BAGGINESS AND BAGGY STREAKS: A NOVEL MEASUREMENT TECHNIQUE TO QUANTIFY TENSION PROFILE OF A WEB IN CROSS-DIRECTION AT HIGH RESOLUTION

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ABSTRACT

A tension beam was designed to quantify cross-directional tension profile of a moving web at high resolution and high accuracy. The beam, composed of 50 individual Teflon pads resting on load cells, allows the measurement of the tension profile of a 1270 mm wide web. The tension beam was installed on a roll tester machine that has the capabilities of unwinding large roll. A method to evaluate the tension profile of a full width machine from individual rolls was also developed. Over the past years, the beam was used to test different types of material, from lightweight paper to polymer films, airlaid material and paperboard. Tension analysis showed that cross-directional tension profiles may vary a lot for different web conditions. Examples of non-uniform tension profiles on paper machines related to cross-directional properties variations are illustrated. Models that predict the cross-directional tension profile of as full machine width from basic web properties can also be established using the tension beam.

NOMENCLATURE

cm	centimeter (length)
in	inch (length)
g/m^2	gram per square meter (basis weight)
kg	kilogram (weight)
m/min	meter per minute (speed)
PLI	pounds per linear inch (tension)
N/m	Newton per meter (tension)
kN/m	kilo Newton per meter (tension)
CD	cross-direction
MD	machine-direction
TSI	tensile stiffness index
TSO	tensile stiffness orientation

INTRODUCTION

Cross-direction (CD) non-uniformity of web tension often leads to bagginess and slack edges, which may create wrinkles, web weaving, corrugations and misregistration [1,2,3,4]. A non-uniform tension profile will also affect machines and winders runnability as well as the performance of the web during printing and converting operations [5]. Non-uniform tension profiles also affect lateral stability of the web [6].

Bagginess and baggy streaks are often visually observed at the customer's operation but are difficult to quantify [7]. During web production, the cross-machine direction tension profile is not traditionally measured or controlled, and there is no objective way to evaluate the uniformity of the CD tension profile from the basic web properties. Usually, operators will observe that a visibly baggy or sagged section of the web is under no tension [8].

Web cross-directional tension measurement is not a new concept as many tools and methods have been proposed and developed during the past two decades. Quantifying cross-directional tension of a web can be done at no cost by the strip method [8] that consists of measuring the length of paper at different CD positions and compare the length profile in CD. Strips of paper with baggy areas (or lower tension) will be longer than the strips with higher tension. This method is long and tedious and is not suitable for routine test.

Other tools were developed to measure and study different paper machines cross-web tension profiles, such as the Tensor [9], the Tenscan [10], the CTSensor [11] and the Biaxial web tension transducer [12]. However, neither of them is available now on the market. Limitations of these systems were the low resolution in CD and the fact that it was not possible to get a complete profile without scanning the web. Only the CTSensor (based on the Vidimon Shapemeter principle successfully used in the metal industry) that used floating rotors on air bearings gave a complete profile in cross-direction, but with a low resolution (from 55 to 110 mm spacing in CD). The CTSensor was nevertheless successful in measuring the cross-web tension profile of paper on rewinders and on printing presses [13].

A successful tool for measuring web tension is the METSO Automation's IQ tension beam [2,3,14]. It is a non-contact method for measuring the web tension profile on-line. The use of the IQ tension beam requires a machine speed higher than 400 m/min, to form an air film between the paper and the beam (Figure 1). The IQ tension tool can be installed on paper machine or on the printing press. A potential limitation is the resolution, since the sensor spacing is 100 mm at the edges of the machine and 300 mm in the center (where the tension is usually more uniform).

Another tool that seems promising is the new Metso's iRoll measurement technology [15] that can be used for measuring either web tension profiles or nip load profiles in wind-up. A sensor is mounted on the roll body and measures the force applied by the web (Figure 1). The sensor rotates under the wrap angle generating a tension profile. CD mapping of the profiles can then be calculated on the basis of the angular position of the roll. The iRoll instruments provide a complete CD profile on each full turn of the roll.

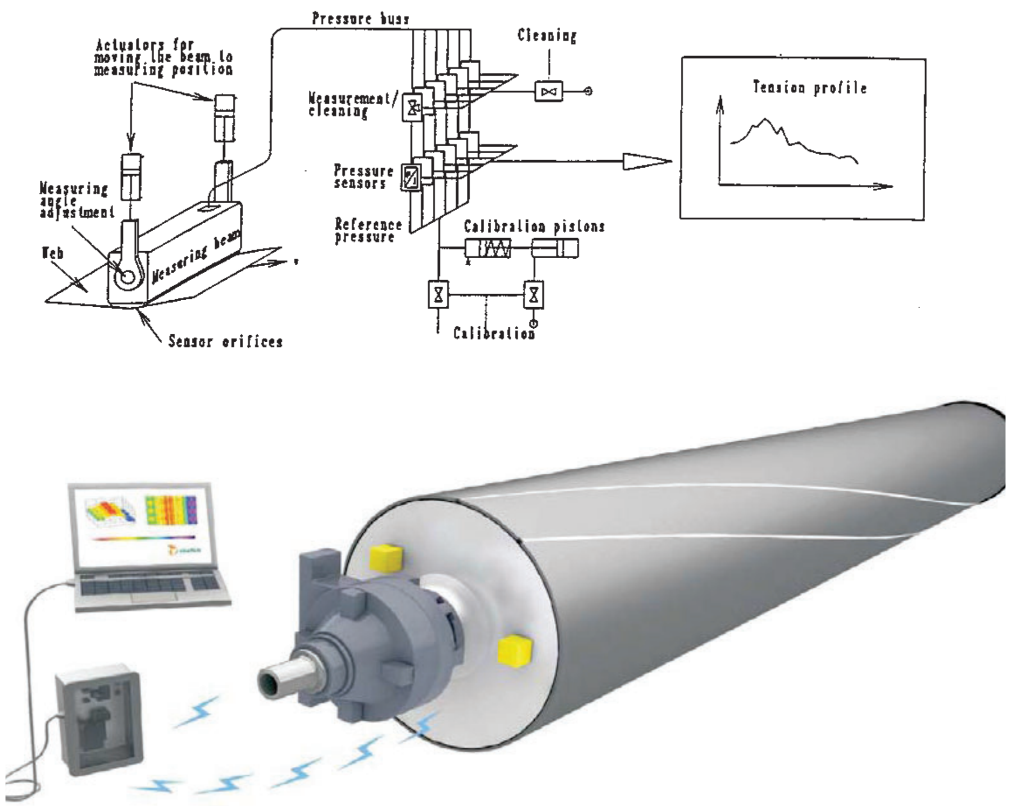


Figure 1 – Metso's IQ Tension beam (top) and iRoll (bottom)

Actual cross-web tension measurement systems have technical limitations such as the resolution (number of sensors in cross-direction is low because of cost) and the web speed (that must be over a certain threshold to work properly). Many of these systems are also very expensive to install and difficult to maintain in good conditions of operations on machines (they require regular cleaning, maintenance and calibration).

To answer the need of investigating web tension profile at high resolution, high accuracy and at affordable cost, we have developed a new tension beam that is mainly used off-line. In this paper, we describe the new tension beam and present results from the measurements. We demonstrate that the web can be run at a wide range of speeds without affecting the results. Its precision is also evaluated. A method to evaluate the tension profile of a full width machine from individual parent rolls measurement is then illustrated. Finally some case studies of tension measurements and analysis for different web conditions (baggy edge and baggy streaks) are presented.

METHODOLOGY

Development of an Off-Line Prototype for Measuring Cross-Directional Tension Profile

Previous analysis on visual bagginess assessment (low tension zones) showed that the tension measurement must be done at high resolution to pick up very small and sudden changes in the CD tension. CD bagginess zones may occur in the scale range between 25 and 100 mm.

The first design criterion was to develop a system that can measure the web CD tension profile with high accuracy and high resolution. The system had to be sensitive enough to detect small tension variations within a width of only a few mm. Other design criteria were: no web speed effect, reasonable cost and easy maintenance and calibration. Several designs were analyzed and a preliminary study showed that the most feasible solution consisted of paper traveling over units mounted on a load cell. The idea of using 25 mm wide pads of Teflon individually mounted on load cells was demonstrated with a 12-unit wide prototype (Figure 2), with a total width of 305 mm.

Each unit included an S-beam load cell, a half Teflon cylinder 25 mm wide, and an aluminum support. Teflon was chosen because of its low friction coefficient. The Teflon pads are not directly mounted on the load cells but rather pivot on a rod and rest on the load cells using adjusting screws and loading buttons. All units are fixed to an aluminum H beam that was designed to minimize flexion.

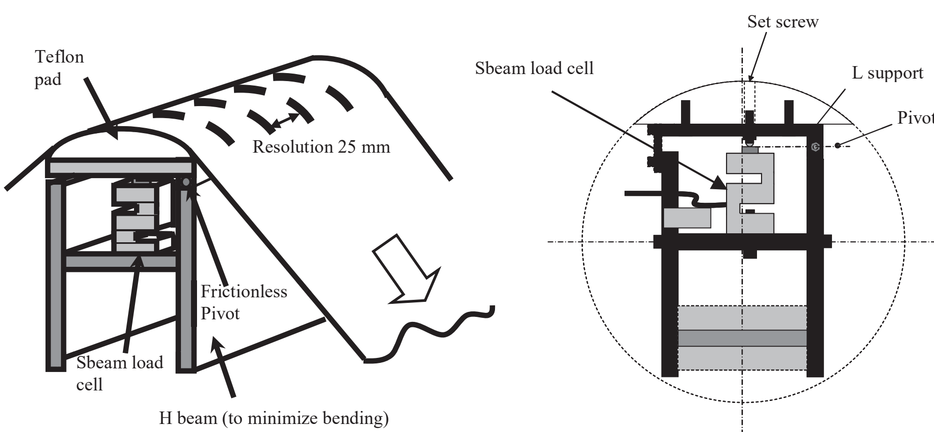


Figure 2 – First 12 unit wide prototype of CD tension measurements

Load cells were calibrated in kN/m using a 10 kg weight. Linearity and repeatability of the voltage were verified for each load cell. All load cells were connected to a power supply and an acquisition card. The load cells values were acquired and displayed on a laptop using Labview software. To convert the load cell force to “real” web tension, the following equation was used to take into account the friction between web and Teflon and the fact that the force on the load cell is created by the help of a frictionless pivot:

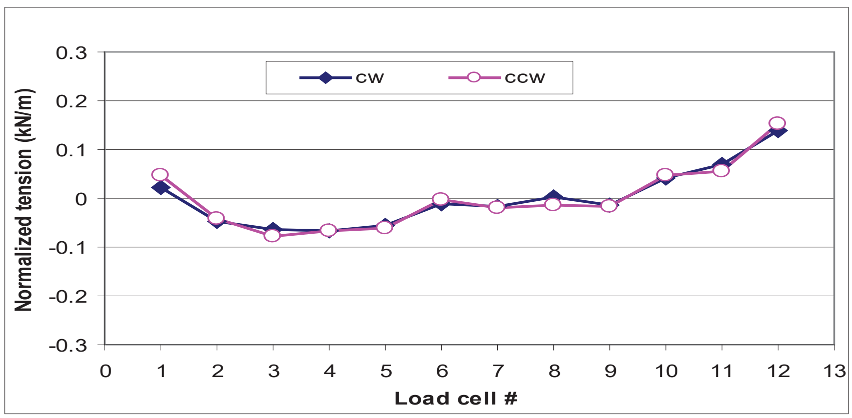
$$T = \frac{F\, n e^{s\theta}}{PA} \qquad \{1\}$$

Where F = Force of the load cell in kN/m

n = Coefficient of friction between web and Teflon
sθ = angle of contact between paper and Teflon
PA = Pivot arm factor (based on geometric calculation)

To validate the tension measurement technique, the prototype was installed on the unwind stand of a laboratory calender. Narrow newsprint rolls (305 mm or 12 inches) were used to validate the accuracy of the measurement, the effect of speed on tension measurement, and the impact of the average tension on measurements.

Figure 3 displays tension profiles clockwise versus counter-clockwise for two different rolls. Clockwise and counter-clockwise are the way the paper rolls were unwound on the laboratory calender (to reverse front to back on the tension beam). We note that for each roll, the counter-clockwise profiles have been reversed to facilitate the analysis. The tension profiles are similar for the two sets of measurements, indicating that the method for measuring the paper tension was appropriate.



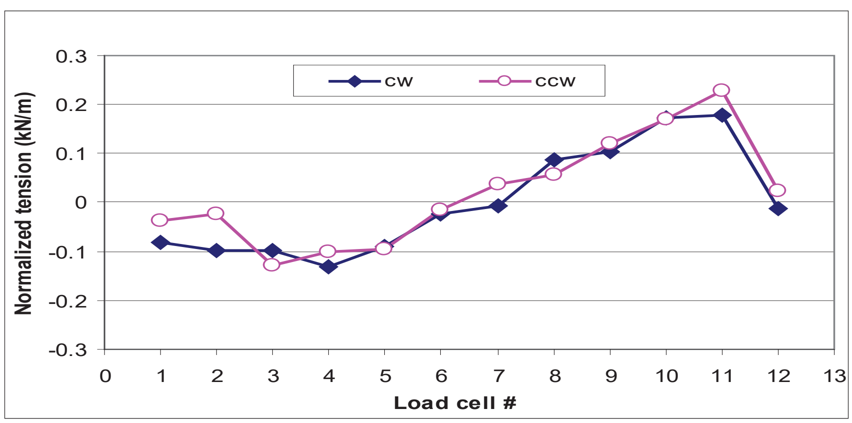


Figure 3 – Tension profiles for two rolls: clockwise (cw) vs counter clockwise (ccw) measurements on the 12 units' prototype

Other results showed that the average CD tension profile is directly proportional to the MD tension applied to the sheet, and the shape of the tension profile is not affected by the MD tension (Figure 4). Measurement speeds ranging between 10 and 400 m/min also showed that the shape of the CD tension profile is not affected significantntly by the web speed (Figure 5).

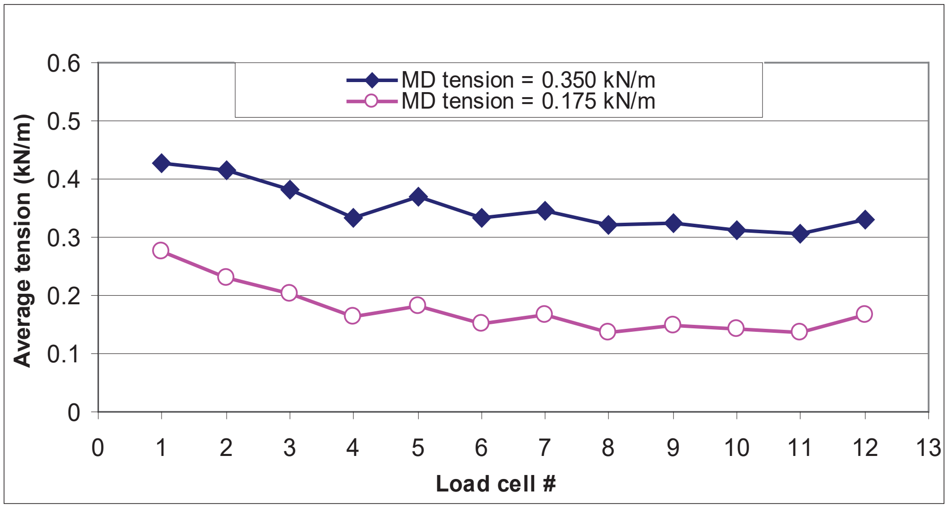


Figure 4 – Effect of MD tension on tension measurements

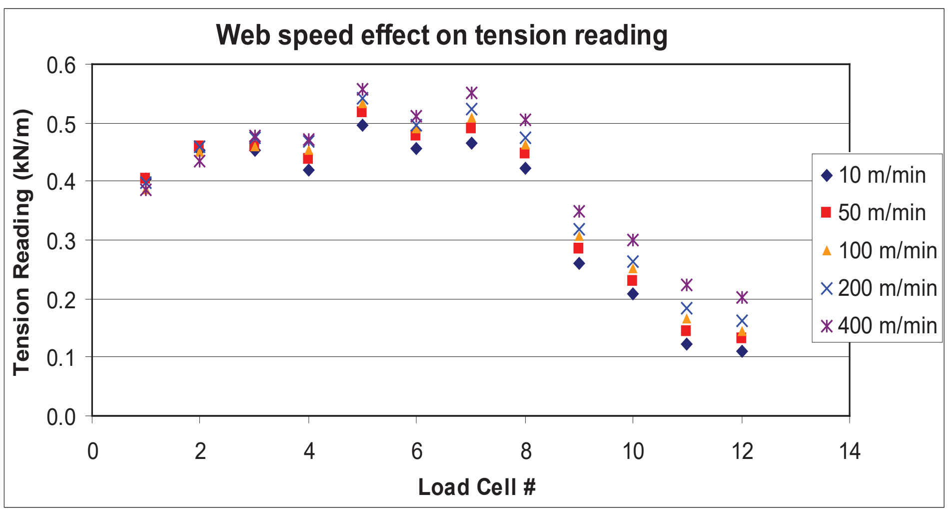


Figure 5 – Effect of web speed on tension measurements

Validation of the narrow tension beam shown in Figure 2 led to the development of a 1270 mm (or 50 inches) wide tension beam, a width that is usually common in the printing industry. Like the prototype, all fifty Teflon pads were individually assembled on a 1270 mm long aluminum H beam before being machined on the lathe at a radius of 125 mm. The load cells were added to the beam on the lathe and a dial indicator was used to adjust all units with 2.5 micrometers of precision. Pictures of the tension beam are shown in Figure 6.

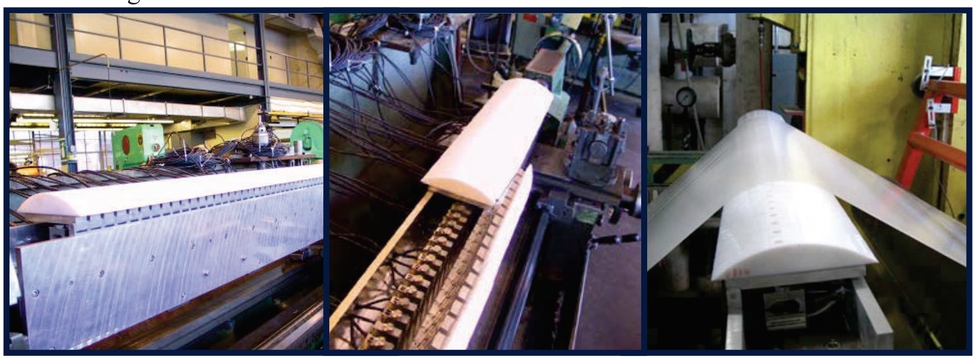


Figure 6 – The 50” beam installed on the lathe during its fabrication (left), inside view of the 50 load cells (center) and the beam in operation with paper on it (right).

The tension beam was installed near the unwind stand of a roll tester (Figure 7). This was chosen because this equipment has the facilities for installing, threading and unrolling large rolls (1270 mm wide rolls X 1270 mm diameter) at constant machine direction tension. All 50 units were connected to a PC and Labview software was used to acquire the data. All load cells were individually calibrated using a 10 kg weight. Linearity and repeatability of the voltage were also verified for each load cell.

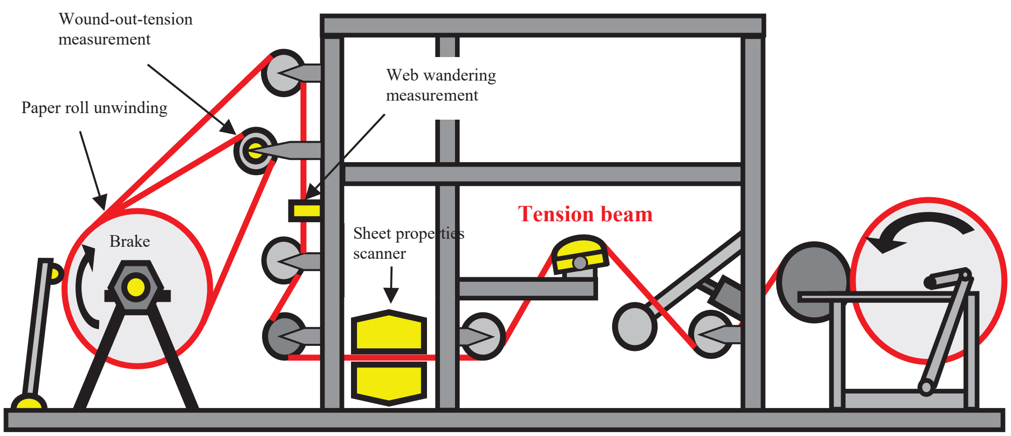


Figure 7 – Schematic representation of the tension beam installation on roll tester equipment

All equipment rolls were aligned using a very accurate laser technique. Even with roll alignment completed, a calibration procedure was developed to take into account any minor roll misalignment that can affect the tension profile. Roll alignment is very critical since a few microns of roll misalignment would lead to major differences in the front-to-back tension measurements.

Validation of the method of measurement was achieved by measuring paper rolls clockwise and counterclockwise (as presented in the previous section). Paper rolls for the tests were unwound at a speed of 100 m/min and a MD tension of 0.175 kN/m at the tension beam. Figure 8 shows an example of the tension profiles for newsprint paper. The two profiles (clockwise and counter clockwise) are similar. An average difference of 0.00875 kN/m on the average tension of 0.175 kN/m (1 PLI) was found between the two profiles (5% of error).

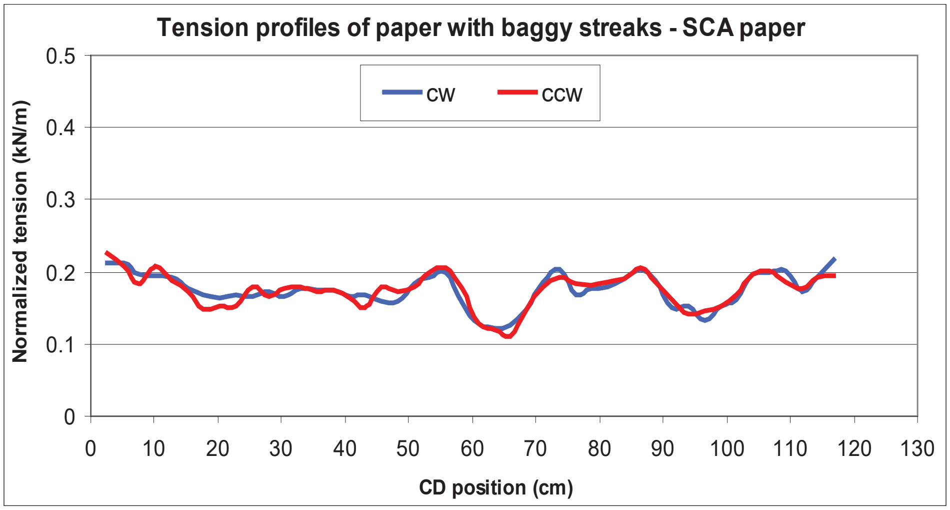


Figure 8 – Tension profiles in CD: clockwise (cw) vs counter clockwise (ccw) measurements on the 1270 mm wide tension beam

Description of the Tension Reconstruction Method for a Full Paper Machine Width

To obtain the full width tension profile of a paperr machine at the reel, a method has been developed to reconstruct the CD tension profile from individual rolls measurements. A correction with the TSI_{MD} (tensile stiffness index in machine direction) is done when these measurements are provided by the mill.

All individual profiles are first measured under an average tension of 0.175 kN/m (1 PLI). From each individual roll, we get the tension profile in cross-direction. Then the stretch profile of each roll is calculated using the following equation:

$$T(x) = E(x) \times BW \times (\varepsilon - \varepsilon_{0(x)}) \qquad \{2\}]$$

Where $T(x)$ = Local tension (N/m) (tension CD profile measured with beam)
$E(x)$ = Local modulus of elasticity (TSI_{MD} in Nm/g)
BW = Basis weight (g/m^2)
ε = Stretch applied to the entire paper width
$\varepsilon_{0(x)}$ = Local initial stretch (stretch CD profile)

Figure 9 shows the CD initial stretch profile of paper from the machine reel unrolls on the floor. The section of the web that is the longest will represent the part of the web that will show the lowest tension in machine direction, because the local initial stretch is the highest. The other CD section of the web will show higher tension since their local initial stretch is lower.

Figure 10 shows that all individual stretch profiles are “stitched” together, that is, the stretch at the beginning of the second roll starting from the front side is digitally connected to the stretch of the end of the first roll and so on up to the back roll. A TSI correction is then applied on the data according to the equation 2.

The final tension profile can be modified by changing the draw (or stretch applied to the entire paper, see equation {2}. Tension profiles are generally reconstructed and calculated as a function of the draw between the calender and the reel. The draw only influences the average tension value and does not modify the overall profile.

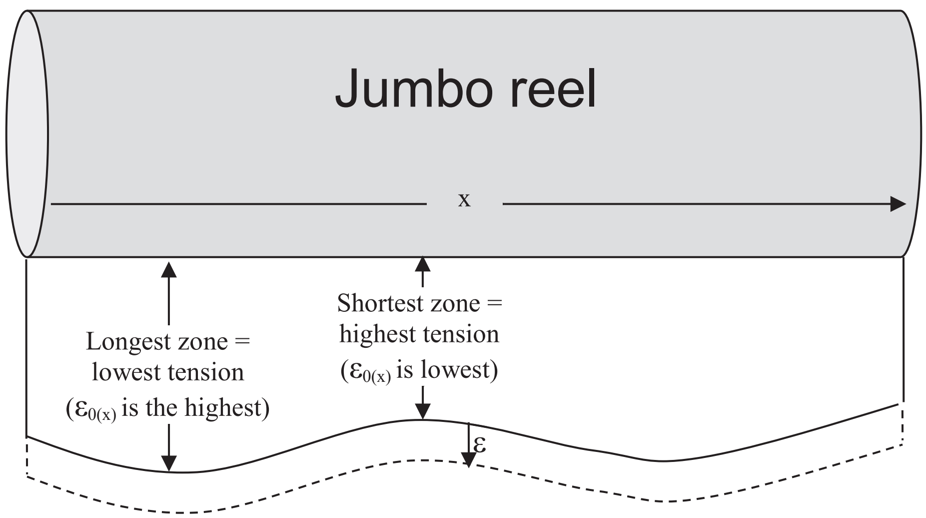


Figure 9 – Unrolled reel on floor will show different paper length in CD

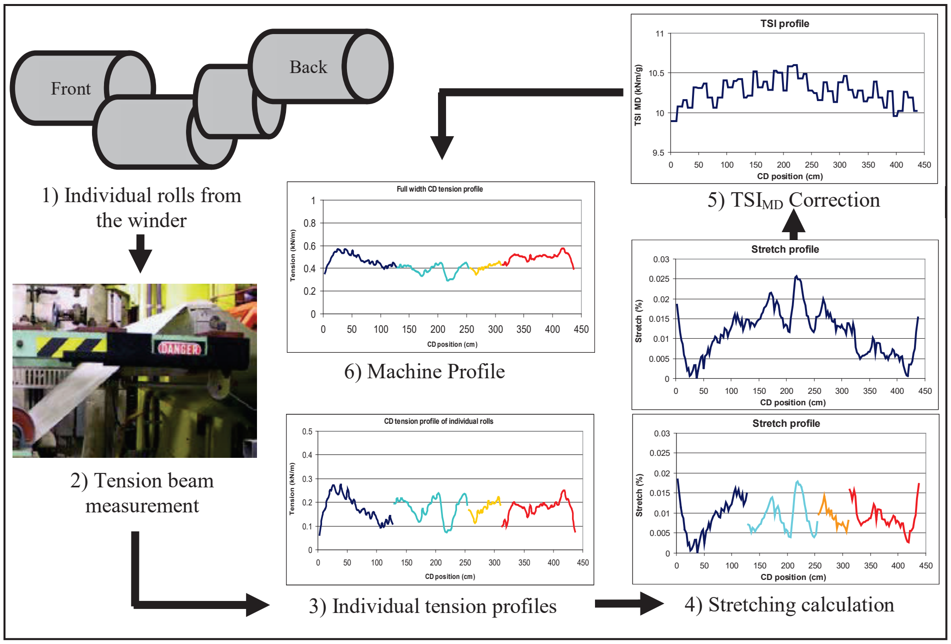


Figure 10 – Tension profile reconstruction steps for a 4 rolls wide machine

RESULTS

Using the tension beam, we have evaluated the tension profiles of many individual rolls from different types of material, from lightweight paper to polymer films, airlaid material and textile films. In each case, we use the tension beam to quantify the uniformity of the tension in cross-direction. Based on the results, we can suggest corrections on the producing machine. We have gained a lot of expertise with the paper industry to solve baggy edges and bagginess issues. Non-uniform tension profiles on paper machines are often related to properties variations in cross-direction. Baggy edges on paper machines can also be created during the drying history, where the paper shrinks in CD and elongate in MD, leading to longer web and therefore bagginess.

In this section, we will present typical case studies of tension measurements and analysis that are related to some common problems on paper machines, such as baggy edges and bagginess areas. We will also show how the tension measurement can be predicted using basic web properties.

Measuring Baggy Edge and Correction by Changing Drying History

One mill producing newsprint paper had issues with loss of register from paper rolls produced at the back side of one of their newsprint machine. Many customers rejected paper rolls from that position and requested only rolls from the centre of the machine. The loss of registration appeared to be related to a lack of tension at the back of the machine. One back position roll is shown unwinding on Figure 11. The lack of tension at the edge of the machine is clearly visible. The mill's attempts to correct the tension at the back by optimizing fiber alignment were not successful. There was also an observation that the TSI MD appeared to be highly correlated to the problem, in such a way that the mill observed a drop in the TSI MD at the back of the machine.

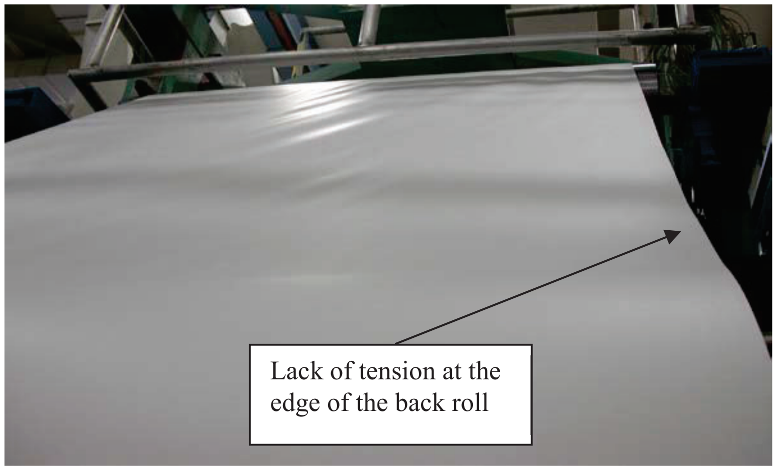


Figure 11 – Baggy edge problem at the back of the machine is clearly shown here at the unwind station of the unwind roll tester

A full set of five rolls (45 gsm newsprint) across the width of the machine was shipped to to be analyzed with the tension beam. Each roll was unwound at a speed of 100 m/min and an MD tension of 0.175 kN/m at the tension beam. The average tension profile was calculated for each roll and the reconstructed tension profile, which was reconstructed from the individual measurements, is shown in Figure 12. The dashed lines represent the individual rolls cut on the winder. The letters represent the roll position on the machine (A = front or tender side).

The tension profile was reconstructed and calculated for a draw of 0.12% which was representative of the draw between the calender and the reel (giving an average tension of 0.4375 kN/m). The tension profile had a "frown" shape, with the tension being higher at the centre. The tension was quite uniform for the centre rolls (B, M, Y positions) but the two edge rolls show a very low tension towards the machine extremities. For the front edge roll, the tension dropped by 0.25 kN/m while the back dropped by 0.45 kN/m to almost zero tension. As shown, the tension profile was not symmetrical and tended to drop more towards the back edge. Based on our experience, a tension drop of more than 0.175 kN/m (over 1270 mm roll width) at the edges of a newsprint machine would create runnability problems.

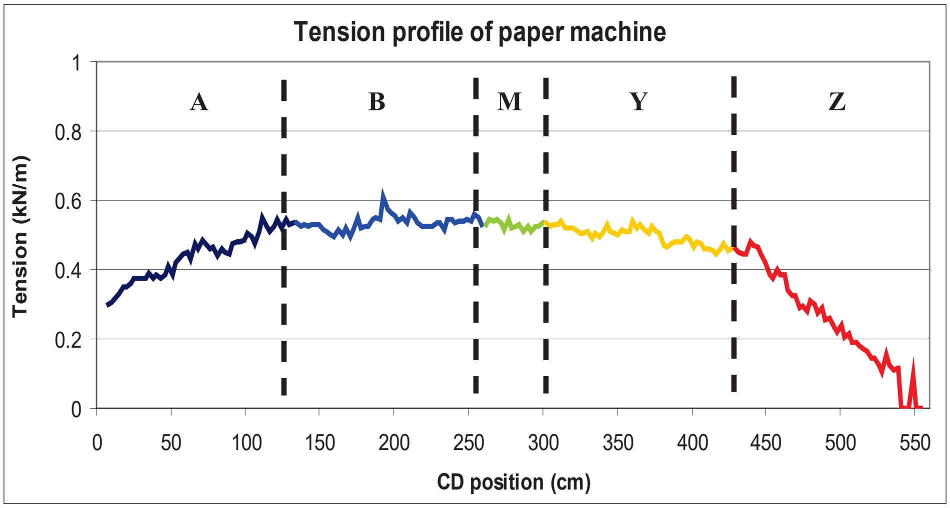


Figure 12 – Tension profile in CD with the decrease of tension at the back of the machine (roll Z)

The TSO and TSI profiles as well as basic sheet properties (moisture, basis weight and thickness) did not explain the drop of tension at the back of the machine. The observation of the control profiles of the moisture shows that the Steamtrol actuator opening (moisture control in the press section) had the same asymmetry in its profile as the tension profile. A low opening of the actuator at the back indicated that the sheet had a tendency to be drier at the back. The CD control gave an indication of the adjustment of the machine that will affect the drying history and therefore tension profile.

Trials were then conducted at the mill to evaluate the effect of changing solids content at the edges (with steambox actuator set-points) after the press section on the CD tension profile [16]. For each trial, a full set of paper rolls covering the width of the machine was shipped for testing. Adding more steam at the edges (edges drier before the drying section) showed that the tension increased significantly and therefore eliminated the baggy edge at the back of the machine (Figure 13). At the front edge, the tension also increased. This indicates that the problem originated from the drying section since the sheet needed to be wetter at the back to get uniform moisture profile at the reel. Using drying audit data in a drying simulation program, we determined that the tension profile was related to non-uniform drying. Modifications introduced in the drying section helped to improve the tension profile. As shown in Figure 14, the difference in tension between the two profiles for the Z position rolls was decreased from as much as 0.4 kN/m to about 0.2 kN/m.

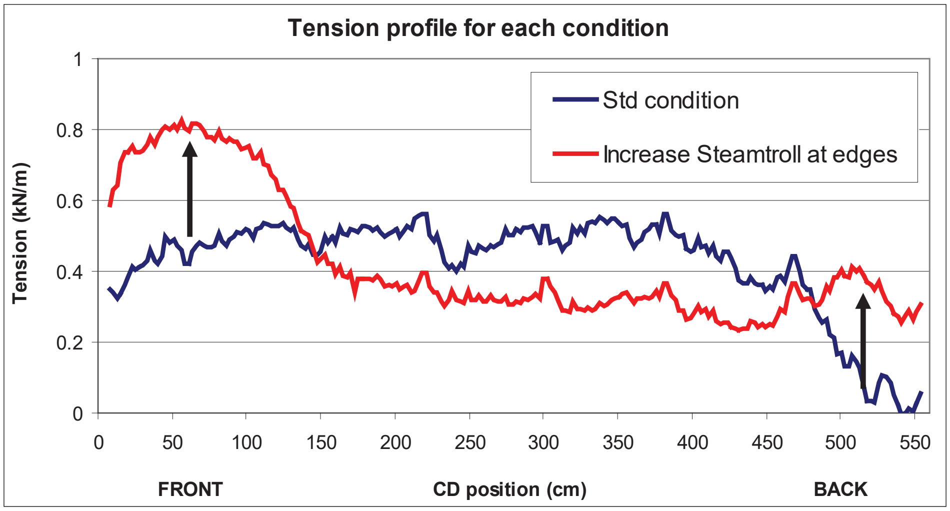


Figure 13 – CD tension profile for two conditions tested: normal versus steam increase at the edges of the machine

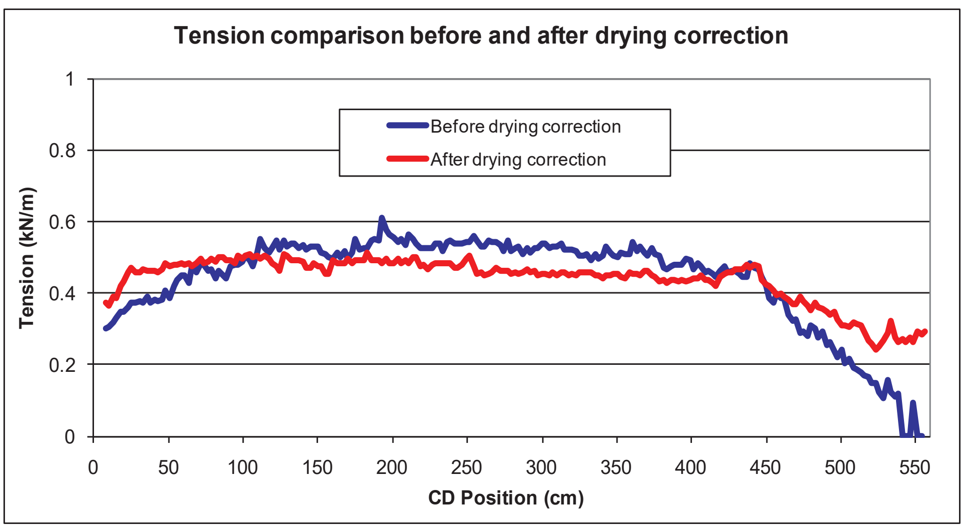


Figure 14 – CD tension profile comparison before and after drying modifications at the edges of the machine.

<u>Measuring Bagginess Areas and Correction by Changing CD Properties Profiles</u>

Another form of non-uniform tension profile is known as baggy streaks that appear to be zones of lower tension across the width of the paper machine. Figure 15 shows narrow baggy streaks across the width of a super-calendered paper web. These baggy zones are in fact areas where the local tension is lower. These zones of lower tension are generally cyclic in the cross-direction and are related to zones of higher moisture and/or basis weight. Higher moisture/BW zones take longer to dry and therefore the sheet locally elongates (higher stretch) at these areas, creating the bagginess (lower tension zones). Figure 16 shows the CD tension profile of a full width super-calendered paper machine having baggy streaks. Zones of lower tension are clearly shown and a frequency analysis completed on the tension profile showed that there was a periodicity in cross-direction: there was a zone of lower tension (or baggy area) every 6.80" in cross-direction. When a comparison was made with cross-width basis weight profiles, it was also found that there was a dominant frequency in the basis weight profile corresponding to the same frequency found in the bagginess profile.

Figure 15 – Narrow baggy streaks issue across the width of super-calendered paper

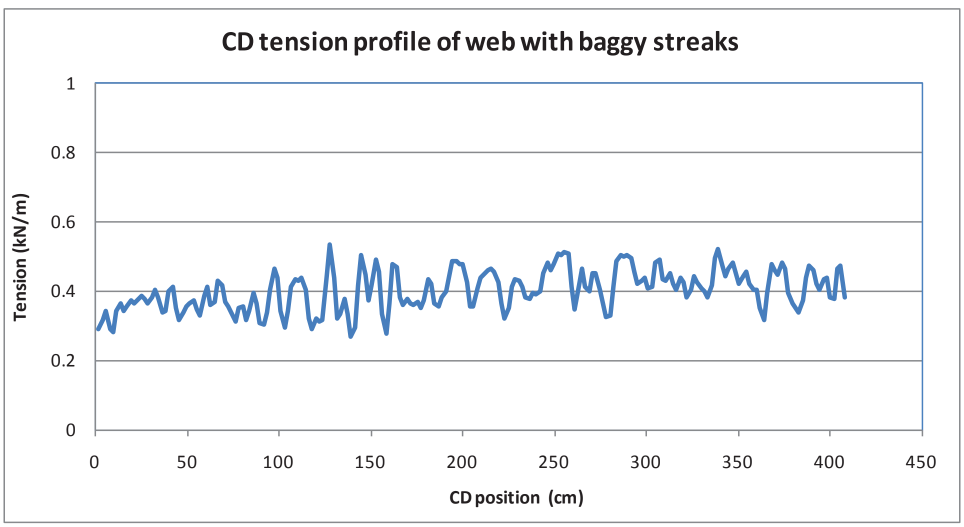


Figure 16 – Tension profile measurements of narrow baggy streak across the width of super-calendered paper machine (lower tension areas = baggy streaks)

As the baggy streaks were related to the basis weight CD profile, the mill took actions to decrease basis weight variation by changing headbox actuators spacing in CD (from 4.5" down to 3"). A frequency analysis completed after the headbox change showed that the dominant frequency in the CD basis weight profile disappeared (Figure 17). This also allowed eliminating the baggy streaks across the width of the machine.

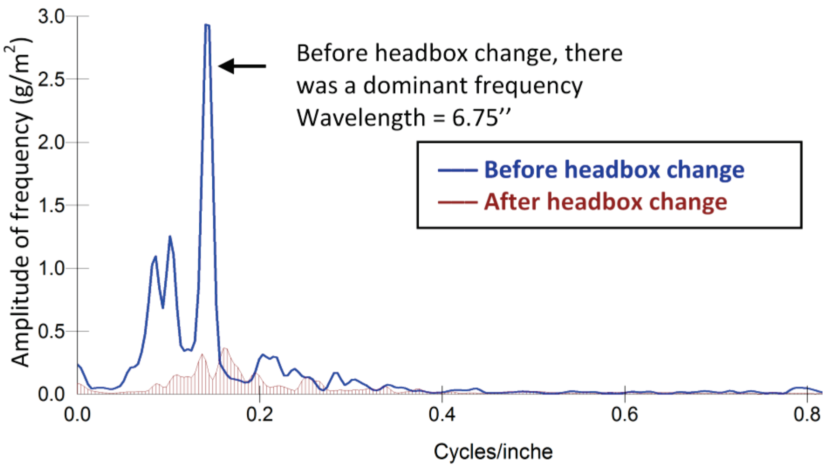
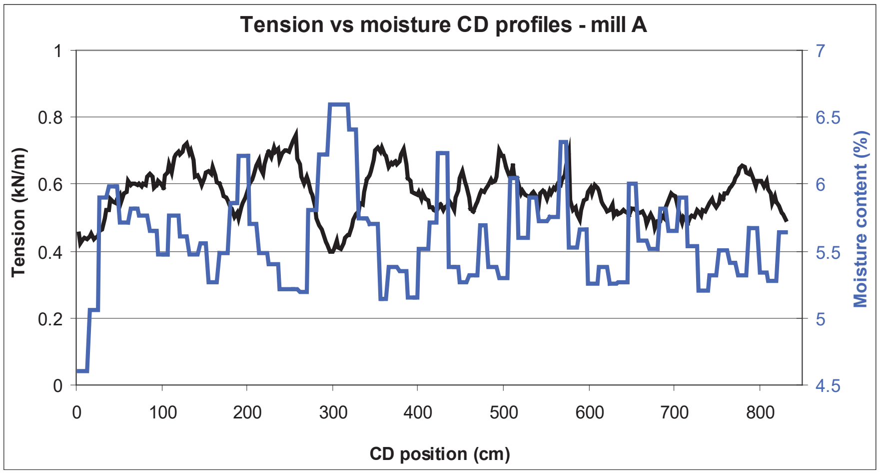


Figure 17 – Frequency analysis of the CD basis weight profiles before and after changes in headbox actuators spacing

Similarly to basis weight variations, it is well-known that moisture variations can affect tension in the CD and therefore cause bagginess in the pressroom. As shown in Figure 18 for a newsprint machine (mill A), measurement on the tension beam and comparison with the moisture profile demonstrated that the bagginess zones (defined as zones where the tension variations are lower by 0.2 kN/m or more) are related to high moisture content zones.

Moisture variation in CD can lead to significant bagginess problems, as shown on Figure 18 where the middle of a directory paper machine (mill B) shows significant tension drop of 0.2 kN/m over a 1 meter width. Again, there was a strong correlation between moisture and tension CD profiles. Regression analysis showed that the lower tension zones are closely related to higher moisture content. A strong correlation (R^2 =0.75 was found from the linear regression between the two parameters.



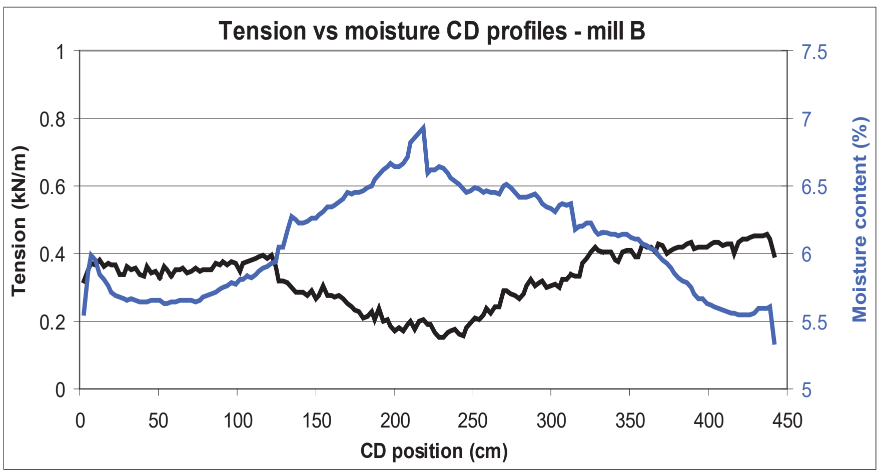


Figure 18 – Relationship between CD tension profile and CD moisture content profile for two different paper machines (higher moisture areas = low tension areas)

Correction in these cases is simple and consists of reducing moisture variations in CD. Moisture correction can be completed at the press section by the help of steambox. The use of crown or ends relieve on press loading can also be used to change moisture CD profile entering the dryer section.

Predicting CD Tension Profile from Basic Web Properties

Previous researches have shown that in some cases, it is possible to predict the CD tension profile with basic web properties [17]. In most of the cases for paper grades such as newsprint, directory and super-calendered grades, the CD tension profile would rely on CD moisture and CD basis weight profiles as explained in the previous section. However in other cases, the tension can be predicted with a mix of many properties. Multi-factors linear regression can be used to predict full width CD tension profile from available web properties measured in laboratory.

In the present case, the mill wanted to get a prediction of their CD tension profile from basic web properties measurements available at the mill. So instead of sending rolls on a regular basis to verify the uniformity of their CD tension profile, we developed a model that can be used to predict the full width cross-web profile at the mill. So based on the prediction, the operator can act rapidly to correct non-uniform property in case of excessive non-uniformity in the tension profile.

The model took into account many paper properties measurements as shown in equation 3. Some parameters have more influence than others on the predicted tension profile such as the TSI_{MD}, the TSI_{CD} and the moisture profiles.

Predicted Tension $= -7.72 + (1.40TSI_{MD}) - (2.05TSI_{CD}) + (0.12TSO) - (0.56Moisture) - (0.23Dry\ weight) + (0.17Caliper)$ {3}

Figure 19 shows a comparison between the measured profile using the tension beam and the predicted profile using a multi-variables linear regression of many web properties measured at the mill. Both profiles are similar, showing the large variations in the tension profile (especialy for the first half of the machine width). Now the mill has a tool to predict the full width CD tension profile. After major shut-downs or after machine modifications, the mill sends a full set of rolls covering the width of the machine for validation and correction of the model.

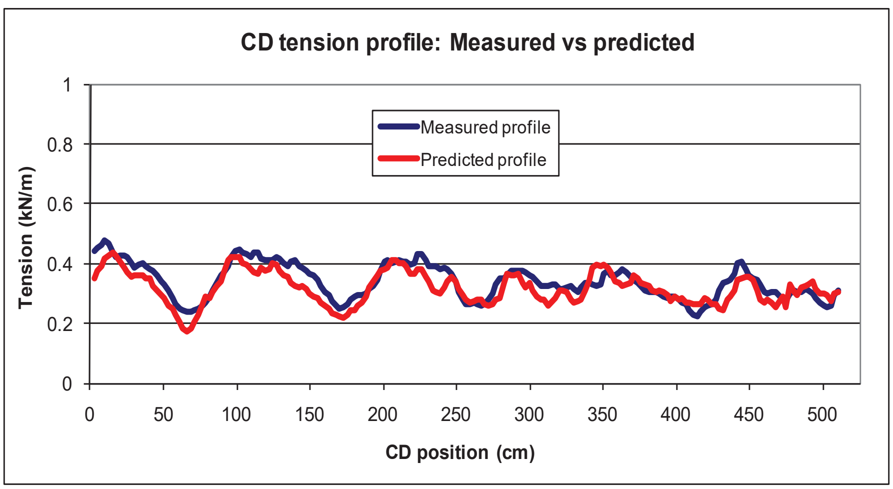


Figure 19 – Comparison between measured CD tension profile and predicted CD tension profile from basic web properties

CONCLUSION

A tension beam was developed to quantify CD tension profile of paper web. With a high accuracy (<5% error) and a high resolution (50 units over 127 cm width), this new tool was successful in measuring the tension non-uniformity of different types of web material. A reconstruction method was also developed to evaluate the tension profile of a full width machine. Bagginess and baggy edge can be quantified and predicted from basic web properties. The tension beam can be used to monitor the tension profiles corrections and later to ensure the uniformity of the profiles with time.

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Bagginess and Baggy Streaks: A Novel Measurement Technique to Quantify Tension Profile of a Web in Cross-Direction at High Resolution

F. Parent & J. Hamel, FP Innovations, CANADA

Name & Affiliation	**Question**
Ron Swanson, 3M Company	Can you explain TSI and TSO?
Name & Affiliation	**Answer**
F. Parent, FP Innovations	TSI is tensile stiffness index and TSO is tensile stiffness orientation. You may use this to quantify the fiber orientation on the machine. This is kind of a modulus of paper. You try to have a balanced TSO in order to have fibers oriented toward the edges and towards the machine direction in the center.
Name & Affiliation	**Question**
Ron Swanson, 3M Company	How are these parameters physically measured?
Name & Affiliation	**Answer**
F. Parent, FP Innovations	They are measured using ultrasound.
Name & Affiliation	**Question**
Unknown	I have a couple of questions about the functionality of the beam which measures the web tension with respect to CMD location. Each sector infers tension from a load transducer. The Teflon cylindrical sectors are 1 inch wide and there are 50 of them to measure tension variation across a web 50 inches wide. Is there an concept to use the instrument in a downstream application where variances in tension can be modified upstream in situ? Can it be used to monitor profiles to make corrections? Is there something that can be done to make a tension correction upstream in the process?
Name & Affiliation	**Answer**
F. Parent, FP Innovations	The tension beam can be used to monitor the CMD tension profiles and by itself cannot be used to correct tension variations.
Name & Affiliation	**Question**
Unknown	If your sensors can recognize bagginess in the web, will we be able to adjust the tension to correct for the bagginess upstream?
Name & Affiliation	**Answer**
F. Parent, FP Innovations	You would need to troubleshoot where the bagginess is coming from upstream in your process. The beam will not be able to adjust the tension variation, just measure it.
Name & Affiliation	**Question**
Kevin Sartain, Kimberly Clark	In your reconstruction method for the full parent rolls: Did you validate that using 12 inch smaller rolls to validate how you'd reconstructed to get to the full edge effects?

Name & Affiliation	**Answer**
F. Parent, FP Innovations	We have validated it. I cannot present it here because it is confidential. We have compared the measurements with the IQ and tension that was installed on a newsprint machine. We were able to compare the tension profile with the machine profile and found good similarity.