Temperature Control System Research for Double Roller Heat Sealing Machine Based on the Fuzzy-PID Control

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Abstract. In order to ensure the pressing quality and production efficiency of the cotton insulation coating layer film, it is necessary to have an accurate temperature control for double roller heat sealing machine. Due to the characteristics of big inertia, pure time-delay, nonlinearity and imprecise mathematic model, Fuzzy-PID algorithm is proposed based on PLC system. The simulation results show that the proposed strategy improve the output characteristics. These excellent performances are a theoretical basis for further PLC programming.

Introduction

A double roller heat sealing is a heat sealing way, which is to meet the special processing requirements of the cotton insulation coating layer film production for aircrafts, such as non-standard and irregular shape. The rollers spin and the films make a level movement in the workbench. At the same time, the operating personnel guide a direction with the hands. The upper roller is a vertical pressure giver by a cylinder. The bottom roller is a driving part and the heating component. The nickel-chromium wire is adopted as a heating device which is coated on the heating roller rims.

On aircraft cotton heat sealing occasions, the temperature plays a key role on product quality. Thus, it is essential to improve working efficiency by real-time monitor and control[1]. Considering the heating device with hysteresis and nonlinearity, it is so difficult to establish accurate mathematical model that the high accuracy of temperature control is scarcely possible[2]. Based on S7-200 PLC system, Fuzzy-PID strategy is proposed. This method can improve the output characteristics with a better controller performance.

Control Systems

Hardware of the System

As a CPU module, S7-200CN series PLC are small programming controllers with the application of industrial production. This system adopt 226 series ordinary transistor input and output of the CPU with a built-in self-tuning of PID controller and a high performance.

Considering the rapid changing of the surface temperature, K type thermocouples has been adopted, which was launched as CO series by the OMEGA company. The great advantage of CO series is their simple structure with the adhesive type and the fast response, for example, the response speed is less than 30 ms. At the same time, the analog extended modules are all products of the Siemens company, such as the thermocouple signal acquisition module EM231 and the analog output module EM232. The former delivers the temperature signal which is collected by a thermocouple to CPU of S7-200, the latter will get the voltage signal from CPU which is used to control the heating power supply.
Fuzzy-PID Theory

The characteristics of Fuzzy-PID are the combination of all advantages which are only in two control ways respectively, such as the nonlinear control ability in fuzzy control and the simple structure, the high reliability in conventional PID[3].

The Figure 1 shows that the control system consists of a standard PID controller and a fuzzy controller, a two-dimensional structure of two input parameters and three output parameters.

The fuzzy controller makes a comparison of the expected temperature value with the temperature data collected by the temperature sensors. Then the temperature difference e(t) and the rate of change in temperature difference ec(t) are calculated. Thus the suitable increments are get through the basic process which includes the fuzziness of precision, fuzzy reasoning and defuzzification. Now there are three parameters, Kp=Kp0+ΔKp, Ki=Ki0+ΔKi, Kd=Kd0+ΔKd, where Kp0, Ki0 and Kd0 are the original conventional PID parameters[4].

Fuzzy-PID Controller

E, EC are the input language variables for Fuzzy controller, and the output variables consist of ΔKp, ΔKi, ΔKd. The language variables in their respective fields are all divided into seven fuzzy subsets[11], E=EC={NB,NM,NS,ZO,PS,PM,PB}, ΔKp=ΔKi=ΔKd={NB,NM,NS,ZO,PS,PM,PB}.

Actually, rules of the fuzzy controller are a set of multiple conditional statements and fuzzy relations representation from the input fields to the output fields. The fuzzy inference is the key to design a fuzzy controller, and the common Mamdani inference method[5] is adopted in this paper. Language format of the control rules are shown as follows:

R: if E=An and EC=Bn then U=Cn.                                                                                                (1)

Where U is a set including three increments, ΔKp, ΔKi, ΔKd.

In order to improve control performance, the Fuzzy controller adjusts the control parameters online according to the laws of the conventional PID on the base of stability of the system[6]. When the error is bigger, the main goal is to eliminate the error as soon as possible. When the error is small, the preferred factor is to prevent the overshoot.
Table 1. list of Fuzzy-PID control rules.

<table>
<thead>
<tr>
<th>E</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>ZO</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE</td>
<td>PS/NB/PB</td>
<td>NS/NB/PB</td>
<td>NB/NM/PM</td>
<td>NB/NM/PM</td>
<td>NB/NS/PS</td>
<td>NM/ZO/ZO</td>
<td>PS/ZO/ZO</td>
</tr>
<tr>
<td>NM</td>
<td>PS/NB/PB</td>
<td>NS/NB/PB</td>
<td>NB/NM/PM</td>
<td>NM/NS/PS</td>
<td>NM/NS/PS</td>
<td>NS/ZO/ZO</td>
<td>ZO/ZO/NS</td>
</tr>
<tr>
<td>NS</td>
<td>ZO/NB/PM</td>
<td>NS/NM/PM</td>
<td>NM/NS/PM</td>
<td>NM/NS/PS</td>
<td>NM/NS/PS</td>
<td>NS/ZO/ZO</td>
<td>ZO/PS/NS</td>
</tr>
<tr>
<td>ZO</td>
<td>ZO/NM/PM</td>
<td>NS/NM/PM</td>
<td>NS/NS/PS</td>
<td>NS/ZO/ZO</td>
<td>NS/PS/NS</td>
<td>NS/PM/NS</td>
<td>ZO/PM/NS</td>
</tr>
<tr>
<td>PS</td>
<td>ZO/NM/PS</td>
<td>ZO/NS/PS</td>
<td>ZO/NS/ZO</td>
<td>ZO/PS/NS</td>
<td>ZO/PS/NS</td>
<td>ZO/PM/NS</td>
<td>ZO/PB/NS</td>
</tr>
<tr>
<td>PM</td>
<td>PB/ZO/ZO</td>
<td>NS/ZO/ZO</td>
<td>PS/NS/PM</td>
<td>PS/NS/PM</td>
<td>PS/PM/NS</td>
<td>PS/PB/NB</td>
<td>PB/PB/NB</td>
</tr>
<tr>
<td>PB</td>
<td>PB/ZO/ZO</td>
<td>PM/ZO/ZO</td>
<td>PM/NS/PM</td>
<td>PM/NS/PM</td>
<td>PM/PM/NS</td>
<td>PB/PB/NB</td>
<td>PB/PB/NB</td>
</tr>
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</table>

Table 1 shows the table list Fuzzy-PID control rules according to the expert knowledge. Even though there is the certain universality in this table, the rules should be changed to add or delete on the basis of different objects and simulation models[7].

The input and output variables in their respective fields are all divided into thirteen fuzzy subsets, \{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}. Membership functions are all used timf, namely triangular membership functions. And, the adjacent membership degree is 0.5.

Considering that the reasoning calculation on-line can't meet the timeliness, it is necessary to calculate the off-line control strategy scale by programming, which is stored in the PLC as a file. According to the input of information, the system gets the control rules from the control strategy scale where it executes the query[8]. Limited to space, there is no longer the control strategy scale.

Simulations

The temperature model has characteristics such as big inertia and pure time-delay, the heating system can be approximately equivalent to a model in series with a large inertial link and a time-delay link. The control objective is shown as the following transfer function [9]:

\[
G(s) = \frac{\frac{1}{2000s + 1}}{s^{1000}}
\]
In the actual production line situation, the working temperature is 150°C with the temperature deviation ±5°C. It is a reasonable conception to assume that the working temperature starts from 0°C. The domain of the temperature difference is approximate [-155, 5]. Though the experiment is not carried out, the domain of the rate of change in temperature difference is [0.58, 0.5] by a simulation.

As shown in Figure 3, the quantitative factors are that $K_e=0.04$, $K_c=1.4$, the scaling factor $K_{pu}=0.02$, $K_{iu}=0.01$, $K_{du}=0.5$. With many trials, the initial value of PID parameters is calculated by Z-N method, where $K_{po}=1.2$, $K_{io}=0.04$, $K_{do}=4$.

Under the action of the step signal, the response curves of the conventional PID and the fuzzy PID control system are shown in Fig4. Due to the inaccuracy of system model, the simulation results are too idealistic, but it can be seen that the time of fuzzy-PID control to achieve steady state is obviously less than that of conventional PID, the overshoot is smaller and there is no steady-state error[10].
Programming of Fuzzy-PID

The function of PID closed-loop control is mainly to achieve the temperature control after the decision-making of the parameters. The key to achieving the closed-loop control function is to obtain the values of the increments $\Delta K_p$, $\Delta K_i$, $\Delta K_d$ because of the built-in PID programming module in S7-200. As an example, it is appropriate to adopt the sophisticated look-up table to determine the increment $\Delta K_p$. A data block should be defined which is used to store the fuzzy control lookup table of the $\Delta K_p$ control output value, and it can be called in the program segment[11].

![Figure 5. The control scale of $\Delta K_p$ in the data block.](image)

The content of the control scale is stored in order from the left to the right, from the top to the bottom in the data block with the initial address VD1000. According to S7-200 VD format storage space with 4 bytes, the address offset is calculated by the following equation: $4 \times 13 \times (E-1) + 4 \times (EC-1)$. Then address corresponding to the storage control scale is VD1000 + $4 \times 13 \times (E-1) + 4 \times (EC-1)$. By this method, the corresponding value of the control scale can be obtained.

The function of the PID instruction in Siemens S7-200 is to make use of the input information in the loop table and the configuration software[12]. The instruction format is: PID TBL, LOOP. TBL for the loop table address, is specified by the VB byte data; LOOP for the loop number, the range is 0 ~ 7. The loop table must be set before it is executed in the PID adjustment.

Conclusions

This paper proposes a Fuzzy-PID control strategy. The effects of conventional PID and Fuzzy-PID control are compared by simulation via Simulink module of Matlab. The results show that fuzzy PID avoids large overshoot, which saves the time of temperature regulation and has no stable temperature difference. So the Fuzzy-PID control can be applied to the double roller heat sealing machine system, which provides the theoretical basis for the subsequent PLC programming based on Siemens S7-200.

References


