

Design and Implementation of Fuzzy PID Control for Oil Temperature in Overvoltage Withstand Test

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Abstract—It is difficult to control the temperature, due to the specific heating of the insulating oil and the high viscosity. It is necessary to design other method to control the temperature rather than the conventional control method. Combined with some characteristics of temperature control, a method of fuzzy PID control is proposed and validated by MATLAB for the adaptive control ability. The simulation results show that the control strategy has good robustness and stability, and the control precision is higher than conventional PID control.

Keywords—fuzzy control; control algorithm; temperature control; MATLAB simulation

I. INTRODUCTION

The traditional pressure tester does not consider the control of the ambient temperature of the tested sample. In this paper, the temperature control of the insulating oil of the test cup in the pressure tester is studied. The specific practice is to intercept part of the XLPE (cross-linked polyethylene) into the pressure test cup and fix it, and the cup is filled with insulating oil. The temperature of insulating oil is the ambient temperature of XLPE. This paper uses the 25# transformer oil as insulating oil. Through regulating the temperature of the insulating oil, it can achieve the purpose of controlling the ambient temperature around the XLPE. The heating is carried out mainly by heater strip. The heat generated by heater strip at the time of operation causes the oil around it to heat up and expand. Through the oil up and down convection, the heat spread to the upper cup. The balance of heating is achieved through the combination of heater strip and stirrer. The temperature of the insulating oil is controlled by the algorithm studied in this paper to ensure the stability of the ambient temperature of XLPE.

A. PID control

PID control is simple, easy to implement, wide application and strong stability, so it is widely used in industrial control. According to statistics, in the field of industrial control, the proportion of PID control and its associated optimization control up to 90%. Even in the rapid development of advanced control technology, PID control technology is still the first to consider the method and occupy the most important position in the application. The performance of PID control mainly

depends on the tuning of three parameters of P, I and D. Only to set the appropriate parameters, PID controller can achieve optimal control to meet the control speed and accuracy.

B. Theoretical feasibility of PID

The general block diagram of PID control system is shown in Fig.1.

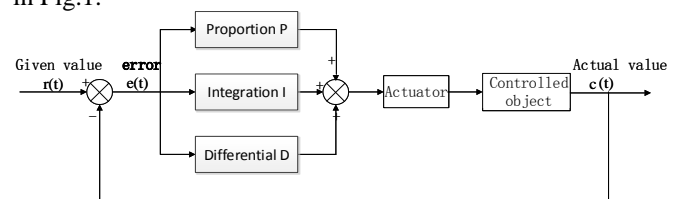


Fig. 1. Schematic diagram of a conventional PID control system.

From Figure 1, we can deduce the relationship between $r(t)$, $c(t)$ and $e(t)$ in the PID controller

$$e(t) = r(t) - c(t). \quad (1)$$

$e(t)$, respectively, through the proportion of links, integral links and differential links, and then the three linear combination, can constitute the control amount $u(t)$. So as to control the controlled object, the continuous form is

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_d \frac{de(t)}{dt} \right]. \quad (2)$$

Where K_p is the coefficient of proportionality; T_i is the integral time constant, and T_d is the derivative time constant.

Under normal circumstances, a complete PID controller is composed of the proportion of links, integral links and differential links of the three links, the various links in the control process played by the role is different, the specific control of each link described as follows:

Proportional adjustment function: the real-time proportional to the actual value of the system and the reference value between the deviation $e(t)$ to respond, as long as the control system bias, the system immediately targeted control to reduce the bias. The proportional coefficient K_p directly

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determines the strength of the proportional adjustment effect. The larger the K_P , the smaller the steady-state error, but will increase the overshoot accordingly, which will lead to oscillation and make the control system not stable enough.

Integral regulation: This link is mainly used to eliminate static errors. The integral adjustment effect is determined by the value of T_I . The T_I is larger, the weaker the integral effect will be, the corresponding overshoot will decrease, whereas the integral action is strong, also can decrease the static error, but the overshoot will increase, therefore, it should pay attention to the balance between them.

Differential regulation: This part of the transient change of the reaction system deviation, ahead control, can effectively improve the dynamic performance of the system. The magnitude of the differential regulation is determined by the value of the T_D , and the T_D is greater, the stronger the effect of the error suppression, the smaller the T_D value, the weaker the effect of the error variation, and the differential regulation to amplify the noise. When the differential control effect is too strong, it will reduce the system's anti-jamming capability.

II. FUZZY PID CONTROL

A. Basic principles of fuzzy control

Fuzzy control is an algorithm based on fuzzy logic. The principle is that the state of the controlled object is blurred into the fuzzy quantity described in the human language in the control process, then, according to the language control rules formulated by the actual control experience, the fuzzy value of the output control quantity is obtained by fuzzy reasoning. Finally, the fuzzy value of the control quantity is converted into the precise control quantity that the actuator can play a role in the control.

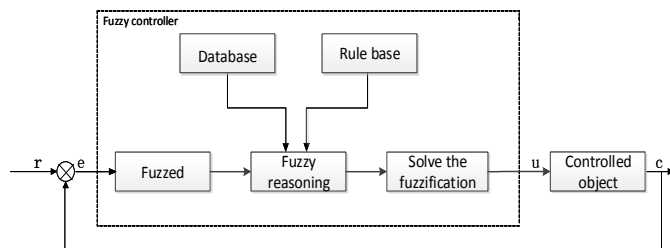


Fig. 2. Fuzzy control system structure

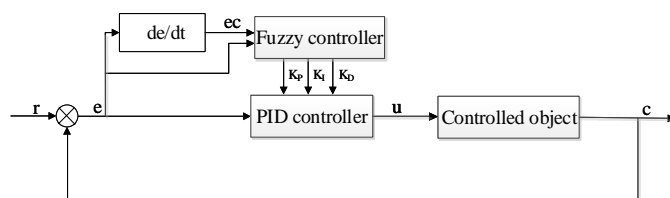


Fig.3. Fuzzy control system structure

As can be seen from the figure, the fuzzy controller consists of the following four parts.

1) *Fuzzy module.* The function of the fuzzy module is to change the value of the precise input and output related to the

control to the fuzzy language value through certain rules. The design step is actually the process of defining language variables on the domain.

2) *Knowledge base.* Knowledge base is composed of two parts: database and rule base. The database includes the definition of the fuzzy variable and the membership function. The rule base is mainly composed of fuzzy language control rules, the main basis is to sum up the practical experience in the control.

3) *Fuzzy reasoning module.* Fuzzy reasoning is based on fuzzy input and related data, the appropriate rules derived output fuzzy value.

4) *Defuzzification module.* The de-fuzzification is to convert the fuzzy output obtained by fuzzy reasoning into the precise control quantity to achieve the precise control of the actuator. At present, the conversion method widely used is the weighted average method and the maximum membership method.

B. Fuzzy self-tuning PID control

Fuzzy control has two very obvious advantages: first it can rely on people in the production practice of control experience, in which case the control task is not necessary to establish a precise model of the controlled object; Second, the fuzzy control is suitable for the control of the system with hysteresis, because of its stability, fast response, overshoot small. The shortcomings are obvious, it is difficult to summarize the fuzzy control rules.

Once the rule is established, it cannot be changed online, in addition to the fuzzy controller is not integral part, so the steady-state accuracy is not high.

Therefore, the combination of fuzzy control and traditional PID control, the use of fuzzy self-tuning PID parameters of the complementary advantages, so fast and accurate to complete the control task, the specific system structure shown in Fig.3. The fuzzy controller performs fuzzy reasoning based on the input quantities e and ec , outputs the precise PID control parameters K_P , K_I and K_D , and then controls the greenhouse temperature by the PID controller.

III. FUZZY SELF-TUNING PID CONTROL ALGORITHM

In this design, the design steps of the fuzzy module are as follows.

1) *Determine input and output variables.* When the control quantity is adjusted in the field, it is mainly controlled according to the actual output and output rate of change. Therefore, the error e and the error rate of change ec are taken as the input of the fuzzy module in this system. The fuzzy controller has three output controls, namely " ΔK_P ", " ΔK_I " and " ΔK_D ". In this system, set the temperature T , then $e = T$ set value- T current value, $ec = d(e \text{ current value}-e \text{ on the moment}) / dt$. Combined with the actual situation of field control, the range of positive and negative direction of the error e can not be symmetrical in the system design, otherwise the overshoot will be too large, Therefore, the value of the input value e is in the range of $[-4, 12]$, the range of the value of ec is

$[-1,1]$, the output value ΔK_P is in the range of $[-900,900]$, and the range of ΔK_I is $[-12,12]$, ΔK_D is in the range $[-6000,6000]$.

2) *Design language variable domain.* In this paper, we define the language variables "error E" and "error change EC" respectively on the domain of e and ec , and define the language variable "control quantity ΔK_P " on the domain of ΔK_P , ΔK_I , ΔK_D , "Control amount ΔK_I ", "control amount ΔK_D ". In the fuzzy controller, the domain of the language variable is usually a finite discrete integer.

In the fuzzy control system, the quantization factor $K_e = 1/2$, $K_{ec} = 6$, the scale factor $K \Delta K_P = 150$, $K \Delta K_I = 2$, $K \Delta K_D = 1000$. Fuzzy controller input

$$E = \text{round}(k_e \cdot (e - \frac{e_H + e_L}{2})), \quad (3)$$

$$EC = \text{round}(k_{ec} \cdot (ec - \frac{ec_H + ec_L}{2})). \quad (4)$$

◇ Represents rounding.

3) *Define the language value of the variable.* The fuzzy subset of E is negative, ZO (zero), PS (positive), PM (median), PB (positive)}, EC and ΔK_P , ΔK_I , ΔK_D {NB (negative), NM (negative), NS (negative), ZO (zero), PS (positive), PM (median), PB (positive)}.

4) *Determine membership function.* The two inputs of the fuzzy controller, the input range of the error E is moderate, and the input range of EC is too small. Therefore, both of them are suitable for the triangular membership functions with higher resolution. Since the value of the three outputs is magnified by a factor of 1000, the effect of the actual temperature on the need for rapid sensitivity, so the same use of three-star membership function. Triangle function is characterized by sharp shape, so the resolution is high, the output caused by the output changes are relatively large, with high control sensitivity.

5) *Establish fuzzy control rules.* PID parameter tuning, which takes into account the entire control process, K_P , K_I , K_D three parameters each play a role in the control process, and the effect of each in control. The key to fuzzy PID self-tuning control is to rely on the practical experience of the relevant control process, through the practice of continuous testing, modification, summary, and thus establish a good control performance and meet the control requirements of the control rules.

The control rules of ΔK_P . ΔK_P value directly related to the controller in the system response speed, can make the system bias smaller. In the early stages of adjustment, ΔK_P should take a large value to speed up the system response. In the middle of the adjustment, ΔK_P should be appropriately reduced, while ensuring the response speed to prevent excessive overshoot. In the late adjustment, ΔK_P value should be moderate or smaller, it is necessary to maintain the system stability should also prevent excessive overshoot.

The control rules of ΔK_I . ΔK_I in the control of the role of the system to reduce the steady-state error. In the pre-adjustment period, in order to effectively prevent the integral saturation and a large overshoot, therefore, ΔK_I value is smaller, usually take 0. In the middle of the regulation, in order to play the role of integral, it should be appropriate to increase the value of ΔK_I . In the later stage of regulation, the value of ΔK_I is large, which can effectively reduce the static error of the system.

The control rules of ΔK_D . ΔK_D is mainly used to control the dynamic operating characteristics of the system. In the early stage of adjustment, ΔK_D value is larger, in order to increase the differential effect, thereby reducing the final overshoot. In the middle of the adjustment, ΔK_D changes on the dynamic characteristics of relatively large, so ΔK_D value should be appropriate to reduce. In the later stages of regulation, the value of ΔK_D is small in order to effectively reduce the effect of disturbance.

6) *Solve the fuzzification.* The fuzzy output value is obtained by querying the fuzzy control rule table, and then the fuzzy control process is transformed into the precise control quantity to realize the control of the actuator. The fuzzy language variable of the output is obtained by querying the rule table, and then the fuzzy control can be obtained by determining the membership degree of the fuzzy language variable. In the process of solving the fuzzy process, the system uses the maximum membership method.

IV. THE EFFECT OF FUZZY PID CONTROL IN TEMPERATURE CONTROL

In the experiment, two methods of conventional PID control and fuzzy self-tuning PID control are taken respectively, and the final control effect is recorded respectively. Statistics the thermometer to display the data, recorded every 30 seconds, and according to this data to draw out the control effect map.

Fig.4 and Fig.5 show the temperature control effect of the conventional PID and fuzzy self-tuning PID control when the temperature is 30°C. It is found that fuzzy self-tuning PID control can effectively improve the oversampling problem of conventional PID control. This control method also shortens the time to stabilize, and the final result satisfies the requirement that the error be within $\pm 2^\circ\text{C}$.

At the same time as the insulating oil and room temperature difference between the larger heat dissipation is better, cooling time required significantly reduced.

Fig.6 and Fig.7 show the temperature control effect of the conventional PID and fuzzy self-tuning PID control when the temperature is 90°C. By comparing Fig.6 and Fig.7, it can be seen that fuzzy self-tuning PID control can appropriately reduce overshoot and improve dynamic characteristics over conventional PID.

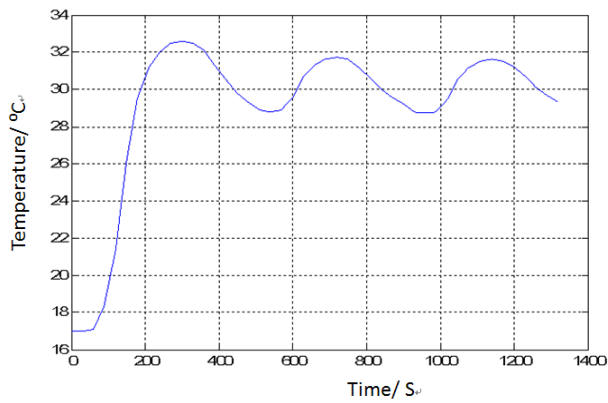


Fig.4. Effect diagram of PID control setting temperature 30°C

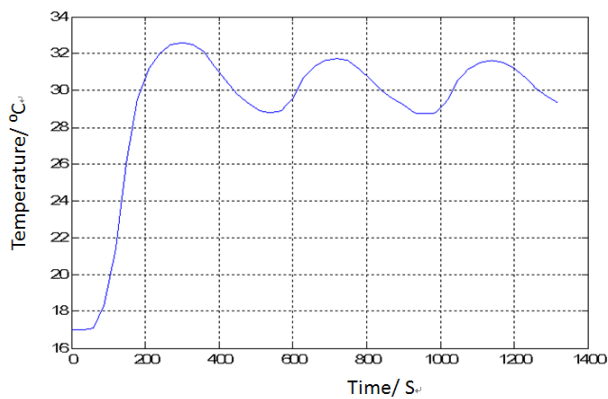


Fig.5. Effect diagram of fuzzy PID control setting temperature 30°C

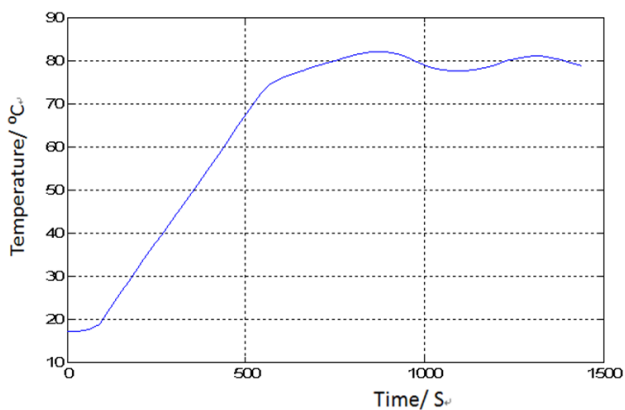


Fig.6. Effect diagram of PID control setting temperature 90°C

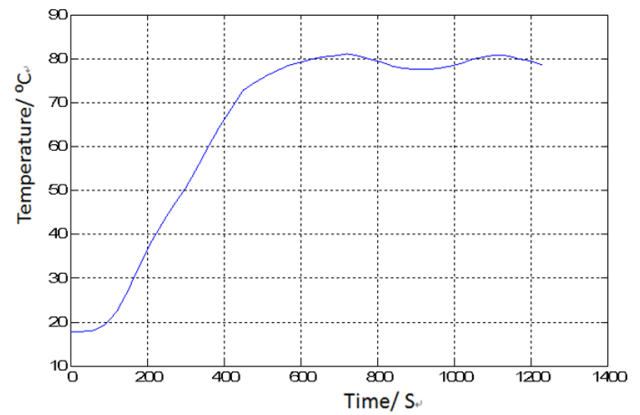


Fig.7. Effect diagram of fuzzy PID control setting temperature 90°C

V. CONCLUSION

Through the simulation analysis, the fuzzy control with fuzzy self-tuning PID control compared with the conventional PID control, with better robustness and reliability. It has a very important role in the effective control of temperature in the process of agricultural production and bio-fermentation.

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