

# Sensorless Tension Control in Paper Machines

M. Anibal Valenzuela, *Senior Member, IEEE*, John Martin Bentley, *Life Fellow, IEEE*, and Robert D. Lorenz, *Fellow, IEEE*

**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 run.

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  $\text{lb/in}^2$  for newsprint, to over 1 000 000  $\text{lb/in}^2$  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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M. A. Valenzuela is with the Department of Electrical Engineering, University of Concepción, Concepción, Chile (e-mail: avale@udec.edu.cl).

J. M. Bentley is at 5239C Interview Drive, Manitowish Waters, WI 54845 USA.

R. D. Lorenz is with the Departments of Mechanical Engineering and Electrical and Computer Engineering, University of Wisconsin, Madison, WI 53706 USA (e-mail: lorenz@engr.wisc.edu).

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TABLE I  
TENSION-RELATED SHEET CHARACTERISTICS

Property	News	Free	LWC	Linear
Modulus $E$ ( $\text{lb}/\text{in}^2$ )	20.4	25.7	34.8	27.1–3
Caliper ( $\mu\text{m}$ )	0.003	0.004	0.002	0.002
Modulus of Elasticity ( $\times 10^3$ $\text{lb}/\text{in}^2$ )	250.7	360.7	240.7	380.7
Tens. $\sigma$ Strength (Ult. Mod. $\text{lb}/\text{in}^2$ ) (PS)	0.870	27.08	10.21	57.708

where:

- $\Delta T_{\text{tens}}$  change in tension (p.u.);
- $E$  sheet modulus of elasticity in the machine direction;
- $t$  sheet thickness (caliper);
- $\Delta V$  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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