그래비어 옵셋 프린팅 압력 제어 알고리즘 개발에 대한 연구

On a new approach for gravure/offset printing pressure control algorithm development using the full state feedback controller

*최경현[1], #탄충탄[1], 양봉수[2], 도양회[2], 김동수[3]

*K. H. Choi[1], #Tran Trung Thanh[1](thanhvi@hotmail.com), B. S. Yang[2], Y. H. Doh[2], D. S. Kim[2]

[1] 제주대학교 기계공학과, [2] 제주대학교 전자공학과, [3]한국기계연구원 나노융합기계연구본부

Key words : full state feedback controller, printing pressure, roll printing, back-stepping

1. Introduction

In recent years, there are many applications which employed roll-to-roll web technology for mass production such as web printing, papers machine, film processing, and textiles fabrics and so on to make cheaper production in shorter time. In order to improve the quality of product and the precision of roll to roll processing, many important aspects should be considered such as web tension, lateral error, printing pressure and so on. In recent years, applications of gravure/offset printing technology to make micro-level devices have been taken attention by many researchers and scientists. With the increasing demand about the applicability to web with micro-level thickness and accuracy of line printing, printing pressure control algorithms play an important roll in producing the product with high quality. Until now, almost all roll to roll printing system setups based on offline calculations, supplemented by trial and error procedures during operation [4]. In this paper, the goal is to develop the printing pressure control algorithm that controls the gap with micro-level precision between two rollers, maintains the precise web pressure and thickness, avoids the slippage and fast responds with disturbances. Thus, proposed pressure printing control algorithm development is based on eliminating the slippage and keeping gap at suitable distance. A mathematical model of roll printing pressure control system using the pneumatic system is proposed. By writing the system of dynamic equations in strict feedback form and applying the back-stepping theory, a full state feedback controller is obtained with gains that are determined optimally by genetic algorithm. A printing pressure control algorithm is given by using the proposed mathematical development and controller. The simulation results employed in Matlab/Simulink show the stability and high precision of the proposed algorithm

2. Mathematical model development

Figure 1 shows the model of offset printing pressure control system that consists of two air cylinders, nip roll, offset roll and ink roll. Cylinders with controlled valves are used to change pressure and move up and down nip roll to reference positions to make printing pressure at suitable level.

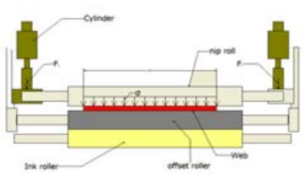
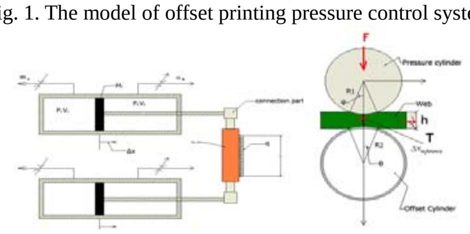


Fig. 1. The model of offset printing pressure control system



(a) (b)

Fig. 2. a) Model of roll printing pressure control system using the pneumatic system; b) Model of cross-section area of roll printing system

Figure 2a shows the model of roll printing pressure control system using the pneumatic system. Figure 2b shows the cross-section area of contact model between web and rollers. By the assumption about uniform nip pressure and uniform tension on cross-section of web and the independent action that the effect of nip pressure and web tension is independent. Thus, the deformation sum under vertical direction due to nip pressure will be the sum of two components. Because of symmetry of system, mathematical model of a cylinder and nip roll will be given. It is assumed that the air is ideal and the process is isothermal.

From the above considerations and using the elastic theory, Newton's law, and it is assumed that rollers are rigid body and have the same radius; dynamic equations are written as follows:

$$\Delta\dot{x}_1 = \Delta x_2$$

$$\Delta\dot{x}_2 = \frac{A_p p_{AB} - ([\sigma]R_1\varphi w - \frac{p_w}{2} + \mu\frac{T}{wh}) + K_F\Delta x_2}{M_s} \qquad (1)$$

$$\dot{p}_{AB} = -\frac{p_s A_p}{V_0/2}\Delta x_2 + \frac{K_2 p_s}{V_0/2}\frac{p_0}{\rho_0}u_v$$

And

$$\Delta x_{\mathrm{Re}\,f} = h - \frac{([F] + p_W/2)h}{ER_1\varphi w} - \mu\frac{T}{EW}$$

Where Δx_1 :The piston displacement; Δx_2 :The displacement speed of piston; K_2 :Valve coefficient; p_s :Supply pressure (p_{supply}); u_v : input voltage; V_0 :The total air volume; ρ_0 :The reference density; ρ_0 :Reference pressure; A_p :The cross-section area of cylinder; M_s :The sum of mass of piston, rod and half of nip roll; F_L :The external forces; F_{Fric} :The frictional force; F_{Load} : Force acts on the pressure roll; p_w : Gravity force of nip roll and connecting mechanisms; h : The thickness of web; R_1 : Radius of nip roll; μ : Poisson coefficient; T: web tension; $[\sigma]$: Allowable compression stress; w : The width of web; $\Delta x_{\mathrm{Re}\,f}$: Convenient gap between pressure and offset roll; E: Young module;

3. Full state feedback controller design

By applications of the back-stepping theory, the full state feedback controller of the dynamic equations of printing pressure control system (1) is given:

$$u_v = (-c_3(p_{AB} - \alpha_2) - a_4\Delta x_2 + \dot{\alpha}_2)/a_5 \qquad (2)$$

Where

$$\alpha_1 = -c_1(\Delta x_1 - \Delta x_{\mathrm{Re}\,f}) + \Delta\dot{x}_{\mathrm{Re}\,f}\,;\ \dot{\alpha}_1 = -c_1(\Delta x_2 - \Delta\dot{x}_{\mathrm{Re}\,f}) + \Delta\ddot{x}_{\mathrm{Re}\,f}$$

$$\ddot{\alpha}_1 = -c_1(a_1\Delta x_2 + a_2 p_{AB} + a_3 - \Delta\ddot{x}_{\mathrm{Re}\,f}) + \Delta\dddot{x}_{\mathrm{Re}\,f}\,;$$

$$\alpha_2 = (-c_2(\Delta x_2 - \alpha_1) - a_1\Delta x_2 - a_3 + \dot{\alpha}_1)/a_2\,;$$

$$\dot{\alpha}_2 = (-(c_2 + a_1)(a_1\Delta x_2 + a_2 p_{AB} + a_3) + c_2\dot{\alpha}_1 + \ddot{\alpha}_1)/a_2$$

$$a_1 = K_F/M_s\ ;\quad a_2 = A_p/M_s\ ;\quad a_4 = -\frac{p_s A_p}{V_0/2}\ ;$$

$$a_5 = \frac{K_2 p_s}{V_0/2}\frac{p_0}{\rho_0}\,;\ a_3 = -([\sigma]R_1\varphi w - \frac{p_w}{2} + \mu\frac{T}{wh})/M_s\,;$$

The parameters c_1, c_2, c_3 in full state feedback controller are positive gains that are determined by using the modified genetic algorithm

4. Printing pressure control system design

In industrial applications, almost all gravure/offset printing systems use the gap control technology. By supplementing by trial and error procedures during operation with each type of web materials, the suitable gap is given. In other cases, pressure feedback control system is designed by using only feedback signal receiving from load cell. In reality, the obtained results are poor and the accuracy is low. With the rapid development of sensor technology, digital computer and computation speed, PC-integrated control systems take a special attention in control system design. Figure 3 shows the block diagram of printing pressure control system using the full state feedback controller.

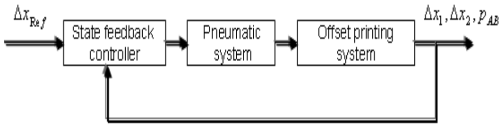


Fig. 3 The block diagram of printing pressure control system

In this algorithm, the load cell, encoder, position sensors are used to feedback the signals of position, displacement speed and pressure of nip roll. From the obtained signals, full state feedback controller generates the control input to adjust the valve of cylinder and makes system obtain the specification performance. Figure 5 shows the diagram of proposed printing pressure control algorithm of using the full state feedback controller in Matlab/simulink tool

5. Simulation

5.1. Simulation parameters

The application of the proposed algorithm of the full state feedback controller shown in the (2) and parameters: web thickness h=0.001 (m), Allowable compression stress $0.08 10^9$ N/m^2; Poisson's coefficient 0.38; web tension 40 N; Young's module $2.7 10^9$ N/m^2; web width 0.3 m; valve coefficient 0.01; frictional coefficient 0.005; supply pressure $7 10^5$ N/m^2; reference pressure 101325 N/m^2; cross-section area of cylinder 0.015386 m^2; the sum of mass of cylinder, rod and roll 3.5 Kg; total air volume of cylinder 0..0038465 m^3; the simulation outcomes can be implemented by using the Matlab/Simulink 8.0 tool. The optimal gains $c_1 = 450$; $c_2 = 300$, $c_3 = 100$ are obtained by using the modified genetic algorithm

5.2 Simulation condition

Simulation result is employed with web material that is PET with parameters above. Depending on the last equation (1) and above parameters; we can calculate the reference position between nip roll and offset roll as follow:

$$\Delta x_{Ref} = h - \frac{([F] + {p_W}/{2})h}{ER_1 \varphi w} - \mu \frac{T}{EW} = 0.0009575(m)$$

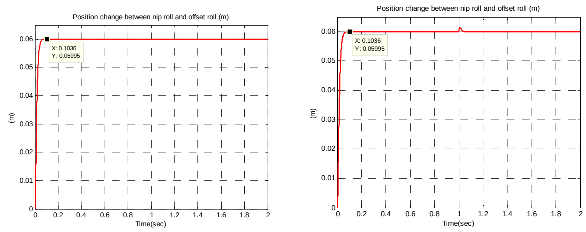
It is assumed that the distance between the center of nip roll and center of offset roll is $H_0 = 0.1(m)$ at initial time. So, we can determine the reference displacement of piston:

$$H_{reference} = H_0 - (2R + h - \Delta x_{Ref}) = 0.05995(m)$$

To estimate the effectiveness of proposed algorithm, simulation results are employed in two cases, the first one is done without the external load force and the second one is with the external load force that changes in time that is at time interval $0 \le t \le 1$, no contact between the nip roll and web happens and at time interval $1 \le t \le 2$, contact force between nip roll and web happens or

$$F_{Load} = \begin{cases} 0 & \text{if } 0 \le t \le 1 \text{ (second)} \\ [F] & \text{if } 1 < t < 2 \text{ (second)} \end{cases}$$

5.3. Simulation results



(a) (b)

Fig. 4 a) and b) Position change between nip roll and offset printing roll in two cases without external force and with external load force, respectively

From the above simulation results, some conclusions are made;

- With simulation result without external load force shown in figure 4a, the response of system reaches the stability and obtains the specification performances with no overshoot and steady-state error and settling time about 0.1 second.

- With simulation result external load force shown in figure 4b at time interval $0 \le t \le 1(s)$, no contact between the nip roll and web happens so response of system is the same with case without load. At time interval $1 \le t \le 2(s)$, nip roll and web have contact and so the external load force is generated. The response of system reaches the stability and obtains the specification performances with overshoot about 4% and settling time about 0.1 second

6. Conclusion

From the above simulation results, it is clear that the proposed algorithm of using the full state feedback controller can be obtained the desired performance specifications of the high precision and stability with large bandwidth under the presence of different conditions. With the rapid development of sensor technology, electronic devices, digital computer and computational speed, the proposed control algorithm of full state feedback controller can result in a control system with high precision and are useful for applications with high digital computational system.

Acknowledgement

본 연구는 지식경제부 중기거점 사업의 지원으로 수행되었습니다.

Reference

1. Alexander Kainz, Konrad Krimpelstatter, and Klaus Zeman, "FE – Simulation of thin strip and temper rolling process," ABAQUS Austria Users' Conference, November 24-25, 2003.
2. Dong-Teak Chung and Kee-Hyun Shin, "Transient wrinkling analysis of steel web rolling," IEEE IAS 2004, 886-890, 2004.
3. Won-Ho Lee, "Mathematical model for cold rolling and temper rolling process of thin steel strip," KSME International Journal, Vol. 16, No. 10, pp. 1296-1302, 2002.
4. David R. Roisum, "Nip impression," Finishing technology, Inc. Neenah, WI 54956.