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A Design for Ink-Supply Circulation System based on Advanced PID Control

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Abstract: This paper presents a well-designed ink-supply circulation system to guarantee adequate ink supply and maintain a stable negative pressure environment for large digital ink jet printing system. In order to make this system fit for a variety of situations, we put forward an adaptive control algorithm. At first, the least square method is used for the identification of the system. Then a fitness function is defined with the consideration of system error, control energy, rising time and overshoot, and genetic algorithm is used to search for the best PID parameters. The system we design has been applied to some industrial companies and has a good performance on digital printing.

Introduction

Nowadays, along with the development of printing technology and computer technology，the printing field has changed so much from traditional printing to digital printing. Low cost and the ability of continuous and stable running are the two demands of a large digital ink jet printing system[1]. Though an industrial printhead is very expensive, it has the advantages of excellent performance and long service life. To reduce the cost, ink-supply system should be separated from the printhead[2].

Ink-supply system provides ink and negative pressure environment for the printhead[3]. It is an important part of the digital ink jet printing system and has a significant influence on print effect. For one thing, we should guarantee adequate supply of ink. If the printhead is lack of ink, ink breaking phenomenon will appear when the printing system is running which will do harm to continuous production. For another thing, we should ensure accurate control of ink supply pressure. Variations in the vacuum can result in image defects. If the negative pressure is too low, ink will drop from the nozzles. If the negative pressure is too high, it is possible to cause the printhead to ingest air and stop firing. Therefore, adequate ink supply and stable negative pressure environment are the purposes in designing an ink-supply system[4,5].

With the printing speed of a large digital ink jet printing system getting faster and faster, traditional negative pressure ink-supply system cannot meet the new requirements. It is necessary to design a new ink-supply system-“ink-supply circulation system”. According to the major technological transfer project-“A design for large scale digital ink jet printing system”, this paper presents a well-designed ink-supply circulation system. It can not only guarantee adequate ink supply, but also maintain a stable negative pressure environment.

In practical application, the number of printheads and the type of ink are variable. Using the same PID parameters cannot get the ideal control effect. In order to make this ink-supply circulation system fit for a wide variety of situations, we put forward an adaptive control algorithm. At first, the least square method[6,7] is used for the identification of ink-supply circulation system. After getting the mathematical model, we set up a fitness function, and use genetic algorithm[8-9] to search for the best PID parameters.

A design for ink-supply circulation system

Compared with traditional negative pressure ink-supply system, ink-supply circulation system provides three main benefits to the print system. It allows for quicker priming times, helps maintain inks that are prone to sedimentation, and it keeps the printhead wetted when handling quick drying inks.

When designing a circulation system, it is important to maintain an outlet pressure from 10 inches H_2O to 50 inches H_2O depending on the jetting fluid, application and system. The key word is maintain. Whatever pressure is right for the application, it is important to make the circulation system to maintain that amount.

Fig.1 shows the ink-supply circulation system we design. It consists of three parts: ink supply, circulation and vacuum generator.

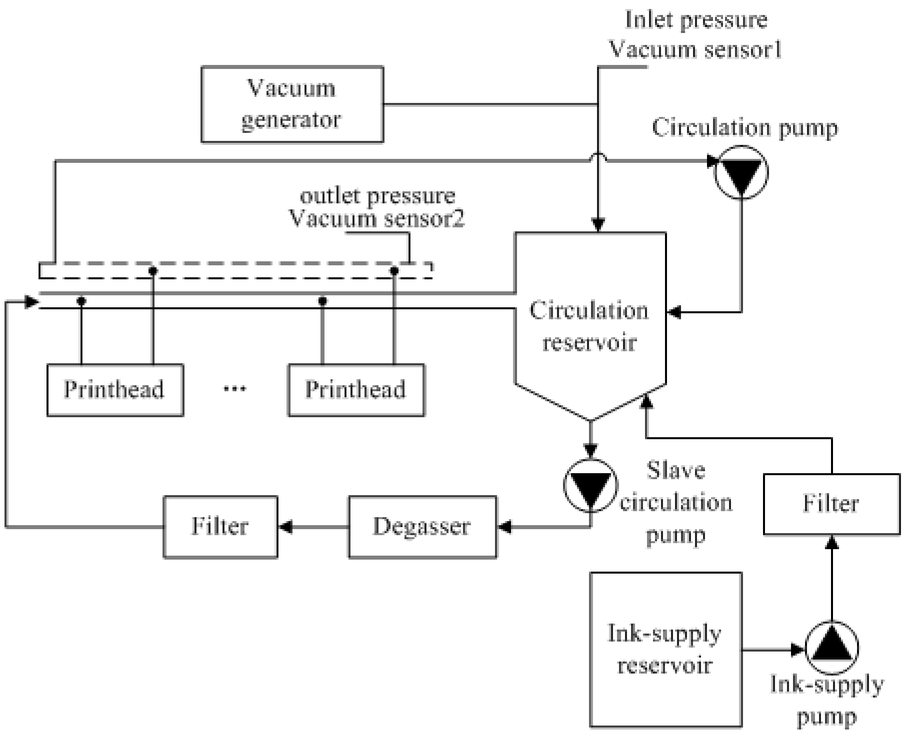

Fig.1 ink-supply circulation system

Ink supply is made of an ink-supply reservoir, an ink-supply pump and a filter. It is used to provide ink for the circulation reservoir. As the circulation reservoir empties, it signals the controller which causes it to refill from the ink-supply reservoir. Vacuum generator is used to maintain an inlet pressure at a certain level (30mbar). Circulation is the most important part of the system. It works in the following manner:

1) Slave circulation pump draws ink from circulation reservoir.
2) The ink passes through the degasser to get the air out.

3) It then passes through the filter to remove any impurities.
4) On one hand, the degassed and filtered ink returns to circulation reservoir. On the other hand, the ink fills the printhead.
5) The printhead prints then circulates additional ink to circulation reservoir through circulation pump.

By controlling the speed of the circulation pump, the circulation system can maintain an outlet pressure at the point we set. Fig.2 is the control block diagram.

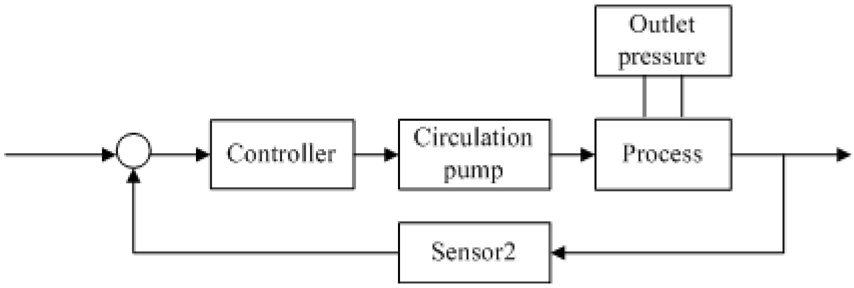

Fig.2 circulation control block diagram

System identification and parameter tuning

The ink-supply circulation system we design can not only provide adequate ink supply, but also maintain a stable negative pressure environment for printhead. However, in practical application, each time we change the number of printheads, the type of inks or the operating temperature, we have to adjust the PID parameters manually. In order to make this system be adaptive to a variety of situations, an advanced PID control algorithm shown as Fig.3 based on system identification and genetic algorithm is applied.

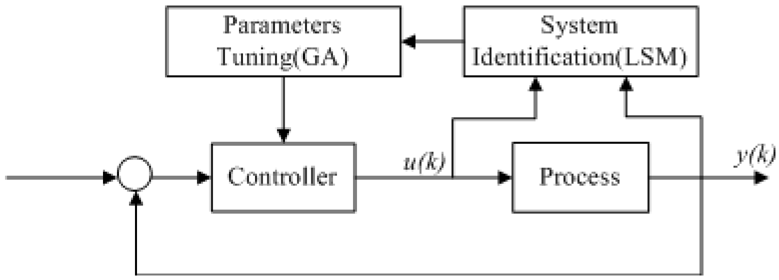

Fig.3 advanced PID control algorithm

Least Square Method. As it is very difficult to get the mathematical model of this system from the theory, system identification becomes the best choice. Consider a grey-box model shown as Fig.4:

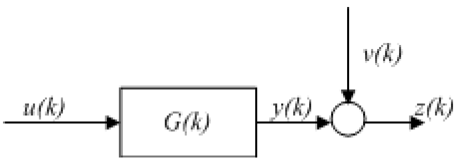

Fig.4 grey-box model

u(k) is the input of the system, *y(k)* is the output of the system, *z(k)* is the Observed value of *y(k)*, *G(k)* is the model of the system, *v(k)* is the measurement noise.

The differential equation of system is defined as

$$y(k) = -\sum_{i=1}^{n} a_i y(k-i) + \sum_{i=1}^{n} b_i u(k-i) \tag{1}$$

Then

$$z(k) = -\sum_{i=1}^{n} a_i y(k-i) + \sum_{i=1}^{n} b_i u(k-i) + v(k) = h(k)\theta + v(k) \tag{2}$$

Where $h(k) = [-y(k-1), -y(k-2), \cdots, -y(k-n), u(k-1), u(k-2), \cdots u(k-n)]$,

$\theta = [a_1, a_2, \cdots a_n, b_1, b_2, \cdots b_n]^T$.

Let $Z = [z(1), z(2), \cdots, z(m)]^T$, $H = [h(1), h(2), \cdots, h(m)]^T$, then we can get the system parameters as follows:

$$\hat{\theta} = (H^T H)^{-1} H^T Z \tag{3}$$

Genetic Algorithm. When getting the model of the system, the PID parameters can be tuned through genetic algorithm. With the consideration of system error *e(t)*, control energy $u^2(t)$, rising time t_u and overshoot, the fitness function[10] is defined as

$$J = \begin{cases} w_1 \int_0^\infty |e(t)|dt + w_2 \int_0^\infty u^2(t)dt + w_3 t_u & e(t) \geq 0 \\ w_1 \int_0^\infty |e(t)|dt + w_2 \int_0^\infty u^2(t)dt + w_3 t_u + w_4 \int_0^\infty |e(t)|dt & e(t) < 0 \end{cases} \tag{4}$$

where $w_1 = 0.95$, $w_2 = 0.05$, $w_3 = 2$, $w_4 = 100$.

Steps for GA:

Step1：Determine the search space of Kp, Kd, Ki and the length of encoding;

Step2：Generate initial population randomly consist of 50 individuals, set iteration number K=100;

Step3：k=1;

Step4：Evaluate the fitness of every individual in the current generation;

Step5：Generate the next generation by selection, crossover, mutation;

Step6：k=k+1; if k>K, go to step7; Otherwise, go to step4.

Step7：Termination. A solution is found that satisfies minimum criteria or fixed number of generations reached.

Result

Fig.5 shows the result of system identification. There are two observed signals, *u(k)* and *z(k),* where *u(k)* is the control signal and *z(k)* is the outlet pressure. The sample period is 0.01s. Assuming that the system is a three-order model, θ is estimated as

$\hat{\theta}$ = [-2.0478,1.3869,-0.3263,0.1731,-0.1918,0.0428]

The curve plotted with "*" shows the predictive value of the outlet pressure. It is very close to z(k), which indicates a good identification.

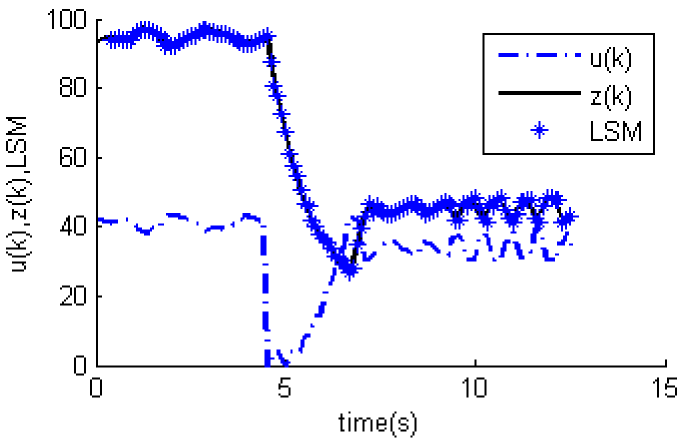

Fig.5 result of system identification

After getting the model of the ink-supply circulation system, PID parameters are tuned by genetic algorithm. Fig.6 shows the control effect with tuned PID parameters. It has the advantages of small overshoot and little response time.

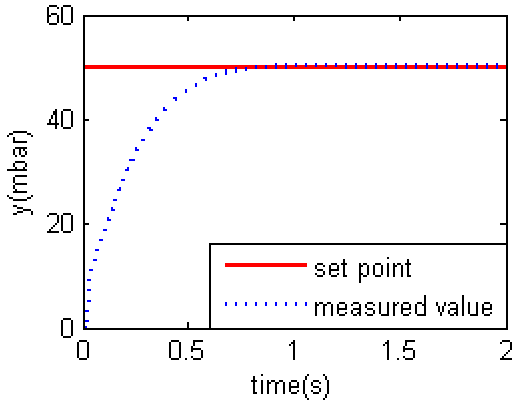

Fig.6 control effect with tuned PID parameters

So far, the ink-supply circulation system we design has been applied to some industrial companies and played an important role in digital printing. Fig.7 shows the ink-supply circulation systems in practice.

Fig.7 applications

Conclusion

This paper presents a well-designed ink-supply circulation system. It can not only guarantee adequate ink supply, but also maintain a stable negative pressure environment. What's more, this system is applicable to a variety of situations. It can drive from one to thirty printheads. In different cases, in order to get the ideal PID parameters, an advanced PID control algorithm based on system identification and genetic algorithm is put forward. After getting the measured value of the system, the model can be identified by least square method. With the consideration of system error, control energy, rising time and overshoot, a fitness function is defined. Finally, we can get the best PID parameters based on genetic algorithm. When applying this circulation system into practice, it has a better performance on print effect and plays an important role in digital printing.

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