need to go through the simulated work environment test. Especially for large commercial air conditioning, Requirements for artificial simulation environments are higher. The enthalpy difference laboratory is aimed at simulating large commercial working environments, and related staff work on product development and testing through using the enthalpy difference laboratory.

The enthalpy difference laboratory is an experimental device for measuring refrigerating and heating capacity of Air conditioner, including two parts: the lateral chamber and the interior side. The control of the temperature outside the chamber is the core part of the control of the enthalpy difference laboratory . The stability and accuracy of outdoor temperature control affect the accuracy of measuring refrigerating and heating capacity of Measured air conditioner. Therefore, the temperature control of the enthalpy difference laboratory is very important.

However, the temperature control of outside of the enthalpy difference laboratory has great nonlinearity, hysteresis and time variation, and has very strong interference. The simple PID control system is difficult to meet the requirements of the system. When speeding up the regulating speed, the stability will decrease and overshoot will increase. When the stability is increased and the overshoot is reduced, the regulating speed will be slowed down. If regulating time of system is long, which will lead to enthalpy difference laboratory energy consumption increases, and reduce the work efficiency of enthalpy difference laboratory. If the stability is poor and the steady-state error is large, the accuracy of the enthalpy difference laboratory will be reduced or even not up to standard. Therefore, it is important to design a good temperature controller of enthalpy difference laboratory.

At present, most DCS systems adopt PID control mode, so it is difficult to meet the requirements of enthalpy difference laboratory. Because the configuration software is difficult to write the complex algorithm, to make the complex algorithm applied to the temperature control of the enthalpy difference laboratory, it is necessary to use other platform development software to write algorithms, such as VB, VC and other software.

To achieve the above scheme, we must establish communication between the third party platform and DCS, the third party software platform to be able to read and write data in the DCS system. Then in the third party platform, we write complex algorithm control. In this paper, We designed a DCS system that embeds controller of complex algorithms based

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OPC Technology, and adopted switching controller based on fuzzy and PID control is selected as the temperature controller of the enthalpy difference laboratory.

II. Introduction to the Principle of Enthalpy Difference Laboratory

This paper is based on the constructed enthalpy difference Laboratory of an energy-saving technology company, which is mainly used to test the performance indexes of large air conditioners. The simple structure of this enthalpy difference laboratory is shown in Fig.1.

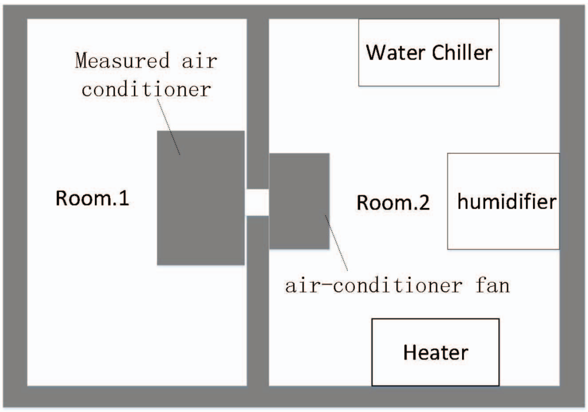

Fig. 1. Introduction to the principle of enthalpy difference laboratory

The enthalpy difference laboratory consists of Room.1 and Room.2. The walls of the two rooms adopt thermal insulation material. Room.1 is the room where the measured air conditioner is located, and room.2 is used to simulated external conditions of meaured air coditioner. The performance of the enthalpy difference laboratory lie is quality of the Room.2 simulating the external environment. Therefore,this paper only gives a detailed description of Room.2.

Room.2 is mainly consists of measured air-condition fan, humidifer, heater, water chiller, temperature sensor and humidity sensor. The work of enthalpy difference laboratory requires Room.2 the environment is constant temperature and humidity. The temperature in the enthalpy difference laboratory is complicated by the presence of an air-conditioner fan in the Room.2 as an uncertain disturbance. In this paper, the following strategies are adopted to solve this problem: setting up the power of the chiller, designing only the controller to adjust the heater power and keeping the room 2 constant temperature. In this paper, the following strategies are adopted to solve this problem: Under the premise that the power of the water chiller is constant, only the controller is designed to adjust the heater power to keep the Room.2 constant temperature.

III. System Architecture of Enthalpy Difference Laboratory

In this paper, the system architecture of the enthalpy difference Laboratory is a DCS system that embeds controller of complex algorithms based OPC Communication Technology.

See Reference [2]. OPC, the full name is Object linking and embedding for process control technology, provides a bridge between application software and industrial process control based on Microsoft windows operating system. It is currently maintained and managed by the OPC organization, based on COM/DCOM technology, and a set of communication standard for information interaction between a variety of industrial control software. As an OPC technology that meet industry standard, it not only eliminates the communication barrier between different software and hardware, but also solves the communication problem caused by the inconsistent data format between different software. The OPC communications standard protocol is developed by Microsoft Corp combined leading automation of software and hardware vendor. It makes industrial control in hardware and software have a unified standard. In software, almost all the popular configuration software at home and abroad have OPC server, and the current mainstream computer programming language supports program development based on OPC communication protocol. In this paper, OPC uses a typical mode of OPC client / OPC server.

The system architecture as Fig.2.

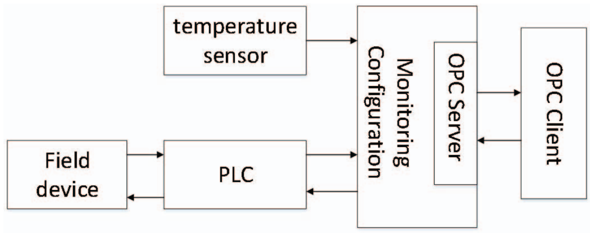

Fig. 2. The system architecture of Laboratory

This paper chooses Kingview, is produced Beijing WellinTech company production, as the configuration monitoring software of enthalpy difference lab system configuration monitoring software, and Select PLC model as PLC S7-200. We adopted Microsoft Visual Basic 6.0 to write OPC client program. OPC client mainly includes two parts: communication protocol and control algorithm.

Kingview connected PLC, and then PLC connected field devices. it can achieve voltage, current and other data acquisition and input, and can complete the basic logic control. However, the above control mode can not complete complex control, so we need to lead into OPC.

Work flow of temperature control: The temperature sensor detects the temperature in the field, and is connected directly to the monitoring configuration software. The monitoring configuration reads data from the temperature sensor according to the set sampling period. Collected data show that in the monitoring interface, at the same time stored in the king of the historical database. The OPC client connects to the OPC server in the Kingview and reads the real-time data from the configuration according to the sample set by the OPC client. OPC writes the read data to the controller, and the controller calculate the voltage signal of the heater through its own control algorithm. The voltage value is written into the configuration software through OPC, and then the configuration software writes it to the PLC. Finally, the PLC writes the voltage value to the heater to complete A cycle of temperature control. Repeat the process until the temperature reaches the set temperature and is stable. The temperature control of the enthalpy difference laboratory is completed.

IV. The Design of Switching Controller

For the enthalpy difference laboratory temperature control system, simple PID and fuzzy control are difficult to meet the requirements of the system, and the complex control algorithm is difficult to achieve in practical engineering. Consequently, this paper adopts switching control algorithm based on PID controller and fuzzy controller. The principle diagram of the design switch controller is shown in Fig.3:

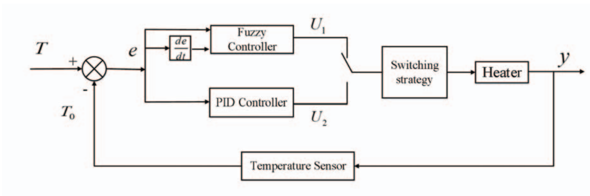

Fig. 3. The principle diagram of the design switch controller

In the Fig.3, T is the expected temperature, T_0 is the actual temperature, and e is the difference value between the setting temperature and the actual temperature. U_1 is the output of the fuzzy controller, and U_2 is the output of the PID controller. In this paper, the switching implementation is based on the size of the error to set the corresponding switching surface. Because the fuzzy controller has the advantages of shorter regulating time and smaller overshoot, and the PID has the advantage of well stability. So we use the following switching strategy:

1). When the absolute value of e is more than the switching surface, the fuzzy controller is selected;

2). When the absolute value of e is less than the switching surface, the fuzzy PID controller is selected;

A. the Design of Fuzzy Controller

The design of the fuzzy controller is mainly divided into three parts:

1).First, blur the values of input and output. By setting the quantization factor, the determined values are quantized into universe. And the corresponding of input and output and membership function of input is designed.

2).Secondly, according to the universe and the linguistic value of input, we formulate fuzzy rules table of controller.

3).Finally, according to the input membership function, the linguistic value of input and output and the fuzzy rules table, the output of the fuzzy controller is obtained by the appropriate ambiguity resolution method.

1).Bluring of the Input and Output

The input of the fuzzy controller is error e and the error rate ec. The output is the digital signal to the heater voltage .

The degree of accuracy of a fuzzy system is closely related to the number of linguistic values. The more linguistic values are, the more sensitive the system is. Meanwhile, it increases the fluctuation of system and can make the switching surface unstable. In the switching controller, the fuzzy controller is used to shorten the regulating time, so the moderate linguistic value is chosen. The linguistic value of input and output are $NB, NM, NS, ZO, PS, PM, PB$, respectively representing negative big, negative medium, negative small, zero, positive small, positive middle and positive big. The universe of input error and error is $[-3, 3]$, and universe of the output is $[-3, 3]$.

After determining the universe, it is necessary to determine the corresponding quantization factors. is the quantization factor of input , the universe of actual error is $[-e_m, e_m]$, and the universe of fuzzy error is$[-n_1, n_2]$. And,

$$K_e = \frac{n_1}{e_m} \tag{1}$$

K_{ec} is the quantization factor of input ec , the universe of actual error rate is $(-ec_m, ec_m)$, and the universe of fuzzy error rate is $(-n_2, n_2)$. And,

$$K_{ec} = \frac{n_2}{ec_m} \tag{2}$$

K_u is the quantization factor of output U_1, the universe of actual output is $(-U_{1m}, U_{1m})$, and the universe of fuzzy error rate is $(-n_3, n_3)$. And,

$$K_u = \frac{U_{1m}}{n_3} \tag{3}$$

The membership function of the input is also a part of the fuzzification. The membership function of input makes the temperature error and error rate have the corresponding membership degree of linguistic value. Generally, the fuzzy membership functions select trigonometric functions, Gauss functions and trapezoidal functions. As a temperature system, the choice of trigonometric functions is the most appropriate. We establish the membership functions of the error and error rate as shown in Fig.4 and Fig.5.

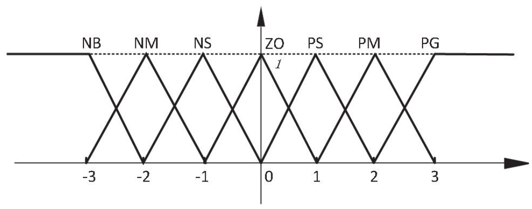

Fig. 4. Membership function of the error

2). Establishing of fuzzy rules table

A fuzzy rule table is used to express the relation between input and output increments, which is mainly based on the

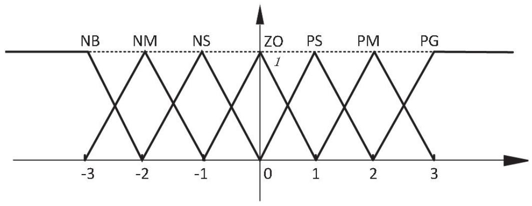

Fig. 5. Membership function of the error rate

constant sum up and practice of experience.ΔU_1 is output increment of fuzzy controller. A combination of each input e and the input ec will have a corresponding output ΔU_1.In this paper, 49 fuzzy rules are used to describe all the combination of input e and ec and output ΔU_1. For example as follows:

1). When input e is PB and input ec is PB, the actual temperature of the system is much lower than the expected temperature, and it also shows a great downward trend, so the system needs to increase the heater voltage rapidly, and ΔU_1 is taken PB.

2). When input e is NB and input ec is NB, the actual temperature of the system is much more than the expected temperature, and it also shows a great ascending trend, so the system needs to decrease the heater voltage rapidly, and ΔU_1 is taken NB.

3). When input e is NB and input ec is NS, through the actual temperature of the system is much more than the expected temperature, rising trend of the temperature of the system has been reduced. The heater voltage can be slowly reduced,and ΔU_1 is taken NM.

4). When input e is ZO and input ec is NS, through the actual temperature of the system is equal to the expected temperature, the teemperatureof the system have a big rising trend. So the system needs to decrease the heater voltage to eliminate rising trend, and ΔU_1 is taken NM.

We create a fuzzy rule table that describes 49 fuzzy rules, It is shown in table 1:

TABLE I
EXAMPLE OF TABLE

ec e	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	ZO
NM	NB	NM	NM	NS	NS	ZO	PS
NS	NM	NM	NS	NS	ZO	PS	PS
ZO	NM	NS	NS	ZO	PS	PS	PM
PS	NS	NS	ZO	PS	PS	PM	PM
PM	NS	ZO	PS	PS	PM	PM	PB
PB	ZO	PS	PS	PM	PM	PB	PB

3).Ambiguity resolution of fuzzy controller

The methods of ambiguity resolution are mainly divided into maximum membership degree, median method and weighted average. Because of the selection of input membership, a set of inputs may correspond to several fuzzy rules, and the selection and decision-making of several different fuzzy rules directly affect the system's effectiveness. In this paper, the weighted average method is adopted to solve the problem of ambiguity, The weighted average method, also called the center of gravity method, which is a widely used method of decision in fuzzy control systems. In the method mainly takes the weighted value of membership function value is clear output value, In the weighted average method, which highlights the main information while taking into account other information, so it seems to be closer to the actual situation, and therefore more widely used. That is:

$$\Delta \bar{U}_1 = \frac{\sum_{i=1}^{n} z_i \bullet \Delta \bar{U}_{1i}}{\sum_{i=1}^{n} z_i} \tag{4}$$

Among them, ΔU_{1i} is the output increment corresponding to the fuzzy rule of i, and Z_i is the weight of the output increment station corresponding to the fuzzy rule of i. ΔU_{1i} is the increment of the fuzzy output.

$$U(k) = K_U[\bar{U}_1(k-1) + \Delta \bar{U}_1(k)] \tag{5}$$

Among them, $\bar{U}_1(k)$ is fuzzy output, and $U_1(k)$ is actual output of control system.

B. Designed of PID controller

Design its PID controller, U2 is output PID controller, e is input, KP is PID controller proportional coefficient, KI is PID controller integral coefficient, KD is the differential coefficient of the PID controller, TI is the integral time of the PID controller, and TD is the differential time of the PID controller.

The control law of the continuous signal PID controller is:

$$U(t) = K_p\Big[e(t) + \frac{1}{T_i}\int_0^t e(t) + T_D\frac{de(t)}{dt}\Big] \tag{6}$$

But in the temperature control of the enthalpy difference laboratory are generally sampling control, The system can only be judged and controlled by the bias value of the sampling. T is the sampling period, the PID controller control law is discretized, and the following increment PID formula is obtained:

$$\Delta U(k) = K_P\big[e(k) - e(k-1)\big] + K_I e(k) \tag{7}$$

$$+ K_D\big[e(k) - 2e(k-1) + e(k+2)\big] \tag{8}$$

$$U(k) = U(k-1) + \Delta U(k) \tag{9}$$

Among, k is the current number of samples;

$$K_I = \frac{K_P \cdot T}{T_I} \tag{10}$$

$$K_D = \frac{K_P \cdot T}{T_D} \tag{11}$$

Because the PID controller is mainly used to increase system stability and steady-state error, a set of parameters with increased stability and small steady-state error is selected. n PID control, K_P is mainly to shorten the regulation time, but too large can lead to system instability; K_I can reduce system shock and increase system stability, and can reduce system overshoot; K_D can reduce system overshoot. According to the above function of parameters, compared with other temperature systems, K_P should take small values, K_I should take medium values, KD should take medium values.

V. Simulation of System

The enthalpy difference laboratory temperature control system model, similar to the greenhouse system model. See Reference [3]. it is a first order lag model.Formula is as follows.

$$G(S) = \frac{Ke^{-\tau s}}{T_1 s + 1} \tag{12}$$

T_1 is the time constant of inertia, and τ is the time constant of delay. In this paper, MATLAB simulation model is used to build the Simulink model, and the enthalpy difference laboratory temperature switching control system is simulated. Select the enthalpy difference laboratory temperature model is shown as:

$$G(S) = \frac{Ke^{-80s}}{40s + 1} \tag{13}$$

And set the parameters of the PID controller: $K_P = 0.38, K_I = 0.008, K_D = 0.08$; the setting of fuzzy controller parameters: $K_e = 60.00, K_{ec} = 0.98, K_u = 10.08$; the setting of switching controller parameters: $K_e = 60.00, K_{ec} = 0.98, K_u = 10.08, K_P = 1.01, K_I = 0.0081, K_D = 0.00$; And choose a smooth and stable switching index of switching controller as follows: when the absolute value of is greater than 1, the fuzzy controller is selected, and when the absolute value of is less than 1, the PID controller is selected. Under setting that sample time is 1 second and simulation time is 1500 second condition, the control effects of PID controller, fuzzy controller and switching controller are compared. The simulation results are shown in Fig.6, Fig.7 and Fig.8. Performance indicators for the three controllers are shown in Table II, Simulation of enthalpy difference laboratory work using model. 1.

TABLE II
EXAMPLE OF TABLE

Performance indicators	PID	Fuzzy	Switching
Rising time	192s	185s	185s
Regulation time	540s	274s	274s
overshoot	13.3	0	0
steady-state error	0.003	0.924	0.004

Model.1 as:

$$\frac{e^{-80s}}{40s + 1} \tag{14}$$

Performance analysis of Fig.5, Fig.6 and Fig.7 and Table.2 can be seen, the switching controller settling time and overshoot is obviously better than the PID controller, and the steady-state error and stability is better than fuzzy controller

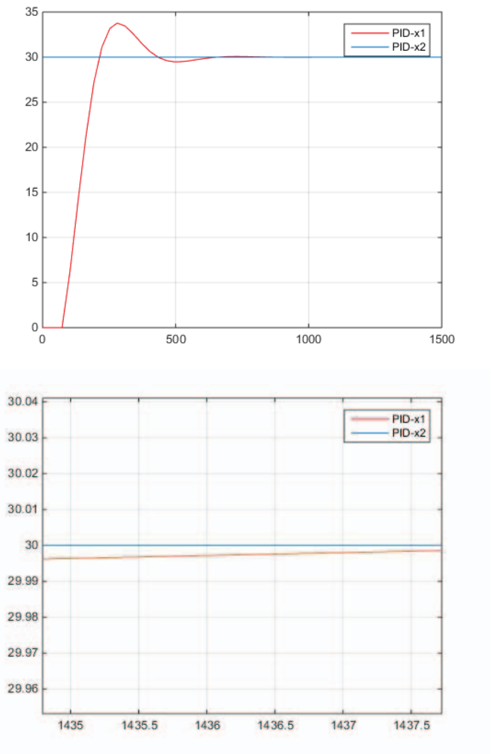

Fig. 6. The simulation results of PID controller

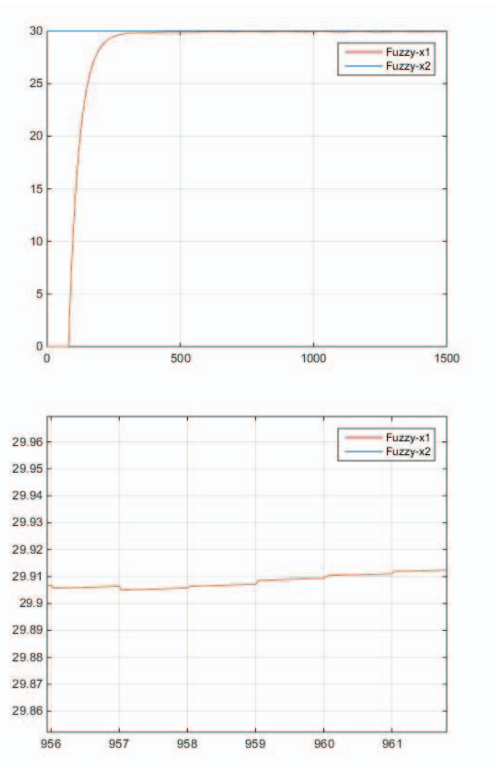

Fig. 7. The simulation results of Fuzzy controller

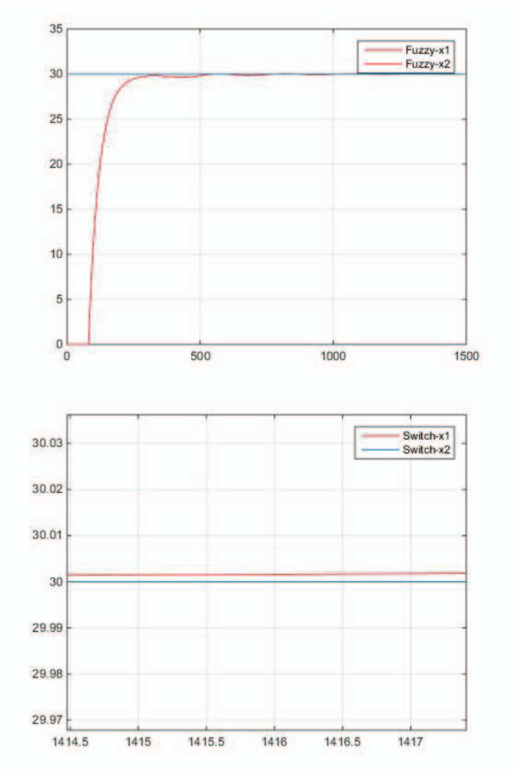

Fig. 8. The simulation results of Switching controller

VI. Conclusion

In this paper, we adopt a DCS system that embeds controller of complex algorithms based OPC Communication Technology as the system architecture of the enthalpy difference Laboratory . The system architecture can use other complex algorithms besides PID control. Therefore, the complex working environment can be solved . Then, we designed a fuzzy and PID switching controller for the temperature control of the enthalpy difference laboratory. Through the simulation we can see, the switching controller combines the advantages of PID controller and fuzzy controller, avoiding the shortcomings of fuzzy controller and PID. Moreover, the dynamic performance and steady-state error of the enthalpy difference laboratory temperature control system are greatly improved.

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