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Research on Tension Control of Heat Sealing Film Packaging Machine based on Fuzzy PID

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Abstract

In order to avoid wrinkles during the heat sealing process of the film packaging machine, it is necessary to ensure that the tension of the film is constant, so as to synchronize the speed of the transverse sealing cutter with the feed speed of the bag film as much as possible. A tension control system based on fuzzy PID is proposed, which combines fuzzy logic to construct a fuzzy adaptive adjustment mechanism for online adjustment of PID controller parameters, thereby adjusting the tension of the film during transportation. The simulation experiment results show that the fuzzy PID controller has better dynamic response and stronger anti-interference ability. This control method can significantly reduce packaging edge wrinkles and greatly improve the packaging quality of bag items.

Keywords

Hot Sealing Film Packaging Machine; Tension Control; Fuzzy PID.

1. Introduction

The heat sealing film packaging machine needs to heat seal the plastic film during the packaging process, so it is necessary to ensure that the film is transported in a fixed length and heat sealed and cut at a suitable position. To achieve precise packaging bag length and smooth and exquisite bag appearance, it is necessary to ensure smooth and unbiased bag film supply, and constant bag film tension. Excessive tension can easily cause deformation, breakage, and tearing of the bag film. Insufficient tension in the bag film can easily cause wrinkling, slipping, and deviation, which in turn affects the quality of packaging bag making, heat sealing, and cutting, and reduces the quality of packaging bag shape. However, due to factors such as the non-linear decrease in the radius of the film roll, changes in packaging speed, uneven thickness and friction of the bag film, the tension of the bag film will change during the packaging process[1]. Therefore, precise and stable control is needed.

2. Modeling of Tension System for Heat Sealing Film

The mechanism of the heat sealing film transfer system during the packaging process is shown in Figure 1. The heat sealing film retraction system consists of a unwinding roller, a wind-up roller, a driving motor, a controller, and a tension detection device. The electric motor in the collection roller provides power for the heat sealing film, and the line speed of the heat sealing film is controlled by the winding controller. The tension of the heat sealing film is controlled by the unwinding roller controller. The specific method is as follows: first, a tension setting value r(t) is given. The tension sensor detects the tension signal of the bag film and converts it into y(t) through A/D conversion. The tension deviation e(t) is obtained by comparing it with the tension setting value. Based on the

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deviation and mathematical model, the controller performs control operations and provides control signals to the unwinding roller brake, thus completing tension closed-loop control.

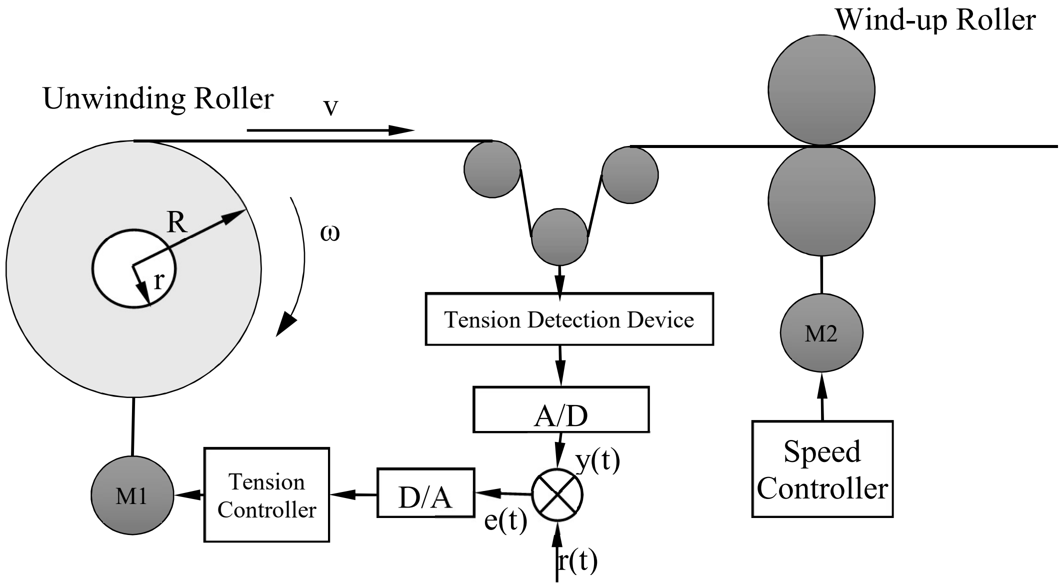

Figure 1. Mechanism diagram of heat sealing film transfer system

During the packaging process, as the packaging bag film is consumed, the radius R of the unwinding roll gradually decreases. The unwinding roll rotating at an angular velocity ω will inevitably cause a decrease in the linear velocity v, resulting in a change in the tension of the bag film[2,3]. Due to the non-linear variation of R and the presence of many interference factors in the tension control system, it is difficult to achieve stable and constant tension control[4,5].

Assuming the moment of inertia of the unwinding roller is J, JR is the moment of inertia of the axis of unwinding roller, ρis the density of the heat sealed film, ρ1 is the density of the axis of unwinding roller, b is the width of the heat sealed film material, R is the radius of the film, r is the radius of the axis of unwinding roller.

The moment of inertia of the unwinding roller J is:

$$J = J_R + J_r = \frac{1}{2}\pi b\rho(R^4 - r^4) + \frac{1}{2}\pi b_1\rho_1 r^4 = \frac{1}{2}\pi b\rho R^4 + J_0 \tag{1}$$

$J_0 = \frac{1}{2}\pi b(\rho_1 - \rho)r^4$ is a constant.

During the packaging process, the heat sealing film is continuously transported, causing the radius R of the heat sealing film to decrease continuously, as obtained by $\omega = \frac{v}{R}$.

$$\frac{d\omega}{dt} = \frac{1}{R}\frac{dv}{dt} - \frac{v}{R^2}\frac{dR}{dt} \tag{2}$$

Assuming the thickness of the heat sealing film is h, the amount of film released per unit time is:

$$hvdt = 2\pi RdR \tag{3}$$

By substituting formula (2), it can be obtained that:

ISSN: 2414-1895 DOI: 10.6919/ICJE.202501_11(1).0004

$$\frac{d\omega}{dt}=\frac{1}{R}\frac{dv}{dt}-\frac{hv^2}{2\pi R^3}\frac{dR}{dt}=\frac{2\pi}{h}\frac{d^2R}{dt}-\frac{hv^2}{2\pi R^3}\frac{dR}{dt} \tag{4}$$

The relationship between the tension F of the heat sealing film, the braking torque MR applied by the brake M1 to the shaft, the friction torque Mf, and the angular velocity ω of the heat sealing film shaft is:

$$\frac{d(J\omega)}{dt}=FR-M_R-M_f \tag{5}$$

The torque generated by the friction of the heat sealing film during transportation is relatively small and can be ignored, so:

$$\frac{d(J\omega)}{dt}=FR-M_R \tag{6}$$

By substituting formulas (1) and (4) into formula (6) and simplifying them, it can be obtained that:

$$F=\frac{M_R}{R}+(\frac{J_0}{R^2}+\frac{1}{2}\pi b\rho R^2)\frac{dv}{dt}+\frac{b\rho hv^2}{R} \tag{7}$$

According to formula (7), it can be concluded that the tension of the heat sealing film is related to the braking torque of the unwinding roller and the radius of the heat sealing film spool, provided that the size of the heat sealing film material is known and the speed of the winding roller is controlled.

3. Tension Control of Heat Sealing Film based on Fuzzy PID

3.1 Traditional PID Control

Traditional PID control has the advantages of simple structure, maturity, and easy implementation, and is widely used in the field of packaging equipment control. Assuming the target tension value for film transport is r(k) the tension sensor samples y(k), and e(k)is the deviation of the tension value at time k, that is:

$$e(k)=r(k)-y(k) \tag{8}$$

The traditional PID controller obtains the control output u(k) based on the superposition of the proportion parameter K_P, the integral parameter K_I,and the differential parameter $K_D$of the error e (k) of the controlled object. The control law is:

$$u(k)=u(k-1)+K_P[e(k)-e(k-1)]+K_Ie(k)+K_D[e(k)-2e(k-1)+e(k-2)] \tag{9}$$

3.2 Fuzzy PID Control Framework

If pure PID control is used, it usually leads to large overshoot and poor robustness in tension control, which cannot effectively overcome the lag of tension changes. The accuracy of tension control is greatly reduced, and the control effect is not ideal, which cannot meet the requirements of tension control for packaging heat sealing films[6-8]. Fuzzy control is based on expert knowledge and mature operational experience for logical reasoning intelligent control, which has strong robustness and applicability to complex control systems[9,10].

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In order to retain the advantages of traditional PID while enhancing its adaptability and robustness, the fuzzy PID control method was introduced to use fuzzy control rules for online real-time tuning of PID parameters, avoiding the repetitive and tedious adjustment of PID control parameters, and achieving precise adjustment of unwinding and rolling torque, improving the accuracy and stability of bag film tension control.

The framework of the fuzzy PID control system is shown in Figure 2.

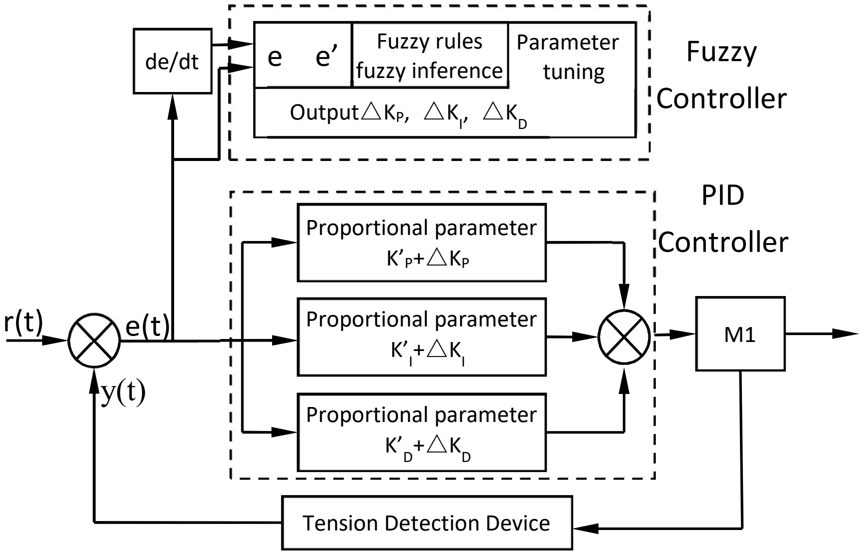

Figure 2. The framework of the fuzzy PID control system

3.3 Fuzzy Rules of Fuzzy PID Control

Using a two-dimensional fuzzy controller as a tool for PID parameter tuning, the deviation and rate of deviation between the heat sealing film tension and the set tension at any time are taken as input variables of the fuzzy controller. According to the fuzzy control rules and its inference, the language variables ΔK_P,ΔK_I,ΔK_D are output, and the tuning parameters K_P,K_I,K_D are corrected online in real time.

In order to simplify complex systems, a discrete domain of finite integers was used instead of the continuous domain of input and output variables, and was designed in the form of a control query table. In the tension control system of heat sealed film, it is required that the steady-state error of the system be within 5%. Therefore, the domain of $e(k)$ and $e'(k)$ is roughly taken as [-3-3], quantified as subsets {-3, -2, -1,0,1,2,3}. The corresponding 7-level fuzzy level is {NL, NM, NS, ZO, PS, PM, PL}, and each element in the subset represents: large negative bias, medium negative bias, small negative bias, zero, small positive bias, medium positive bias, and large positive bias. Similarly, the domain of ΔK_P is {-3, -2, -1,0,1,2,3}, and the quantization levels are {NL, NM, NS, ZO, PS, PM, PL}. Take the domain of argument {-2, -1,0,1,2} for $\Delta K_I$and Δ ΔK_D, with quantization levels {NL, NS, ZO, PS, PL}.

Based on the analysis of the tuning rules of PID parameters, the following assignment tables for fuzzy control rules have been developed, as shown in Tables 1-3.

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Table 1. Fuzzy assignment table of K_P

ΔK_P		$e'(k)$						
		NL	NM	NS	ZO	PS	PM	PL
$e(k)$	NL	PL	PL	PM	PM	PS	ZO	ZO
	NM	PL	PL	PM	PS	PS	ZO	NS
	NS	PM	PM	PM	PS	ZO	NS	NS
	ZO	PM	PM	PS	ZO	NS	NM	NM
	PS	PS	PS	ZO	NS	NS	NM	NM
	PM	PS	ZO	NS	NM	NM	NM	NL
	PL	ZO	ZO	NM	NM	NM	NL	NL

Table 2. Fuzzy assignment table of K_I

ΔK_I		$e'(k)$						
		NL	NM	NS	ZO	PS	PM	PL
$e(k)$	NL	NL	NL	NM	NM	NS	ZO	ZO
	NM	NL	NL	NM	NS	NS	ZO	ZO
	NS	NL	NM	NS	NS	ZO	PS	PS
	ZO	NM	NM	NS	ZO	PS	PM	PM
	PS	NM	NS	ZO	PS	PS	PM	PL
	PM	ZO	ZO	PS	PS	PM	PL	PL
	PL	ZO	ZO	PS	PM	PM	PL	PL

Table 3. Fuzzy assignment table of K_D

ΔK_D		$e'(k)$						
		NL	NM	NS	ZO	PS	PM	PL
$e(k)$	NL	PS	NS	NL	NL	NL	NM	PS
	NM	PS	NS	NL	NM	NM	NS	ZO
	NS	ZO	NS	NM	NM	NS	NS	ZO
	ZO	ZO	NS	NS	NS	NS	NS	ZO
	PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
	PM	PL	PS	PS	PS	PS	PS	PL
	PL	PL	PL	PM	PM	PM	PS	PL

$$\begin{cases} K_{\boldsymbol{P}} = K'_{\boldsymbol{P}} + \Delta K_{\boldsymbol{P}} \\ K_{\boldsymbol{I}} = K'_{\boldsymbol{I}} + \Delta K_{\boldsymbol{I}} \\ K_{\boldsymbol{D}} = K'_{\boldsymbol{D}} + \Delta K_{\boldsymbol{D}} \end{cases} \tag{10}$$

In the formula, K'_P, K'_I and K'_D are the initial PID parameters, ΔK_P, ΔK_I and ΔK_D are the three output parameters of the fuzzy controller. During the operation of the system, online parameter tuning can be automatically completed by querying the fuzzy rule table. Using the Mamdani minimax algorithm for fuzzy inference, the membership degree of the inference results was described using triangular membership functions.

4. Simulation Analysis

In order to verify the effectiveness of the fuzzy PID controller designed in the tension control of heat sealed films, Matlab was used for simulation, as shown in Figure 3. The initial parameters of PID control were set to K_P as 0.51, K_I as 0.35, and K_D as1.2. The initial tension value was set to 10 N. At t=30s, the tension value was modified to 5N to compare the system's response speed, overshoot, and stability. Added a negative disturbance with an amplitude of 1N at t=60s to simulate the effects of speed changes and other factors on tension control, in order to compare system reliability. Simulation data shows that the maximum overshoot of traditional PID control is 18%, the rise time is 2.1 seconds, the steady-state error is 0.7%, and the adjustment time is 8 seconds. The maximum overshoot of fuzzy PID control is 4%, the rise time is 2.3 seconds, the steady-state error is 0.5%, and the adjustment time is 7 seconds. It can be seen that compared to traditional PID control, fuzzy PID control has faster response speed, smaller overshoot, higher control accuracy, and better stability. When disturbed for 60 seconds, fuzzy PID control exhibits higher reliability and better robustness.

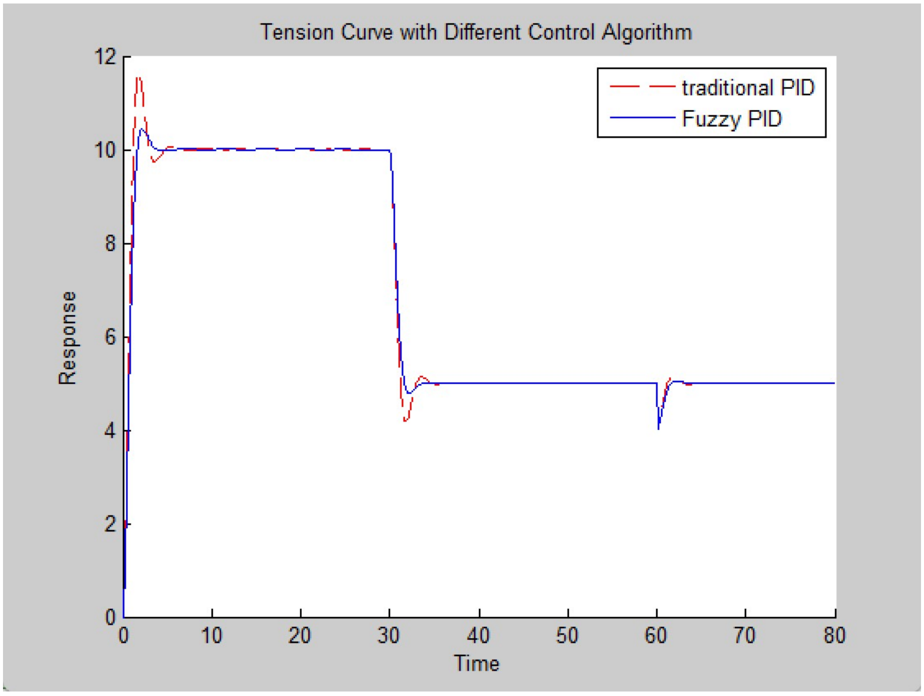

Figure 3. Comparison of simulation results between traditional PID and fuzzy PID

5. Conclusion

The article focuses on the need for controlling the tension of the heat sealing film on the unwinding roller of the heat sealing film packaging machine. Based on the working mechanism of the unwinding tension system, a mechanism model for controlling the tension of the heat sealing film has been established. A tension control method for a heat sealing film packaging machine was designed based on the nonlinear and multi disturbance characteristics of the system. Theoretical analysis and simulation experiments showed that the system design is feasible, which can improve the dynamic performance of the system and enhance its anti-interference ability. This control method can improve

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the tension accuracy of packaging heat sealing film to a certain extent and enhance the robustness of the tension control system.

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