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The application of Self-adaptive Fuzzy PID control the evaporator superheat

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Abstract: *In view of the characteristics of the cold storage refrigeration system, such as nonlinear, time-varying and coupling, the traditional PID control accuracy is low, this study adopted the method of adaptive Fuzzy PID to control the superheat of the evaporator outlet. Fuzzy PID controller can adjust the parameters according to the deviation and deviation rat. It can avoid the disadvantages of traditional PID controller that it cannot adjust control parameters according to operating conditions.*

Keywords: *Clod storage; Superheat; Electronic expansion valve; Fuzzy PID*

I. INTRODUCTION

Superheat is refers to the difference of overheating temperature and saturation temperature of the refrigerant in the same evaporating pressure. With the increase of evaporator superheat, the Overheated Zone is become longer, and the Two Phase Zone is become shorter. The heat transfer coefficient of the Two Phase Zone is 4~5 times of the Overheated Zone[1]. Therefore, in order to improve the heat transfer coefficient, the length of the Two Phase Zone should be increased, and the decreasing of the superheat can increase the length of the Two Phase Zone. Due to the two aspects of contradiction, with the increasing of superheat, the evaporator heat transfer effect is reduced. With decreasing of superheat, it will cause the liquid impact phenomenon of the compressor. So, the refrigerant should be controlled in appropriate state of overheating. The traditional approach is to use PID controller and conventional PID controller is established on the basis of the simplified and the constant model. But the characteristics of evaporator will change with the load and operating conditions vary, and the parameters are coupled with each other, which makes the evaporator shows strong characteristics of nonlinear. If the superheat of evaporator is controlled by the conventional PID, it is difficult to obtain good effect. The Fuzzy PID controller has the advantages of simple structure, quick adjustment, and the object does not require very high degree of accuracy[2], so the Fuzzy PID controller is applied to evaporator superheat in this study.

II. The composition of superheat control system and its principle

This system uses the master-slave structure. The Siemens S7-300 PLC is used as the lower machine, acquisition and processing of system data; WinCC is used as a host computer, to display, record, alarm, parameter setting and other functions to achieve data. Temperatures, pressure from the refrigerant of evaporator outlet were collected by PLC, and calculate real-time superheat (PV). Superheat set value (SP) can be set through the WinCC interface; the superheat deviation E and deviation change rate EC can be catch, the Fuzzy PID algorithm to get the corresponding output. This system uses the electronic expansion valve Danfoss ETS6 as actuator system, refrigerant flow is regulated according to the output of the Fuzzy PID controller, so that the degree of superheat can achieve certain value. As shown in figure 1.

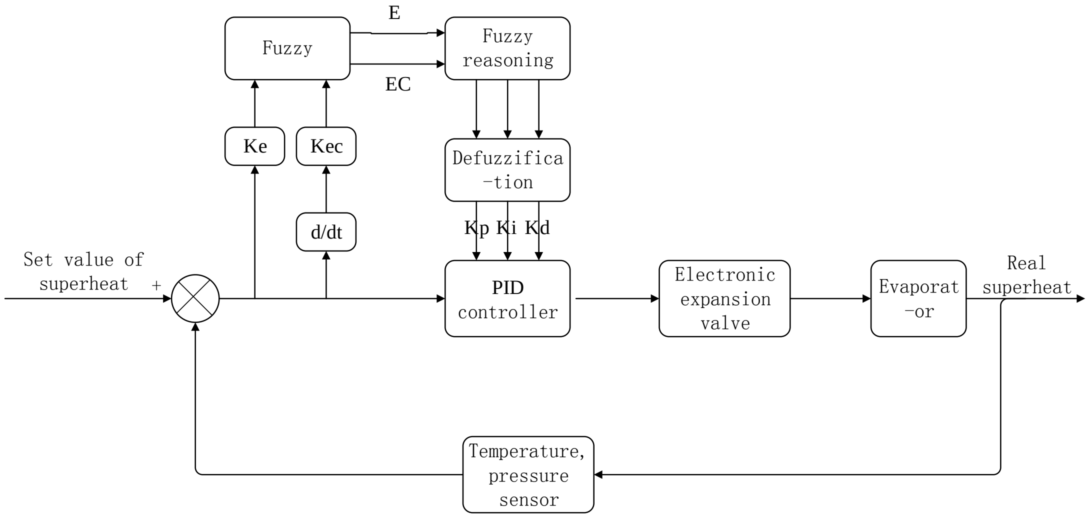

Fig. 1 Diagram of fuzzy PID control system

The traditional PID control parameter setting has two kinds of methods: Mathematical model method and the Cut-and-Trial method. Mathematical model method needs to establish the model of the controlled system and then get the parameters of PID controller by method of using optimization method. The Cut-and-Trial method requires repeated experimental try the parameters of the controller, and optimal the control effect. The traditional PID controller is simple and easy to master, but in the practical application, the controlled object is always nonlinear, time-varying, multi parameter coupling and uncertain characteristics, thus it is hard to establish mathematical model of the controlled system, such as the controlled object, the evaporator superheat degree. Fuzzy PID algorithm does not need to establish accurate mathematical model in solving a problem of this sort, and only need to adjust the experience with some vague language to represent the control rules, which ultimately form the controller's query table. The superheating temperature deviation and deviation change rate were set as the input value of the query table, it can get the corresponding query proportion, integral and differential control parameters, and then the result is passed to the PID controller. The most prominent characteristics of the Fuzzy PID controller is that it can be achieved online self-adaptive function, which means control parameters of the PID controller were adjusted in real time according to the collected data. The control parameters of the PID controller can be adjusted: proportional coefficient K_P, integral time T_I and differential time T_d, so as to achieve the purpose of adjusting control parameters according to the actual situation. The traditional PID controller in the control of evaporator superheat, once the control parameters were set, the parameters can't be adjusted online. It will not be able to adapt to the new operating conditions, when the characteristics of the controlled object is changed, and the steady state recovery time is relatively long, regulating effect is poor. Fuzzy PID in controlling of superheat of the evaporator, it can adjust the corresponding control parameters according to real-time data, and make the control to achieve the optimal effect.

III. Fuzzy PID controller

This article uses the position type PID control algorithm, and its formula is as formula (1) or formula (2):

$$u(k) = K_p \left\{ e(k) + \frac{T}{T_i} \sum_{i=0}^{k} e(i) + \frac{T_d}{T} \left[e(k) - e(k-1) \right] \right\}$$ formula (1)

$$u(k) = K_p e(k) + K_i \sum_{i=0}^{k} e(i) + K_d \left[e(k) - e(k-1) \right]$$ formula (2)

Among them, $K_i = K_P \times \frac{T}{T_i}$ is called as the integral coefficient, $K_d = K_P \times \frac{T_d}{T}$ is called as the differential coefficient, $u(k)$ is called as the output of the controller. $e(k)$ is called as the deviation, T is the sampling period, K_P is the Proportion coefficient, T_i is the integral time, and T_d is the differential time. Their effects are as follows: (1) The proportion: according to the deviation, the controller adapts the controlled quantity based on the proportion, to reduce the deviation. Proportion coefficient is used to speed up the system response speed, the greater the proportion coefficient, the faster the coefficient of response. If the proportion coefficient is too big, it may cause overshoot, bring oscillation to the system. The smaller the proportion coefficient, the longer time the system takes to be stable, reduce the control accuracy, and the static, dynamic characteristics of the system goes bad. (2) The integral: it is used to eliminate static difference, decrease the difference of process value and the setting value. The strength of the integral action depends on the size of the integration time, the smaller the integration time, the greater the integral action, but too much integral action can cause the oscillation of the system. (3) The differential: according to the change trend of deviation value, it regulates the control quantity of the system. Before the large changes in the amount of deviation, make the system control quantity in advance to change this trend, so as to accelerate the speed of adjustment, and reduce the adjusting time. If differential time is too big, it may cause the system oscillation[3].

Fuzzy PID controller is still based on the PID controller; using fuzzy controller generates the control parameters of PID controller and using the parameters to establish the query table. The fuzzy controller with two input and three output mode, namely the deviation E and deviation change rate EC as input of controller, according to the E and EC query the stable to obtain the corresponding parameters, and passed the parameters to the PID controller.

3.1 Fuzzy and the determination of membership function

(1) Fuzzy, that means translate the precision value of superheat deviation *e*, the deviation rate *ec*, K_P, T_i, T_d into fuzzy value. The actual scope of deviation *e* and deviation change rate *ec* is [-10℃,10℃], [-0.1℃/s, 0.1℃/s]. Because the actual value is continuous variable, in order to fuzzy processing, so it is necessary to quantify the actual value (discrete) to the fuzzy theory sets. *e*, *ec* were quantified to E and EC. The quantized sets is {-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6}, the quantitative factor ke=0.6, kec=60. The sets of K_P, T_i, T_d is {0,1,2,3,4,5,6,7,8}. The fuzzy sets of e and ec were {NB, NM, NS, ZE, PS, PM, PB}, as shown in figure 2. The fuzzy sets of K_P, T_i, T_d were {ZE,S,M,B,VB}, as shown in figure 3.

(2) The membership functions which describe the degree of an element belongs to a certain collection, this paper adopts triangular membership function which is commonly used in engineering.

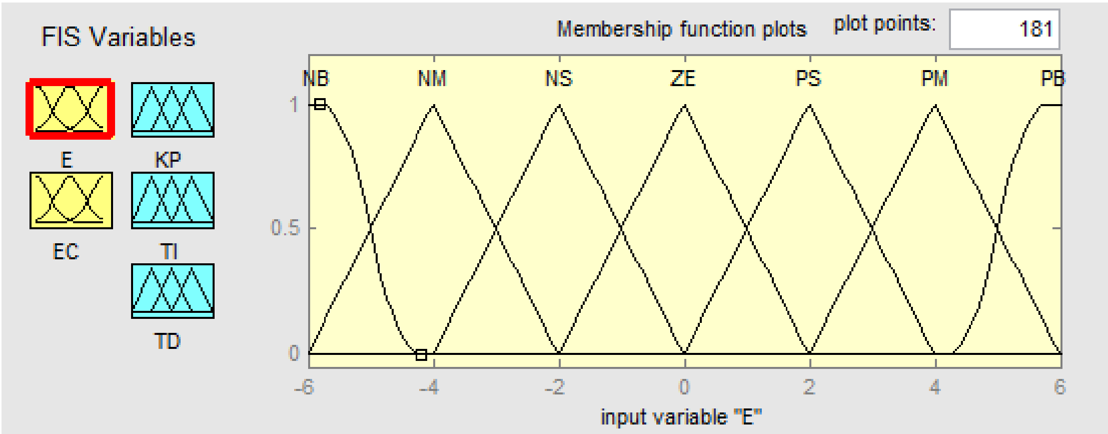

Fig. 2 The membership function of E, EC

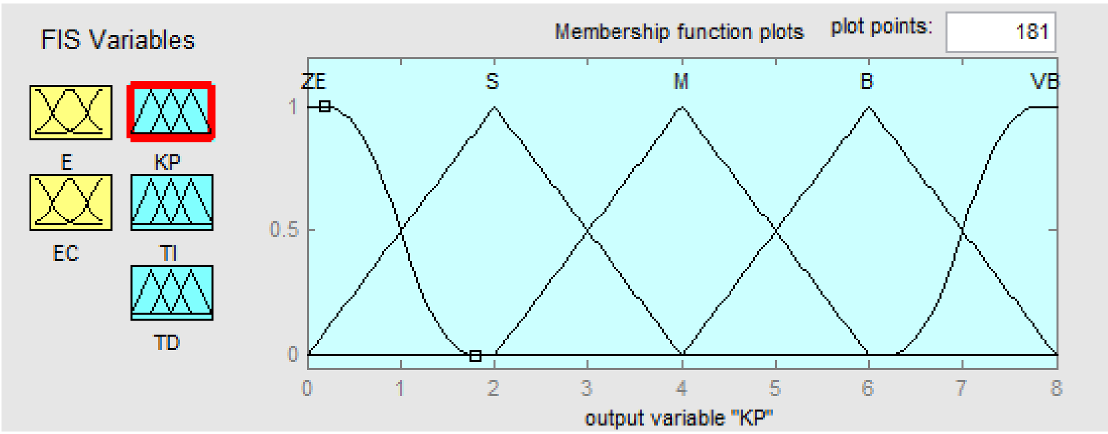

Fig. 3 The membership function of K_P, T_i, T_d

3.2 The establishment of control rules

According to the experiences of adjusting cold storage control system, the fuzzy control rules table can be established, as shown in table 1~table 3.

Table 1 The fuzzy control rules of K_P

EC / E	NB	NS	NM	ZE	PS	PM	PB
NB	VB	VB	VB	VB	VB	VB	VB
NM	VB	VB	VB	VB	VB	VB	VB
NS	B	B	B	B	B	B	B
ZE	M	M	M	M	M	S	M
PS	S	S	S	M	M	M	M
PM	B	B	B	B	B	B	VB
PB	VB	VB	VB	VB	VB	VB	VB

Table 2 The fuzzy control rules of T_i

EC / E	NB	NS	NM	ZE	PS	PM	PB
NB	ZE	ZE	ZE	ZE	ZE	ZE	ZE
NM	ZE	ZE	ZE	ZE	ZE	ZE	ZE
NS	ZE	ZE	ZE	ZE	ZE	ZE	ZE
ZE	M	S	S	ZE	ZE	M	S
PS	S	M	M	M	M	M	B
PM	M	B	B	B	B	B	VB
PB	VB	VB	VB	VB	VB	VB	VB

Table 3 The fuzzy control rules of T_d

EC / E	NB	NS	NM	ZE	PS	PM	PB
NB	ZE	ZE	ZE	S	ZE	VB	VB
NM	ZE	ZE	ZE	S	M	B	B
NS	ZE	ZE	ZE	ZE	S	M	B
ZE	M	M	S	ZE	ZE	ZE	ZE
PS	B	M	S	ZE	S	M	B
PM	ZE	ZE	ZE	ZE	S	S	M
PB	ZE	ZE	ZE	ZE	ZE	ZE	ZE

By using Rule Editor of fuzzy logic toolbox the in MATLAB, edit fuzzy control rules of K_P, T_i, T_d in accordance with the way of If (E is NB) and (EC is NB) then (KP is VB) (TI is ZE) (TD is ZE), and the fuzzy decision take the Mamdani decision method, fuzzy solution. Defuzzification take the method of centroid, the clear calculation results of K_P, T_i, T_d can be obtained from Rule Viewer in fuzzy logic toolbox[4].

IV. PLC program design and experiment

Make all the clear result of K_P, T_i, T_d in Rule Viewer as a query form. According to the deviation and deviation change rate of real-time, obtain the corresponding control parameters by using the fuzzy control table pointer. This way of off-line query control table can avoid large amount of disadvantages, such as lots of computation and time consuming[5]. Because E and EC are divided into 13 files, so there are 169 groups of control parameters. If the programming takes the way judge sentence, the program will become more complex and time consuming. SIEMENS S7-300 PLC has rich functional modules, which provides convenience for the realization of Fuzzy PID. Establish the data type of STRUCT in DB1, and establish the type of ARRAY in the STRUCT type. The array was definite as the two-dimensional array of 13*13, and it is used to store 169 groups of control parameters.

4.1 PLC program design

This system takes the outlet superheat of the evaporator as the control object, the superheat is refers to the difference of overheating temperature and saturation temperature under same evaporation pressure. Overheating temperature refers to the temperature of the refrigerant at the outlet of the evaporator; the saturation temperature refers to the temperature corresponding to the saturation pressure, and the saturation temperature can be obtained by the corresponding pressure of the refrigerant. The obtained superheat be taken as a process value PV, and compared with the set value SP, get the deviation and the deviation change rate. At this time, the value of e and ec belong to the actual sets, and e, ec need to be quantified to E, EC. E and EC need to deal with the roundness, the purpose of roundness is to make quantified E and EC as an integer, which is advantageous for the fuzzy control query table[6]. After the roundness of the E and EC, they were put in variable X_i and Y_j. Because this article adopts the way of pointer query table, the query table pointer address need to be computed, the calculation formula is as shown in formula 1~3.

$$K_{\mathrm{P}} = DB1.DBD\left[12 * \left(13X_i + Y_j\right)\right] \tag{1}$$

$$T_{\mathrm{i}} = DB1.DBD\left[12 * \left(13X_i + Y_j\right) + 4\right] \tag{2}$$

$$T_d = DB1.DBD\left[12 * \left(13X_i + Y_j\right) + 8\right] \tag{3}$$

```
L     MD   152
SLD   3
T     MD   152
OPN   DB    1
L     DBD [MD 152]
L     5.000000e-001          //Proportion coefficient
*R
T     "P/I/D".GAIN           //Kp

L     MD   156
SLD   3
T     MD   156
OPN   DB    1
L     DBD [MD 156]
L     1.250000e+001          //Integration time
*R
T     "P/I/D".R1
L     "P/I/D".R1
L     1000
*R
T     "P/I/D".TI             //Ti

L     MD   160
SLD   3
T     MD   160
OPN   DB    1
L     DBD [MD 160]
L     6.250000e+000          //Differential time

*R
T     "P/I/D".R2
L     "P/I/D".R2
L     1000
*R
T     "P/I/D".TD             //Td
```

Fig. 4 The program of table pointer

As shown in figure 4, the storage variable MD152, MD156, MD160 were used to store the address number of K_P, T_i, T_d. Because the value of K_P, T_i, T_d were stored in the DB1 array in this paper, therefore DB1.DBD[MD152], DB1.DBD[MD156], DB1.DBD[MD160] are the parameters in fuzzy control query table. In the process of the actual control of superheat, the proportion coefficient is 0~4, the integration time is 0~100s, and the differential time is 0~50s. The scope of the fuzzy domain is 0~8 respectively, so during the solution of fuzzy processing, proportion coefficient is $K_{up} = 4/8 = 0.5$, integration time is $T_{ui} = 100/8 = 12.5$, differential time is $T_{ud} = 50/8 = 6.25$. The PID control parameters K_P, T_i, T_d were obtained by fuzzy after the defuzzification. K_P, T_i, T_d as the control parameters of PID controller, the output of the PID controller is applied to the electronic expansion valve, and control its opening, so as to adjust the superheat of the evaporator outlet.

4.2 Experimental comparison

Take the set point of superheat of 5℃, do the simulation experiment of superheat control by using Fuzzy PID and traditional PID respectively, the control curve is as shown in figure 5. That can be observed by the control curve, compared with the traditional PID control, Fuzzy PID parameters self-adaptive control has good dynamic performance: small overshoot, and short adjusting time, which shows good robustness.

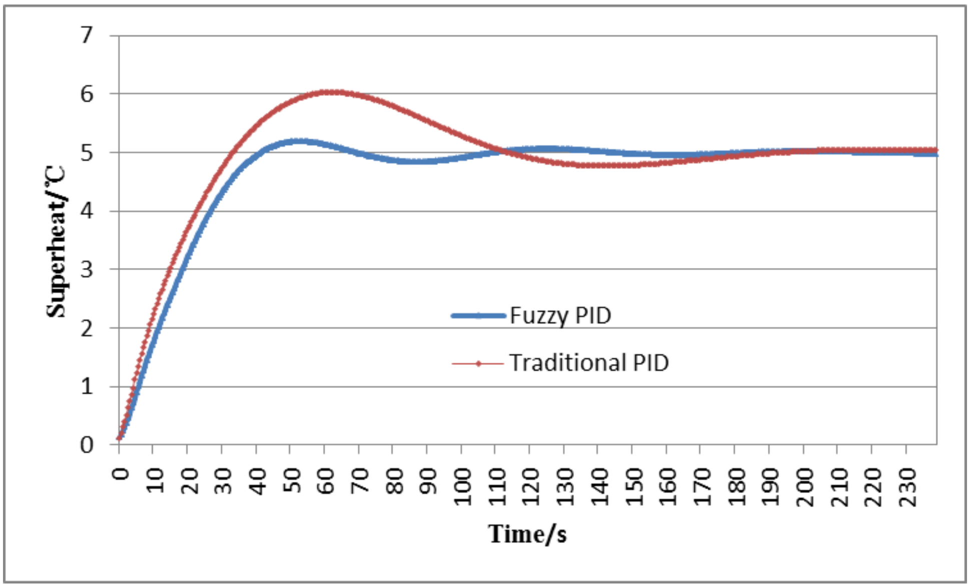

Fig. 5 Contrast of the control effect of Fuzzy PID and traditional PID

V. Conclusions

Programming in the environment of MATLAB, this paper calculates the off-line query table. Fuzzy PID controller was realized in STEP7 programming. According to the real-time acquisition of the temperature and pressure of refrigerant evaporator outlet, calculate the degree of superheat of refrigerant evaporator outlet, and the resulting the superheat deviation and the deviation change rate. The control parameters were adjusted according to the deviation and deviation change rate at real-time, to avoid the disadvantages that the traditional PID cannot adjust the control parameters according to the condition of the shortcomings in the controlling degree of superheat. According to the experiment, Fuzzy PID in the application of controlling evaporator superheat, compared with the traditional PID control, Fuzzy PID parameters self-adaptive control has good dynamic performance: small overshoot, and short adjusting time, which shows good robustness.

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