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Intelligent Control of Basis Weight and Moisture Content in Paper-Making Process

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Abstract: Paper-making process is very complex and there exists long delay time. In this paper, we present three intelligent control strategies. These control strategies can control the system with long delay time efficiently. After putting them into use, we have obtained good control effects.

Keywords: delay time; PID; fuzzy logic control

纸厂定量/水分的智能控制研究

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摘要: 造纸生产过程中的定量/水分控制十分复杂,存在着大时延的问题.本文提出了三个智能控制算法用以解决大时延的问题.我们在实际中运用这些算法取得了较好的控制效果.应用和仿真结果说明了算法的有效性.

关键词: 时延; PID; 模糊逻辑控制

1 Introduction

Paper-making process has the characteristics of long delay time, strong nonlinearity in the process, time varying parameters and serious stochastic disturbance[1]. Many variables need to be controlled to guarantee the quality of the paper. Among these variables, the most important ones are paper's basis weight and moisture content. There are many factors affecting basis weight and moisture content, including density and flow of pulp, flow of white water, liquid level of headbox, density and flow of stuffbox, temperature and pressure of kiln, etc. These external and internal factors have fair indefiniteness.

Paper-making is a very complicated process of heat and mass transfer, whose mathematics model varies as the factors change. So it is difficult to establish the model of paper machine. To give a quantitative reference in the computer control, it is necessary to construct a rough model. Considering the complicated object of Yixing paper mill, we originally plan to use the identification method to construct the model of basis weight and moisture content. Because the inertia of the washing is too large to reflect the change of the pseudo-random signal and on the other hand the pseudo-random signal needs more time to simulate the system and might waste too much paper, we take step response method. Since there are more changes in traverse quantity, the fixed point sweeping test is used finally. In the test, the conditions are: basis weight is 250g/m^2, speed is 50 m/min, density is 2%, air pressure is 0.8Mpa, the sampling period is 1s. Under the disturbance of stock flow valve, the step response curve of the change of dry basis weight is obtained in [2]. After the test, we use our identification software to process the data gathered from the step response test and get the continuous and discrete transfer functions as below.

$$W(s) = 1.2e^{-100s}/(1+86s)(g/m^2/\%), \quad (1)$$

$$W(z) = \frac{(0.007+0.007z^{-1})z^{-100}}{(1-0.988z^{-1})(g/m^2/\%)}. \quad (2)$$

Based on the model, three intelligent control strategies are presented in Section 2. Section 3 gives the comparison of these control strategies.

2 Intelligent control strategies

Some intelligent control strategies have been studied as below according to the characteristics of the paper-making process.

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2.1 Intelligent batch PID controller

Due to the difficulties of establishing the model of paper machine on line and the model changes as the variation of speed and density, it is hard to use the ordinary control algorithm such as adaptive control or selftuning control. Considering these reasons, intelligent batch PID control algorithm is taken into use. In the algorithm the workers' operation experience is summarized, so the algorithm has the function of artificial intelligence. We separate a controlling period T_o into two parts in the algorithm, one is the controlling time t_c, another is the waiting time t_w, i.e. $T_o = t_c + t_w$, where $t_w \geqslant L$, L is the delay time. The control principle is to modify the PID parameters and the controlling time in real time according to the variations of the object's properties. Fig. 1 shows the block diagram of the system. In Fig. 1, K_1 is the feedforward control coefficient. It can control in advance when density and speed are varied. The decision block function is to judge the variations of the density and speed and to modify the PID parameters and the controlling time with the change of density and speed. When paper snapping happens or quantitative meter needs to be adjusted, the protection block function is to keep the valve still at its original position in case of mistaken operation.

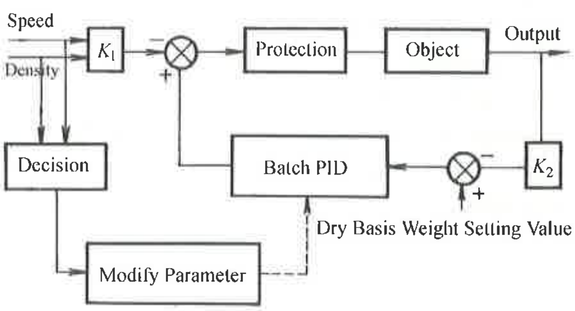


Fig. 1 The Block Diagram of Intelligent Batch PID

In Yixing paper mill, for corrugated paper of 127 g/m^2 ~ 250g/m^2, after the intelligent batch PID is used, basis weight is controlled in the range of +3% ~ −3% and moisture content is in the range of +2% ~ −1%.

2.2 Variable controlling period fuzzy controller

In the practical manual control process, an experienced operator always observes the size and direction of the error or the speed and trend of the change of the error. When the error is large and its change's speed is fast at the same time, the operator would increase the number of operations, i.e., shorten controlling period to eliminate the error quickly. On the contrary, when the error is very small and its change's speed is slow, the controller can be changed little or kept unchangeable, that is, the number of operations is decreased and the controlling period is extended. From the above analysis, we can see that the control methodology on the basis of variable controlling period demonstrates the ideas of man's operation. So fuzzy control theory is used to simulate variable controlling period strategy that man uses in the manual operation.

Fig. 2 shows the block diagram of the variable controlling period fuzzy controller. In Fig. 2, fuzzy controller contains two parts: fuzzy prediction and fuzzy decision. The control variable $\Delta u(t)$ and the output change $\dot{y}(t)$ are fed into the fuzzy prediction. The outputs of the fuzzy prediction $\hat{e}(t+L)$ and $\hat{\dot{e}}(t+L)$, which denote the estimation of the process state variables $e(t+L)$ and $\dot{e}(t+L)$ respectively, are the inputs of fuzzy decision. The output of the fuzzy controller is the controlling period T_c. Thus, by the functions of prediction and decision, fuzzy controller can tune the controlling period. The detailed analysis is given below.

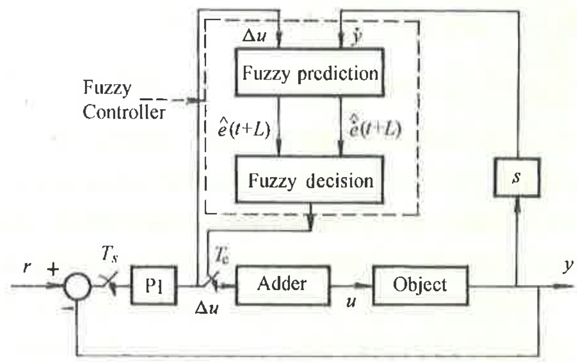


Fig. 2 The block diagram of variable controlling period fuzzy controller

1) Fuzzy prediction.

It is well known that if the object has pure delay time L, control action must be detected after delay time L. So it is necessary to estimate the state variable correctly after the delay time. Fuzzy prediction can be used to complete this function.

Assume that $y(t)$ is the system output at time t, $\Delta u(t)$ is the output of PI controller and $u(t) = \Delta u(t) + u(t-L)$, the derivation term $\dot{y}(t)$ is the change of the output $y(t)$. $\Delta\hat{y}(t)$, the estimation of $\Delta y(t)$, can be estimated by the input increment $\Delta u(t)$ and $\dot{y}(t)$, where $\Delta y(t) = y(t+L) - y(t)$. The estimation process can be simply described as $(\Delta u(t), \dot{y}(t)) \to \Delta\hat{y}(t)$. $\Delta\hat{y}(t)$ can be derived from the synthesis of fuzzy rules and fuzzy reasoning.

From the obtained $\Delta\hat{y}(t)$, based on the equations below, $\hat{e}(t+L)$ and $\hat{\dot{e}}(t+L)$, the estimation of the system state variables $e(t+L)$ and $\dot{e}(t+L)$, can be obtained.

$$\hat{e}(t+L) = e(t) - \Delta\hat{y}(t), \tag{3}$$

$$\hat{\dot{e}}(t+L) = \dot{y}(t) - 2\Delta\hat{y}(t)/L. \tag{4}$$

The detailed deduction can be got in [4].

2) Fuzzy decision.

From the above discussion, prediction process can be described simply as $\begin{bmatrix}\Delta u(t)\\ \dot{y}(t)\end{bmatrix} \to \Delta\hat{y}(t) \to \begin{bmatrix}\hat{e}(t+L)\\ \hat{\dot{e}}(t+L)\end{bmatrix}$, and then fuzzy rules table can be obtained to determine the size of controlling period from the obtained state variables $\hat{e}(t+L)$ and $\hat{\dot{e}}(t+L)$. By using fuzzy rules to simulate man's manual control operation stated before fuzzy prediction table and fuzzy decision table can be obtained with the fuzzy synthesis theory.

3) Simulation result.

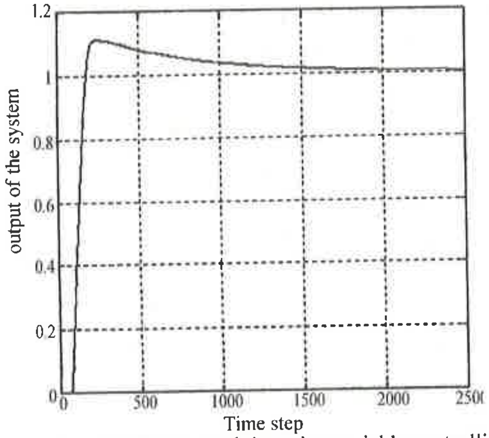
In the simulation we take the model as $y(t) = \frac{e^{-10s}}{(s+1)}u(t)$, where the delay time $L = 10\text{s}$, time constant $T = 1\text{s}$, sampling time $T_s = 0.1\text{s}$ and the input is step signal $r = 1(t)$. Fig. 3 shows the simulation result. It is shown that we obtain good control effect after using the variable controlling period fuzzy controller. In Fig. 3, abscissa is time axis which denotes the steps of sampling we take 2500 steps, i.e. 25s, in the simulations. Ordinate denotes the size of amplitude.

2.3 PIP Controller

Due to the limitation of space, the introduction of PIP controller is omitted here, which is discussed in [4].

3 Conclusion

In this paper we have presented three intelligent control algorithms. Generally these algorithms have advantages and disadvantages respectively[4]. We can take the relevant algorithm corresponding to the properties of the controlled object. It is our hope that this paper may inspire some of you to present more efficient algorithms to improve paper's quality and quantity.



Fim. 3 Simulation result by using variable controlling period fuzzy controller

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