Decentralized PI Controller for Multimotors Web Winding System

Bousmaha Bouchiba, Abdeldjebar Hazzab, Hachemi Glaoui, Fellah Med-Karim, Ismaïl Khalil Bousserhane, Pierre Sicard

Abstract:
Web winding systems allow the operations of unwinding and rewinding of various products including plastic films, sheets of paper, sheets, and fabrics. These operations are necessary for the development and the treatment of these products. Web winding systems generally consist of the same machine elements in spite of the diversity of the transported products. Due to the wide rang variation of the radius and inertia of the rollers the system dynamic change considerably during the winding/unwinding process. Decentralized PI controller for web tension control and linear speed control are presented in this paper. The PI control method can be applied easily and is widely known, it has an important place in control applications. Simulation results show the effectiveness of the proposed linear speed and tension controller for web winding multi motors systems.

Keywords: *multi motors web winding system, PI controller, tension control, linear speed control*

1. Introduction

Many types of materials are manufactured or processed in the form of a sheet or a web (textile, paper, metal, etc.) which then couples the processing rolls and the associated motor drives. The drives are required to work in synchronization to ensure quality processing and rewinding of the product. Tension is a very important web manufacturing and process setting. If severe tension variations occur, rupture of the material during processing or degradation of product quality can occur, resulting into significant economic losses due to material loss and reduced production rate. Therefore, in order to minimize a potential loss, the need arises to adequately control the tension within a predefined range in a mo-ving web processing section. Henceforth, due to their importance in industry, tension control problems have drawn the attention of many researchers. One problem is the establishment of a proper mathematical model. In [1], a mathematical model of a web span is developed, but this model does not predict the tension transfer. This problem was addressed in [2] and [3], with the assumption that the strain in the web is very small. However, the form of the nonlinear and coupling terms in the model are not always convenient for controller design so that other model structures, with comparable precision, are desirable. Several control strategies have been suggested to maintain quality and reduce sensitivity to external disturbances, including centralized multivariable control schemes for steel mill applications

[4], [5] and an H∞ control strategy to decouple web velocity and tension [3], [6]. Also, for tension regulation in a web transport system, [7] proposed a control method based on a unique active disturbance rejection control (ADRC) strategy, which actively compensates for dynamic changes in the system and unpredictable external disturbances. In [8] and [9], Port-Controlled Hamiltonian with Dissipation (PCHD) modeling is considered to develop stabilization strategies with a physical interpretation and motivation of the control action, interpreted as the realization of virtual dampers added to the system, which resulted into a type of dual action controller with velocity feedback and velocity error feedback terms. Some limited improvements were obtained in disturbance rejection properties and robustness with respect to some parameter variations. The conventional PI control dominates industry, it is simple and easy to implement [15]. Tuning of PI controllers is intuitive and is well accepted by practitioners. PIs can at most achieve a compromise in performance in terms of system response speed and stability, and this approach becomes insufficient at the increasingly high web velocities demanded by the industry and with thin or fragile materials. Nonlinearities that appear at high velocities, disturbance rejection properties and robustness to some parameter variations must be accounted for by the controller. A decentralized nonlinear PI controller is proposed to respond to this demand. The model of the winding system and in particular the model of the mechanical coupling are developed and presented in Section 2. Section 3 shows the controllers design for winding system. Section 4 shows the Simulation results using Matlab Simulink. Finally, the conclusion is drawn in Section 5.

2. System model

In this system, the motor M1 carries out unreeling and M3 is used to carry out winding, the motor M2 drives two rollers *via* gears "to grip" the band (Fig. 1). The stage of pinching off can make it possible to isolate two zones and to create a buffer zone [8, 9]. The objective of these systems is to maintain the linear speed constant and to control the tension in the band.

The used motors are three phase induction motors type which each one is supplied by an inverter voltage controlled with Pulse Modulation Width (PWM) techniques. A model based on circuit equivalent equations is generally sufficient in order to make control synthesis. The electrical dynamic model of three-phase Y-connected induction motor can be expressed in the d-q synchronously rotating frame as [13]:

$$\frac{di_{ds}}{dt} = \frac{1}{\sigma \cdot L_s}\left(-\left(R_s + \left(\frac{L_m}{L_r}\right)^2 \cdot R_r\right)\cdot i_{ds} + \sigma L_s \omega_e i_{qs}\right.$$

$$\left. + \frac{L_m \cdot R_r}{L_r^2}\cdot \varphi_{dr} + \frac{L_m}{L_r}\cdot \varphi_{qr}\cdot \omega_r + V_{ds}\right) \quad (1)$$

$$\frac{di_{qs}}{dt} = \frac{1}{\sigma \cdot L_s}\left(-\sigma L_s \omega_e i_{ds} - \left(R_s + \left(\frac{L_m}{L_r}\right)^2 \cdot R_r\right)\cdot i_{qs}\right.$$

$$\left. - \frac{L_m}{L_r}\cdot \varphi_{dr}\cdot \omega_r + \frac{L_m \cdot R_r}{L_r^2}\cdot \varphi_{qr} + V_{qs}\right) \quad (2)$$

$$\frac{d\varphi_{dr}}{dt} = \frac{L_m \cdot R_r}{L_r}\cdot i_{ds} - \frac{R_r}{L_r}\cdot \varphi_{dr} + \left(\omega_e - \omega_r\right)\cdot \varphi_{dr} \quad (3)$$

$$\frac{d\varphi_{qr}}{dt} = \frac{L_m \cdot R_r}{L_r}\cdot i_{qs} - \left(\omega_e - \omega_r\right)\cdot \varphi_{dr} - \frac{R_r}{L_r}\cdot \varphi_{qr} \quad (4)$$

$$\frac{d\omega_r}{dt} = \frac{P^2 . L_m}{L_r . J}.\left(i_{qs}.\varphi_{dr} - i_{ds}.\varphi_{qr}\right) - \frac{f_c}{J}.\omega_r - \frac{P}{J}.T_l \quad (5)$$

Where σ is the coefficient of dispersion and is given by:

$$\sigma = 1 - \frac{L_m^2}{L_s L_r} \quad (6)$$

By using of Hooke's law, Coulomb's law, mass conservation law and the laws of motion for each rotating roll the mechanical part model of the system is given by the two following parts equations [8, 9]:

Part 1: Tension model between two consecutive rolls

$$L\frac{dT_i}{dt} = ES(V_i - V_{i-1}) + T_{i-1}V_{i-1} - T_i V_i \quad (7)$$

Part 2: Roll velocity model

$$\frac{d(J_k(t)\Omega_k)}{dt} = R_k(t)(T_{k+1} - T_k) + C_{emk} - f_k(t)\Omega_k \quad (8)$$

Where E is the Young modulus, S is the web section and f_k is the roller viscous friction coefficient, (i=2,3) (k=1,2,3).

The k-th electromagnetic torques can be expressed as follows:

$$C_{emk} = \left(i_{qs}^k.\varphi_{dr}^k - i_{ds}^k.\varphi_{qr}^k\right) \quad (9)$$
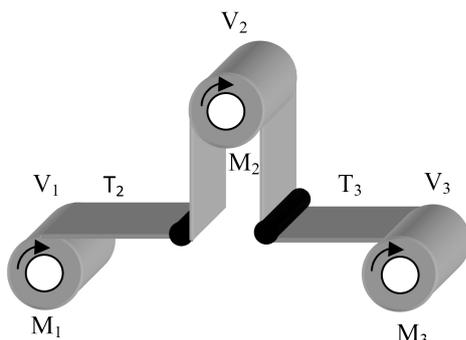
Fig. 1. Simple web winding system

3. Controller design

A. *Linear speed controller design*

The speed controller permits to determine the reference torque, the mechanical equation defined as

$$\frac{\omega_r}{C_{em}} = \frac{P}{f_c + J \cdot s} \quad (10)$$

The diagram of speed controller as shown below
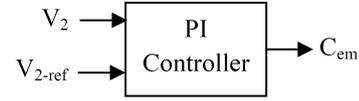
Fig. 2. Linear speed controller

The parameters of the PI controller is

$$K_{i\omega} = \frac{2 \cdot J \cdot \rho_\omega^2}{P} \quad (11)$$

$$K_{p\omega} = \frac{2 \cdot \rho_\omega \cdot J - f_c}{P} \quad (12)$$

B. *Tension Controller Design*

The proposed tension controller in the system permits to get a linear speed of reference in relation with the strength tension. Thus, we can use (7) as follows:

$$\frac{dT_i}{dt} = \frac{1}{L}\left[-V_{i-1}(ES + T_{i-1}) + V_i(ES - T_i)\right] \quad (13)$$

While achieving the linearization

$$U_1 = -V_{i-1}(ES + T_{i-1}) \quad (14)$$

The eq (10) become

$$\frac{dT_i}{dt} = \frac{1}{L}\left[U_1 + V_i(ES - T_i)\right] \quad (15)$$

While introducing the anticipatory term $U_1 = U + U_2$ where $U_2 = -V_i(ES - T_i)$ then we gets

$$\frac{dT_i}{dt} = \frac{1}{L}U \quad (16)$$

This equation allows us to define the structure of controller shows in the Fig 3. Note that this structure contains a controller, an anticipation term as well as a linearization.
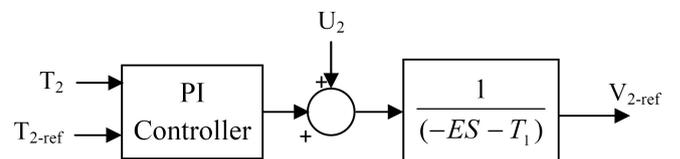
Fig. 3. Tension controller
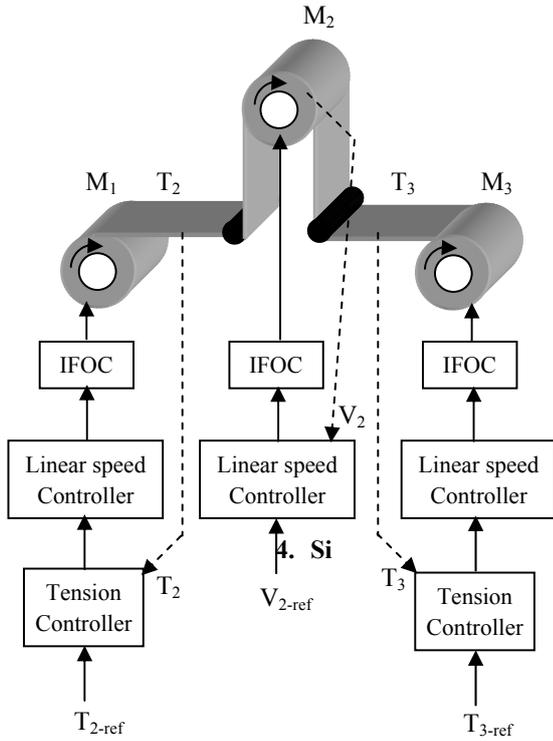
Fig. 4. Decentralized control for web winding system

Where the parameters of the PI controller are

$$K_P = 2\rho L \tag{17}$$

$$K_I = 2\rho^2 L \tag{18}$$

In the sequel, the decentralized structure shown on (Fig. 4) will be considered. The control structure is composed of 3 elementary controllers associated respectively to each motor.

The cascade control configuration uses the tension as primary measurement and velocity as secondary measurement. The manipulated variable is the torque applied to the motors.

4. Simulation Results

The system was simulated in the MATLAB SIMU-LINK environment for a three motors winding system the winding system and the control system parameters are given in Appendix.

As shown in Fig. 5, Fig. 8 and Fig. 11. An improvement of the linear speed is registered, and has follows
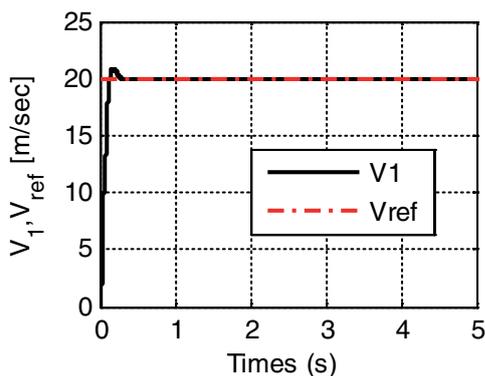
Fig. 5. The linear speed of unwinder M1
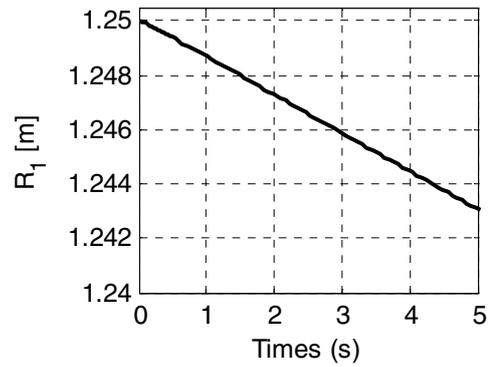
Fig. 6. The radius of unwinder M1
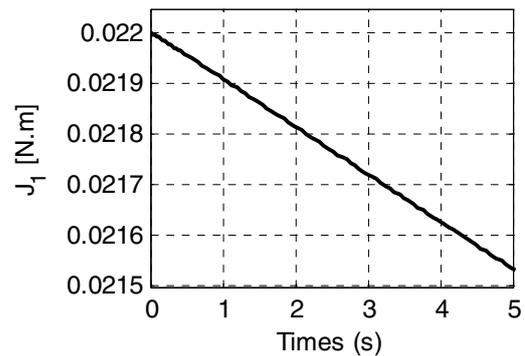
Fig. 7. The inertia moment of unwinder M1
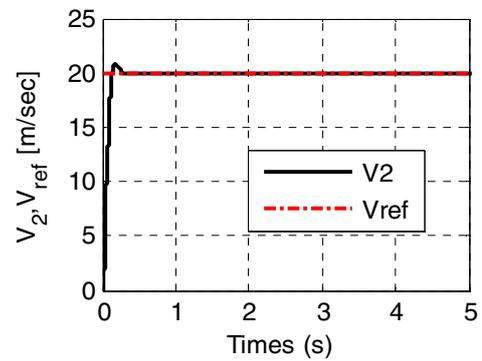
Fig. 8. The linear speed of Motor M2
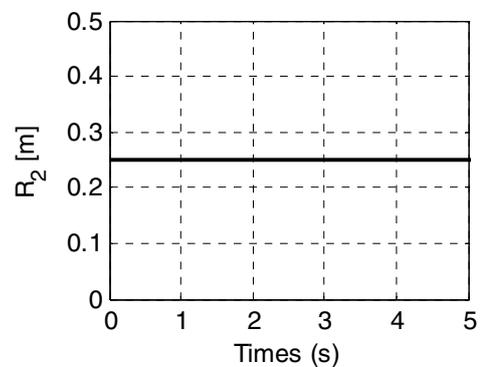
Fig. 9. The radius of motor M2

the reference speed for PI controller after 0.3 sec, in all motors, with the overshoot in linear speed (5%). Fig. 6 and Fig. 7 show that the radius and the inertia moment of unwinder M1 decrease compared with the radius and the inertia moment of Motor M3 is increase shown in Fig. 9 and Fig. 10.
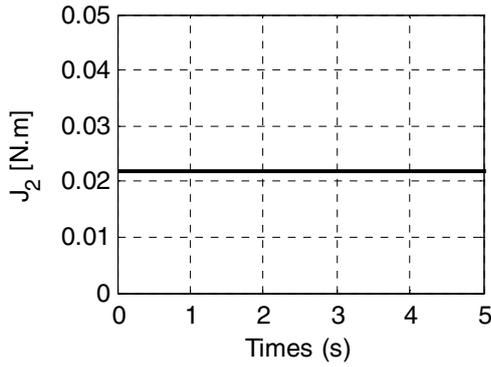
Fig. 10. The inertia moment of Motor M2
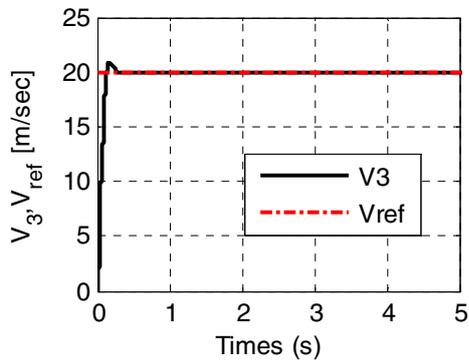
Fig. 11. The linear speed of winder M3
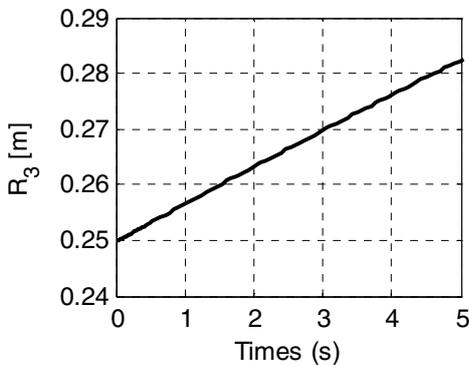
Fig. 12. The radius of winder M3
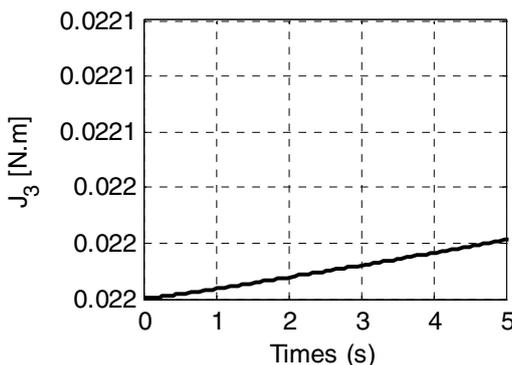
Fig. 13. The inertia moment of winder M3
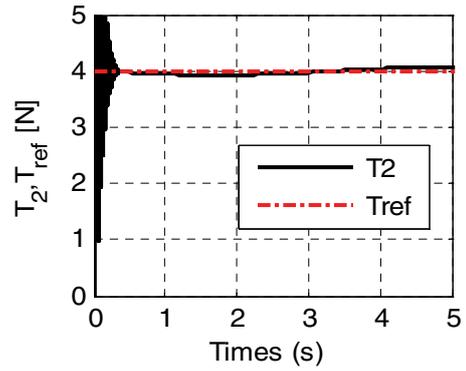
Fig. 14. The tension between Motor 1 and 2
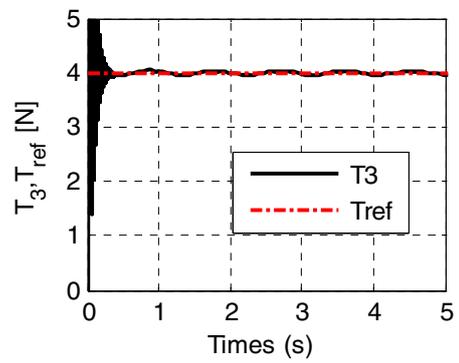
Fig. 15. The tension between Motor 2 and 3

From the Figures (14-15), we can say that: the tension follows the reference tension with application of PI controller.

It appears clearly that the classical control with PI controller in linear speed control and tension control offers better performances in both of the overshoot control and the tracking error. However is easy to apply.

Table 1. System parameters

E	1.6e8	$L_1 = L_2 = L_3$ [m]	5
S [m²]	2.75e-3	$_n$ [Hz]	50
R_1 [m]	1.25	$T_{1ref} = T_{2ref}$ [N]	4
$R_2 = R_3$ [m]	0.25	V_{2ref} [m/s]	20
$J_{01} = J_{02} = J_{03}$ [Kg. m²]	0.022	p	2

5. Conclusion

The objective of this paper consists in developing a model of a winding system constituted of three motors that is coupled mechanically by a strap whose tension is adjustable and to develop the methods of analysis and synthesis of the commands robust and their application to synchronize the three sequences and to maintain a constant mechanical tension between the rollers of the system.

AUTHORS

Bousmaha Bouchiba*, Abdeldjebar Hazzab, Hachemi Glaoui, Ismaïl Khalil Bousserhane – Laboratory of command, Analysis and Optimization of the Electro-Energizing Systems, Faculty of Sciences and technology, Béchar University B.P. 417 Béchar, 08000, Algeria. a_hazzab@yahoo.fr, ghachemi@yahoo.fr, ismail@yahoo.fr

Fellah Med-Karim – Laboratory of ICEPS Intelligent Control and Electrical power Systems University of Sidi Bel-Abbes, Algeria. mkfellah@yahoo.fr

Pierre Sicard – Department of electrical and computer engineering, Université du Québec à Trois-Rivières, Canada. pierre.sicard@uqtr.ca

*Corresponding autor: bouchiba_bousmaha@yahoo.fr

References

[1] D. P. Cambell, *Process Dynamics*, Wiley, 1958, pp.113-156.

[2] G. Brandenburg, "New Mathematical Model For Web Tension and Register Error". In: *Proceedings of the 3rd IFAC Conference on Instrumentation and Automation in The Paper, Rubber and Plastics*, vol. 1, May 1976, pp. 411-438.

[3] H. Koç, D. Knittel, M de Mathelin, G. Abba, "Modeling and Robust Control of Winding Systems for Elastic Webs", *IEEE Trans. Contr. Syst. Technol.,* vol. 10, March 2002, pp.197-208.

[4] J. E. Geddes, M. Postlethwaite, "Improvements in Product Quality in Tandem Cold Rolling Using Robust Multivariable Control", *IEEE Trans. Contr. System. Technology*, vol. 6, March 1998, pp. 257-267.

[5] S. H. Jeon *et al*., "Decoupling Control of Bridle Rolls for Steel Mill Drive System", *IEEE Trans. Ind. Application*, vol. 35, January/February 1999, pp. 119-125.

[6] D. Knittel *et al*., "Tension Control for Winding Systems With Two-Degrees of Freedom H∞ Controllers", *IEEE Trans. Ind. Applicat. Syst.*, vol. 39, January/February 2003, pp. 113-120.

[7] B.T. Boulter, Y. Hou, Z. Gao, F. Jiang., "Active Disturbance Rejection Control for Web Tension Regulation and Control". In: *IEEE Conference on Decision and Control*, Orlando, USA, December 2001, pp. 4974- 4979.

[8] F. Mokhtari, P. Sicard, N. Léchevin, "Damping Injection Control of Winding System Based on controlled Hamiltonian Systems". In: *12th IFAC Symposium on Automation in Mining, Mineral and Metal Processing – IFAC MMM'07*, Québec, Canada, August 2007, pp. 243-248.

[9] F. Mokhtari, P. Sicard, N. Léchevin, "Stabilizing Winding Systems by Injection Damping Control Based on controlled Hamiltonian Systems". In: *Proc. of IEEE International Electric Machines and Drives Conference – IEMDC'07*, Antalya, Turkey, May 2007, pp. 95-100.

[10] Bousmaha Bouchiba, Abdeldejbar Hazzab, Hachemi Glaoui, Fellah Med-Karim, Ismaïl Khalil Bousserhane, "Sliding Mode Speed Control for Multi-Motors System" , *JAMRIS*, vol. 4, no. 3, 2010, pp. 50-54.

[11] Christian Thiffault, Pierre Sicard, Alain Bouscayrol, "Tension Control Loop Using a Linear Actuator Based on The Energetic Macroscopic Representation". In: *CCECE 2004–CCGEI 2004*, Niagara Falls, Canada, May 2004.

[12] S. Charlemagne, A. Bouscayrol, Slama Belkhodja, J.P. Hautier, "Flatness based control of non-linear textile multimachine process". In: *Proc. of EPE'03*, Toulouse, France, September 2003, CD-ROM.

[13] Adlane Benlatreche Dominique Knittel "State Feedback Control with Full or Partial Integral Action for Large Scale Winding Systems". In: *Industry Applications Conference*, Oct. 2005, vol. 2, pp. 973-978.