

Sensorless Tension Control in Paper Machines

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Abstract—Proper operation of the dry end of a paper machine requires some type of sheet tension control. Present systems use either indirect-speed-control-based schemes, or sensor-based direct tension control utilizing load cells or swing rolls. The indirect schemes are inadequate for most newer machines, and both types of the commonly used sensor-based schemes are invasive, expensive, require either special, or extra rolls, and add complexity to the sheet train.

This paper proposes and evaluates sheet tension estimation using only conventional motor and control signals, present in all newer drive controllers, integrated into a process model observer. This observer-based approach eliminates the need for the invasive tension transducers, and may also be used to replace the inaccurate indirect speed control schemes.

Index Terms—Paper machines (PMs), sensorless tension control, tension control, web machine tension control.

I. INTRODUCTION

A. Sheet Tension Fundamentals

AS THE SHEET is formed and leaves the presses at perhaps 30%–40% water, the sheet has essentially zero modulus of elasticity, and as an inelastic medium, cannot support any stress-producing tension (the reason for closed draws at wet-end sections). As the sheet progresses through the dryer sections, the sheet modulus of elasticity dramatically increases, section-to-section, to higher values as it reaches the final water content of perhaps 5% (air dry) at the paper machine (PM) reel. Air-dry modulus of elasticity values range from perhaps 400 000 lbf/in² for newsprint, to over 1 000 000 lbf/in² for high-quality bond sheets. It can be readily seen that the water content is the predominant factor determining the sheet modulus of elasticity in the machine direction. Without going through the math involving the sheet caliper (thickness), the sheet modulus of elasticity determines the linear sheet tension in pound force per linear inch (pli) for a given steady-state speed difference, regardless of the physical sheet length of a given draw span. This relationship is given by the following generalized per-unit equation:

$$\Delta T_{\text{tens}} = E \cdot \Delta V \quad (1)$$

$$E = \frac{\Delta T_{\text{tens}}}{\Delta V} \quad (2)$$

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TABLE I
TENSION-RELATED SHEET CHARACTERISTICS

Property	News	Free	LWC	Linear
Modulus E (lbf/5000 in ²)	20.4	25.7	34.9	27.1–35
Caliper (m)	0.003	0.004	0.002	0.002
Modulus of Elasticity ($\times 10^3$ lbf/in ²)	200.7	360.7	240.7	300.7
Tens. σ Strength (lbf/inches 3×3 total) (PLI)	660	1250	1450	740
Tens. σ Strength (lbf/inches 3×3 total) (PSI)	9.810	27.09	10.21	57.108

where:

- ΔT_{tens} change in tension (p.u.);
- E sheet modulus of elasticity in the machine direction;
- t sheet thickness (caliper);
- ΔV speed difference between sections (draw) (p.u.).

Table I summarizes typical salient tension-related characteristics for the most common grades of sheet and board [1].

A guideline for the most probable operating tension for a given sheet grade may be developed from this table, combined with utilizing papermaking experience in setting up a machine direction tension profile through the machine dry-end sections. Experience has shown that it is advisable to limit the section-to-section tension to perhaps no more than 10% of the tensile strength (ultimate breaking tension). This wide margin is needed to accommodate imperfect paper making conditions, such as “across the sheet” variations in moisture, caliper, etc., producing nonlinear sheet tension “across the sheet.”

B. Tension Control Strategies

1) *Speed Difference Indirect Tension Control*: Since, for most paper grades, the slope of the stress-strain curve (the modulus of elasticity) is quite linear in the practical operating range as the stress increases up toward the fracture point, we get very predictable tension changes for a given speed difference between sections, if the moisture content remains constant. What is the significance of all this? Common sense prevails, and if the sheet moisture remains nearly constant at a given draw in the dry-end of the PM, a good precise speed controller should provide an excellent indirect method of tension control. We might conclude that a quality speed controller solves most of the problems in determining tension, since it inherently provides inertia compensation during dynamic speed changes as well as friction loss compensation, under all conditions in all elements of the drive train and load, since it theoretically is controlling the peripheral speed of the tension producing draw rolls.

Why does not speed control always do the job? Several factors determine the performance of the speed controller as an indirect tension controller.

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Electrical Drive Simulation with MATLAB/Simulink Viktor Perelmuter, 2024-04-26 The chapters of this book discuss the modeling of electric drives taking into account their relationship with the technological process they serve which significantly affects the composition layout and characteristics of the electric drive There are no published books of this kind and this book fills a gap in the literature This book deals with electric drives for rolling mills paper machines a number of several hoisting and transport devices these installations are very common and very complex so that modeling methods in their development and study are mandatory The book focuses on issues such as the transmission of torque by elastic shafts the transmission of torque by an endless elastic belt in paper machines and conveyors the transmission of torque by friction of pressed rolls in the paper industry the consideration of the elastic properties of long ropes in some hoisting and transport machines and the effect of swinging a moving load in such machines More than 100 models of the electrical drives that are made with the use of the program environment MATLAB Simulink are appended to this book The aims of these models are to aid students studying electrical drives of the various manufacturing machines to facilitate the understanding of various electrical drive functions and to create a platform for the development of systems by readers in their fields This book can be used by engineers and investigators as well as undergraduate and graduate students to develop new electrical drives and investigate the existing ones

Algorithms and Computational Techniques Applied to Industry Jorge Luis García Alcaraz, Arturo Realyvásquez Vargas, 2022-06-21 This book presents algorithms and computational applications integrated in software that are being applied in the industry It shows how companies using these tools are more competitive and efficient in the use and resources management The book is organized in three sections depending on the supply chain stage procurement including contact with costumers and product design Production process including relationship with suppliers and among departments and Distribution including logistics and transportation

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Proceedings of the Sixth International Conference on Web Handling James K. Good,2002 **Proceedings of the Fourth International Conference on Web Handling** James K. Good,1998 *Computer Aided Control Systems Design 2000 (CACSD 2000)* J. O. Gray,2001 This Proceedings contains the papers presented at the 8th IFAC Symposium on Computer Aided Control Systems Design held at Salford UK on 11 13 September 2000 Modelling has emerged as a central issue here and industrial users require the development of modelling languages for both analyses and design as well as generic models and tools which can be used for system identification optimisation and fault diagnostics Linear lumped parameter systems of general complexity are currently well addressed by a range of commercially available packages However there is a dearth of tools suitable for the analysis and synthesis of large scale distributed non linear hybrid and stochastic systems which are increasingly a feature in modern manufacturing and process engineering As the scale of the problems to be addressed increases there is a need for numerically robust and efficient computational procedures linked to powerful interactive graphical interfaces which maximise the user of limited human resources and of course standardised data bases which can be used with wide range of analysis and design procedures Topics covered included the now traditional domains of algorithm architectures and tools and there was a very welcome emphasis on applications where no less than four sessions were devoted to this important aspect

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