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Drive requirements for elastic web roll-to-roll systems

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ABSTRACT

This paper analyzes for the first time the influence of the master roller placement of roll-to-roll systems and the effects of velocity and tension bandwidths. In such systems, each motor driven roller is controlled separately (decentralized control). The influence of the master roller position, which is only controlled in velocity and therefore gives the web speed, is studied. The other motor driven rollers are also controlled using optimized PI web tension controllers, automatically synthesized in the fixed-order and structure H_∞ framework. The web speed and tension control bandwidths play a major role on the system performances and therefore have to be chosen carefully. The impact of the master roller placement, considering several setting values of speed and control bandwidths, is analyzed with respect to reference tracking, disturbance rejection and robustness to web elasticity variations. Several configurations and settings are compared in time domain simulations and frequency system/signal analysis.

1. Introduction

Systems handling web materials such as textile, paper, polymer or metal are very common in industry, because they represent a convenient way of transporting and processing a product from one roll to another. The variables to be monitored and controlled in order to achieve the expected product quality are web tension and speed in each span. Therefore, the goal is to move the web at an expected speed while maintaining web tension as constant as possible [1]. In order to set up the speed and tension controllers, requirements have to be fixed. These requirements are the bandwidth of the closed-loop system and the overshoot. Moreover, the master driven roller has to be placed adequately. The master roller position has an impact on the tension control structure: upstream web tension control is used before the master roller and downstream web tension control after (see Fig. 4). For the first time, the influence of the master roller position and the closed-loop bandwidths is analyzed.

A generic roll-to-roll system, composed of seven master driven rollers and six idle rollers is studied. A linear simulator of this plant is developed in the Matlab/Simulink software environment [2,3]. A linear state space model is also built for automatic controller synthesis. Each driven roller speed is controlled by IP controller, whereas web tension is controlled using PI controller. In this work, the decentralized tension control is adjusted using fixed order and structure H_∞ approach [4,5].

This work concerns the study of the influence of closed-loop bandwidth and master roller position regarding reference tracking, disturbance rejection and robustness to web elasticity variation. A preliminary study is dedicated to the description of roll-to-roll systems modeling and web speed and tension control advanced synthesis. The web dynamics is then analyzed for different master roller positions and different bandwidths (the controllers are automatically calculated).

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2. Modeling

The non-linear model of a web transport system is built from the equations describing the velocity of each roller and the web tension behavior between two consecutive rollers [6,2,7].

2.1. Web speed determination

The web linear speed V_i of a roller i, is equal to the linear roller speed assuming that no slippage occurs (see Fig. 1), which depends on the upstream web tension T_{i-1} and the downstream web tension T_i, is given by:

$$J_i \frac{dV_i}{dt} = (T_i - T_{i-1})R_i^2 + K_i R_i u_i - f_d V_i \tag{1}$$

where J_i is the roller inertia, K_i is the torque constant of the motor, R_i is the roller radius, u_i is the roller control signal and f_d is the dynamic friction coefficient. This equation assumes that no slippage occurs: the web speed is equal to the linear roller speed. Moreover a static friction can be added.

2.2. Web tension determination

The strain ϵ_i of web span i, which depends on the upstream web strain ϵ_{i-1} and the speeds of the two consecutive rollers, is given by the differential equation [2]:

$$\frac{d}{dt}\left(\frac{L_i}{1+\epsilon_i}\right) = -\frac{V_{i+1}}{1+\epsilon_i} + \frac{V_i}{1+\epsilon_{i-1}} \tag{2}$$

where L_i is the web span length, V_{i+1} is the downstream roller speed, and V_i is the upstream roller speed.

For an elastic web, the web tension T is obtained using Hooke's law:

$$T = ES\epsilon_i \tag{3}$$

where E is the web Young's modulus and S is the web cross-section.

The web tension is determined using the non-linear differential Eq. (2). This equation can be linearized around working points T_0, and V_0. Considering $T_i = T_0 + t_i$, $V_i = V_0 + v_i$, $T_{i-1} = T_0 + t_{i-1}$ and $V_{i+1} = V_0 + v_{i+1}$ the linear equation becomes [2]:

$$L_i \frac{dt_i}{dt} = V_0(t_{i-1} - t_i) + (v_{i+1} - v_i)(ES + T_0). \tag{4}$$

2.3. Linear model

The relations depicted in Eqs. (1) and (4) permit to construct the state-space representation of the studied roll-to-roll system:

$$\begin{cases} \dot{x}(t) = \mathbb{A}x(t) + \mathbb{B}u(t) \\ y(t) = \mathbb{C}x(t) \end{cases} \tag{5}$$

where x is the state vector, u the control vector, and y the output vector. $\mathbb{A}$ is the state matrix, $\mathbb{B}$ the input matrix and $\mathbb{C}$ the output matrix.

The system scheme is shown in Fig. 2, the big circles (V_i, V_3, V_5, …) correspond to the motor driven rollers and the small circles (V_2, V_4, V_6, …) correspond to the idle rollers equipped with a load cell. The dynamical model needs the calculation of each roller speed and web tension in each span. Therefore, the state vector is composed of the velocity of each motor driven roller, the velocity of each idle roller (equipped with a load cell) and the web tension in each web span:

$$x = [V_1\, Ts_1\, V_2\, Ts_2\, V_2\, Ts_3 \cdots Ts_{12}\, V_{13}]^T. \tag{6}$$

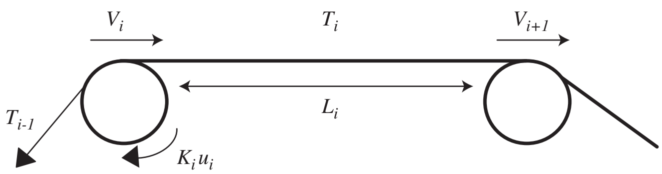

Fig. 1. Analyzed web span.