A LATERAL CONTROL ALGORITHM FOE ROLL-TO-ROLL WEB SYSTEM BASED ON BACK-STEPPING APPROACH

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Keywords: roll-to-roll, lateral control, back-stepping controller**.**

Abstract

Roll-to-roll based manufacturing plays an important role in producing devices at high speed with lower production cost in printed electronics and publishing industry. Web lateral control is one of the most important factors in improving the quality of product and contributes a considerable point in making devices at micrometer-level accuracy. In recent years, most algorithms proposed for web lateral control base on the Shelton's model for designing the feedback control system using the PI controller. Experimental results showed that the existing models do not fully describe the characteristics of the lateral dynamics for some typical operating conditions and so result in poor control algorithms. In this paper, a new lateral control algorithm is proposed for web lateral control system based on back-stepping approach. The outcome of this study proves the reliability throughout simulation results in Matlab/Simulink and comparison with the algorithms based on the existing results.

1. Introduction

In the last decades, 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. Especially, RFID and printed electronics use the principle of roll-to-roll manufacturing to make devices at high speeds for lower cost will have a big impact on the printed electronics and publishing industries. Several developments pushed the burgeoning printed electronics industry and up to now roll-to-roll system technology is seen as the key to producing flexible electronic components, such as organic thin film transistors and other applications. In order to increase the quality of products and accuracy of roll-to-roll processing, many control problems are to be considered such as tension and velocity control, lateral control, printing pressure control and register control. In

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the previous work, an algorithm for roll-to-roll web tension and velocity control system proposed by using the back-stepping controller results in the high precision and stability. Until now, almost web lateral guide products available on the market depend on the Shelton's model and design the feedback control system of using the PI control. However, the existing approach has many limitations proven [1] [6]. In recent years, many researchers take attention in developing the mathematical model and algorithm for web lateral control system [1] [2] [5] [6]. Experimental results showed that the existing models do not fully describe the characteristics of the lateral dynamics for some typical operating conditions and a mathematical model is proposed by developing system identification using a well-know Least Square method [1]. A partial differential equation for the lateral motion of a web conveyance system is derived by modeling the web as a viscoelastic beam under axial tension and the analytical frequency domain model is used to design feedback compensation strategy [7]. The web guide are modeled by using the geometrical relations of guide ignored the mass and stiffness of web and a PID controller is proposed with gains tuned by the Ziegler-Nichols method [11]. With the increasing demand of the accuracy with micro-level and rapid development of digital computer and sensor technology, the existing algorithms are not useful for application. In this paper, a precise lateral control algorithm is proposed for web lateral control system based on the development of mathematical model and a lateral controller design using the back-stepping approach. The result of this study proves the precision and reliability throughout simulation on Matlab/Simulink and is useful for digital control system

2. Mathematical model

The problem of modelling the lateral web dynamics was first developed by Campbell in 1958 and the study of lateral web dynamics was advanced greatly by Shelton. By considering the web as an Euler beam and assumptions of web as no mass and lateral stiffness, the lateral velocity of web is shown in equation (1) by stating that the rate of lateral movement of the web edge is proportional to the difference of the angle of deviation from perpendicularity between the web and roller and the velocity of web [1].

$$\frac{dy_L}{dt} = -V(\theta_r - \theta_L) + \frac{dz}{dt} \tag{1}$$

Where

y_L : The lateral web position at the downstream roller

θ_r : The roller angle measured from the y-axis

θ_L : The web angle measured from the x-axis

Z: The lateral position of the roller

V: The velocity of web

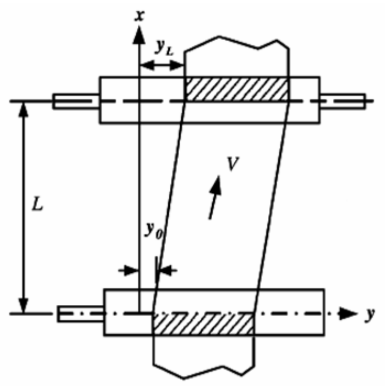

Fig. 1. The first-order model of lateral movement of web

Figure 1 show the lateral movement of web with two parallel rollers. Under the assumption of two fixed rollers and the initial lateral displacement of web y_0 . The equation (1) is written in the following first-order model:

$$\frac{dy_L}{dt} = --V\frac{(y_L - y_0)}{L} \tag{2}$$

Where L is the distance between two rollers

Until now, the equation (2) is used extensively to design the web guide system. Experimental results showed that the existing models do not fully describe the characteristics of the lateral dynamics for some typical operating condition [1]. In this paper, a new mathematical model is proposed based on the idea that the lateral displacement of web is caused by the direction change of web velocity and tension due to the disturbances such as out of roller alignment, steering roller, and so on. Figure 2 and figure 3 show the lateral displacement of a moving web and a web element created by partitioning from a moving web respectively.

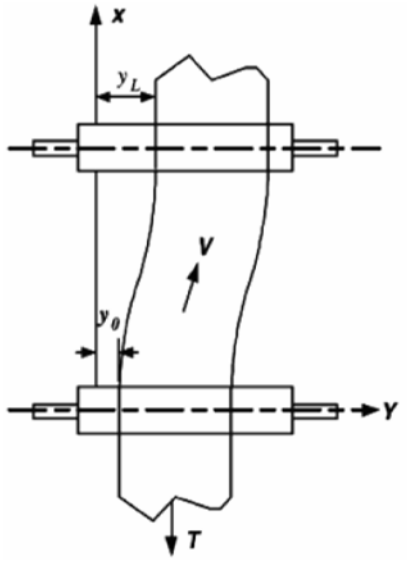

Fig. 2. Lateral displacement of a moving web

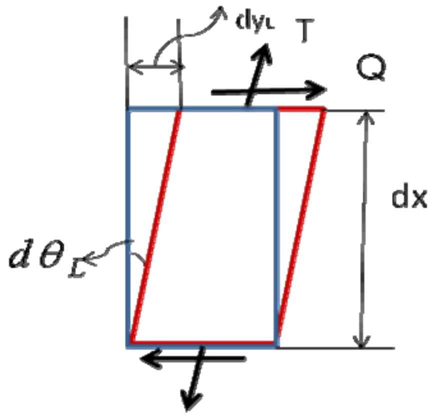

Fig. 3. Web element of lateral displacement

Under the assumption of small deformation, the following expression is implemented from the fig. 3.

$$tgd\theta_L \approx d\theta_L = \frac{dy_L}{dx} \quad (3)$$

The velocity of a moving web is given by the equation:

$$\frac{dx}{dt} = V \quad (4)$$

Combining the equations (3) and (4), the lateral displacement of a moving web is written as follows:

$$\frac{dy_L}{dt} = Vd\theta_L \quad (5)$$

Using the elastic theory, it is assumed that the shear stress on cross-section of web is constant; the lateral dynamics of a moving web is written in form:

$$\frac{dy_L}{dt} = -V\frac{T}{FG}\frac{(y_L - y_0)}{L} + \frac{dz}{dt} \quad (6)$$

Where

T: web tension

F: the cross-sectional area of web

G: Young module of shear deformation

Fig. 4. Offset pivot guide

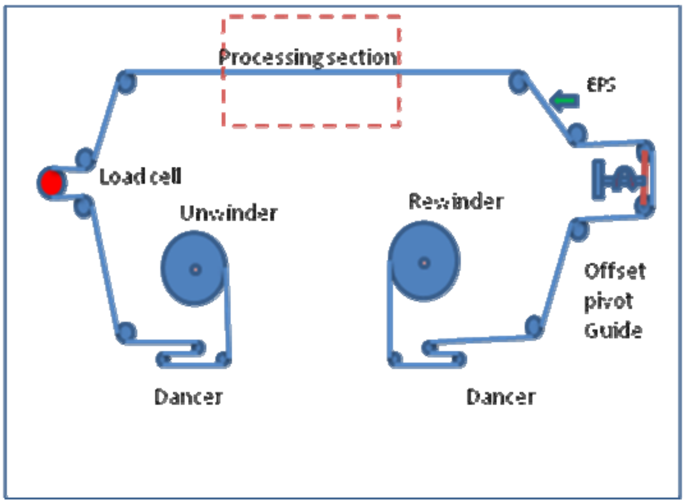

Fig. 5. The model of lateral control system

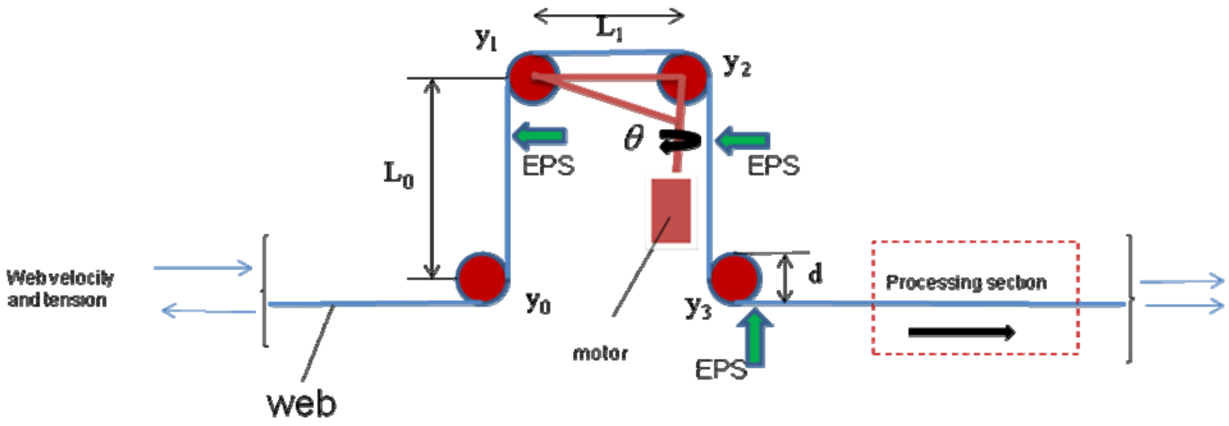

Fig. 6. The model of offset pivot guide

Figure 4 and figure 5 show the offset pivot guide for web lateral control and the model of lateral control system using offset pivot guide mechanism. Figure 5 presents the model of offset pivot guide that consists of the step motor generating the control angle, the edge position sensors (EPS), and pivot mechanism with parameters shown in Fig. 6.

Using the mentioned results, the web dynamics of offset pivot guide is written in form:

$$\frac{dy_3}{dt} = -V\frac{T}{FG}\frac{(y_3 - y_2)}{L_0} \quad (7)$$

$$\frac{dy_2}{dt} = -V\frac{T}{FG}\frac{(y_2 - y_1)}{L_1} + k\theta \quad (8)$$

Where

θ: The control angle that is generated by the stepping motor in Fig. 6.

y_1 : The disturbance due to the external acts.

Using the idea of lateral tracking and back-stepping approach for the system of equations (7) and (8) results in the back-stepping controllers (9) that has the high precision and stability proven in [13].

$$\theta = \frac{1}{k}(-c_2(y_2 - \alpha) - k_2 y_2 + k_1 y_1 + \dot{\alpha}) \quad (9)$$

Where

$$\alpha = \frac{1}{k_1}(c_1(y_3 - y_{ref}) + k_1 y_3) \quad , \quad \dot{\alpha} = (c_1 + k_1)(y_3 - y_2)$$

$$k_1 = \frac{VT}{FGL_0}, \; k_2 = \frac{VT}{FGL1}, \; k = \frac{VTL_p}{FGL_0}$$

y_{ref} : The desired tracking value of lateral displacement of a moving web.

The positive definitive constants c_1, c_2 can be changed to satisfy the performance specifications.

3. **Web lateral control algorithm**

Figure 7 shows the diagram of lateral control system of using the back-stepping controller. In this diagram, the lateral control system uses the offset pivot guide mechanism, the EPS and a step motor. The edge position sensors put at the position presented in fig. 6 determine the lateral displacements at rollers. Depending on these signals and back-stepping controller (9), the step-motor generates the angle θ that eliminates the disturbance. With the rapid development of digital computer and sensor technology, it is clear that the proposed model of lateral control system is useful for building the integrated controlsoftware.

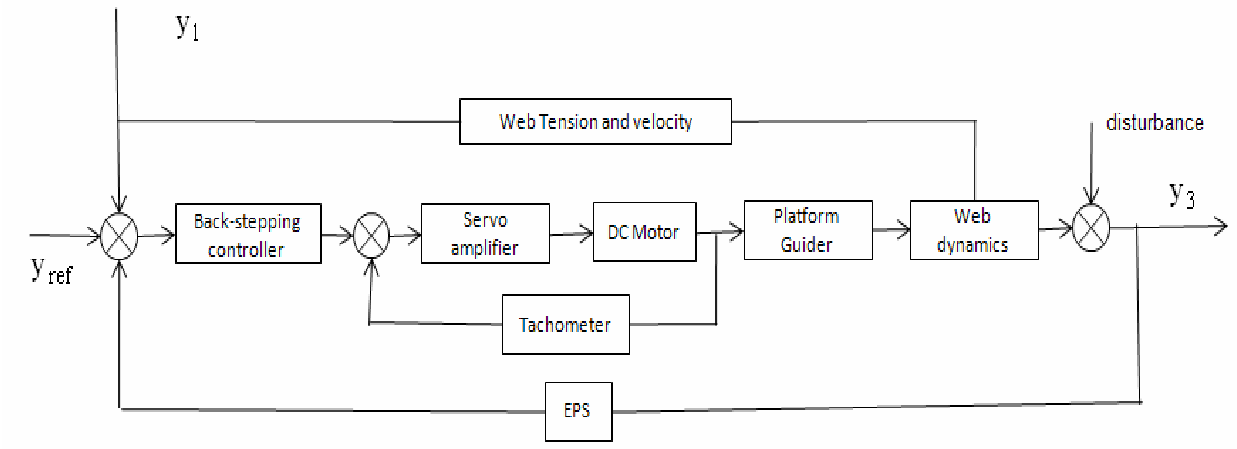

Fig. 7. The diagram of lateral control system using the back-stepping controller

4. Simulation

A. Simulation set-up

The simulation parameters of web lateral control system are shown in table I. The simulation condition is set up with the zero initial conditions, the desired web lateral displacement $y_{ref} = 0$. In order to observe the effectiveness of proposed algorithm of using back-stepping controller, the sinusoidal disturbance is employed at y_1. Two cases will be implemented. The first one uses two EPSs to determine the lateral displacement of y_2 and y_3. The second one uses three sensors to determine the lateral displacements of y_1, y_2 and y_3. The following is simulation results:

Table I. Simulation data

Parameters		values	units
Width of web		0.33	m
Thickness of web		14	μm
Elastic module of web		398	kg/mm^2
Operating tension of web		3,5	Kgf
Operating speed of web		3	m/s
Span length L0		0.8	m
Span length L1		0.381	m
Lp		0.457	m
The sinusoidal disturbance	Frequency	2	Hz
	Magnitude	0.2	cm
c_1		500	
c_2		500	

Case 2: Simulation results with operating tension T=5 kgf, operating speed V= 3 (m/s) and the use

B. Simulation results

Case 1: Simulation results with operating tension T=3 kgf, operating speed V= 3 (m/s) and the use of two EPSs. In fig. 8, the red-coloured line presents the disturbance and the other shows the y_3 lateral displacement of web.

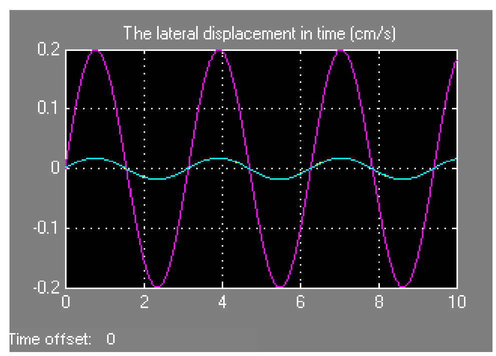

Fig. 8. The lateral displacement of web

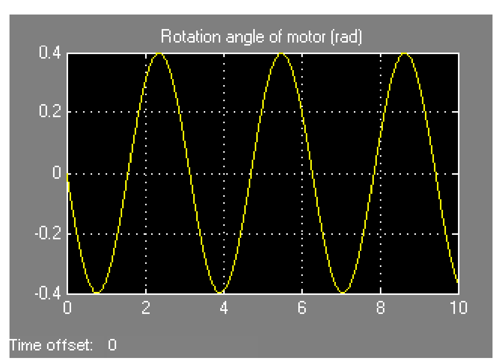

Fig. 9. The rotation angle of motor

of two EPSs. In fig. 10, the red-coloured line presents the disturbance and the other shows the y_3 lateral displacement of web.

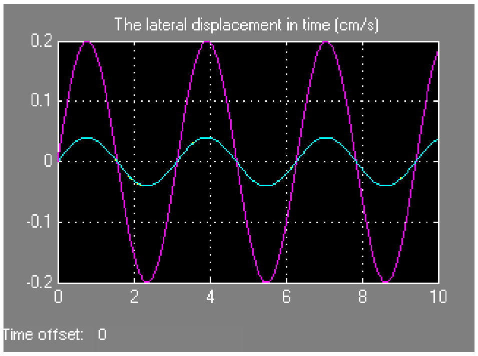

Fig. 10. The lateral displacement of web

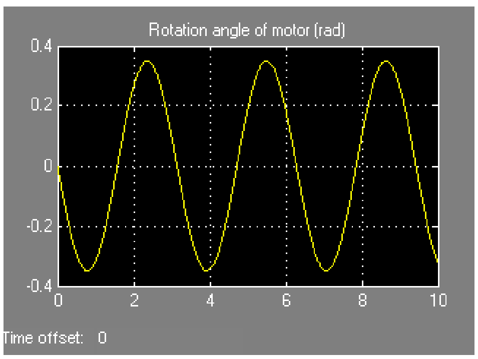

Fig. 11. The rotation angle of motor

Case 3: Simulation results with operating tension T=3 kgf, operating speed V= 3 (m/s) and the use of three EPSs. In fig. 12, the red-coloured line presents the disturbance and the other shows the y_3 lateral displacement of web.

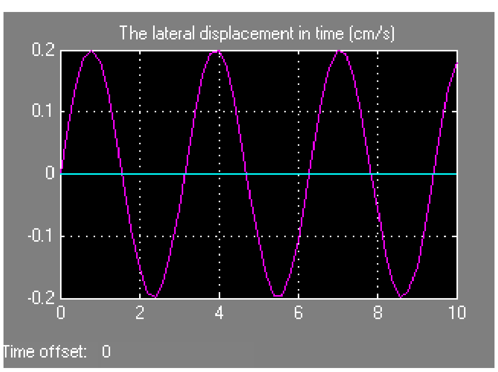

Fig. 12. The lateral displacement of web

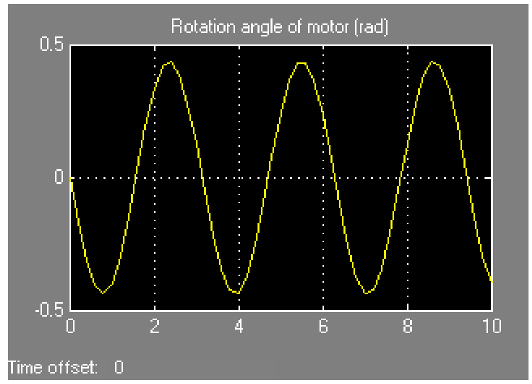

Fig. 13. The rotation angle of motor

From the above simulation results and the existing algorithm, the following comments are made:

- The obtained back-stepping controller results in the high precision and stability.
- The performance of disturbance rejection of algorithm mentioned [1] is improved more than 50 % that of PI controller. The proposed algorithm with using two EPSs can eliminate more 90 % that PI controller and eliminate completely if three EPSs are used.
- The lateral displacement of web is affected by web tension shown in fig. 8 and fig. 10. It is clear that the classic model having no information about tension is not convenient.

5. Conclusion

Nowadays, roll-to-roll manufacturing technology to make devices at high speeds for lower cost has a big impact on the printed electronics and publishing industries. Web lateral control algorithm plays an important role in improving the quality of product. In recent years, almost algorithms for web lateral control system base on the Shelton’s model to design the PI controller. By doing experiments, it is clear that the existing models do not fully describe the characteristics of the lateral dynamics for some typical operating conditions and the PI controller has certain limitations.
In this paper, a new mathematical model is proposed based o the idea that the lateral displacement of web is caused by the direction change of web velocity and tension due to the disturbances. Combining the idea of lateral tracking and back-stepping approach, the back-stepping controller is designed and a web lateral control algorithm is proposed based on the development of mathematical model and the back-stepping controller. The aforementioned simulation results prove the precision and reliability of the proposed algorithm.

6. Acknowledge

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