ON-LINE TENSION PROFILE OPTIMIZATION VIA MOISTURE PROFILE CONTROLS ON THE NEWSPRINT PAPERMAKING PROCESS

by

J. Kniivilä
Metso Paper Automation, Inc.
FINLAND

ABSTRACT

This paper describes a novel multi-profile control, which can simultaneously optimize both moisture and elongation and/or tension profiles of newsprint grades. The controller can include tension profile measurement [1][2] in its optimization to be able to optimize elongation changes in the newsprint.

The relationship between tension, shrinkage and elongation will be explored to enable understanding of how elongation changes can be optimized. Furthermore, differences between tension profile as a property of the papermaking process and as a property of paper will be discussed.

This paper also focuses on an implementation of the new multi-profile control system for the newsprint machine. The implementation as well as experiences from the controller are explored, and mill results presented.

Additionally, the paper explores what is required from the newsprint machine and the automation to be able to have an elongation and/or tension and moisture optimizing profile controller.

NOMENCLATURE

CD = cross-machine direction
MD = machine direction,
PM = Percent Moisture,
TE = Tension,
Tension Profile = Profile of the MD-tensions

INTRODUCTION

The paper web deforms geometrically during manufacture, especially operations involving drying or wetting of the paper web. This deformation includes shrinking as its water content falls below about 35% by mass, and stretching or elongation due to applied forces. Forces are applied especially in the direction of movement of the web, including a tension in the plane of the web. The tension is generally not uniform, since the shrinkage and elongation are not uniform, and these three properties are related to each other.

However, shrinkage and elongation are properties of the paper web, while tension is a property of the process. Non-uniformity in the web tension leads to a variety of problems, including sheet breaks on the paper machine or at finishing part of the paper machine and printing machines.

MAIN PROPERTIES AFFECTING THE TENSION PROFILE

Effect of Shrinkage on Tension Profile

Fig. 1 shows simulation results of the influence of the geometry by reducing the length of the free draw on the shape of the shrinkage profile. The total web width shrinkage was reduced when the length of the free draw was reduced, but the differences in shrinkage between the middle and edges of the web were increased [3].

When we got the opportunity to do a web slit test on a commercial newsprint machine, which makes standard lightweight newsprint papers and has a measurement system for the tension profile, we also wanted to measure the relative shrinkage profile before and after the slit. The sheet was slit by waterjet under the pick-up felt from the wire to the press before the press section.

Fig. 2 shows the results before and after the web slit. As a result from the normal web without slit, we can see a typical non-linear shrinkage profile when paper going through the press and drying sections. We can see how well tension profile measurement in this test correlates with the shrinkage measurement. Even the light asymmetry of the shrinkage profile can be seen in the tension profile measurement. Fig. 2 also shows non-linearity for the shrinkage and tension caused by the press and dryer sections even for the slit web.

Moreover from the shrinkage and tension profiles after the web slit, we can see that there are new edges in the middle of the sheet, which look like normal web edges and make the shrinkage profile look like shrinkage from two narrower machines.

Effect of Web Elongation on Tension Profile

On a pilot machine at Metso Paper Järvenpää, we performed a paper web length measurement test, in which we tried to measure the relationship between the elongation and tension properties. Fig. 3 shows the basic arrangement for the paper web when measuring elongation changes. Paper web was 1.0m wide and cut into 5cm wide strips. The length was measured on both sides of each strip. The paper sample length for the test was 30.24m. Also, the modulus of elasticity was measured for each strip. Fig. 4 shows the measured tension, modulus of elasticity and elongation profiles. The measurement results show us that tension changes on the web correlate better with the length changes of the web than the elasticity of the web. We can also see that where the tension is high, the length of the web is short and vice versa. Differences in the elongation changes with a maximum of 0.03% in this test, were quite small and, as usual required require good accuracy for the measurement to be seen in the results. [4]

Effect of Moisture on Tension Profile

Fig. 5 shows moisture profile measurement changes and related tension profile changes made by a steam box in the presses. We can see that, in the areas where the sheet has dried, tension has increased and vice versa. Also, corresponding results with smaller response amplitude can be seen with rewet at the end of drying section.

Fig. 6 shows the effect of moisture profile changes on the tension over $1\frac{1}{2}$ hours period after the sheet break. We can see that changes in the moisture profile explain changes in the tension difference profile.

Effect of Spreading on Tension Profile

Spreading is a converting process that widens the web on or near the spreading element. If the web is widened, some types of wrinkles can be alleviated. However, spreading rarely leaves any permanent effects for the web [5]. Therefore we do not want to utilize moisture for "correcting" those changes to tension measurement, Fig. 7, which cannot be seen as quality property of the final product. Instead of tension optimization, we want to improve elongation to be able to achieve more even length of the web and improve thus the quality of the paper.

THE BASIC PRINCIPLE OF WEB ELONGATION CONTROL [6],[7]

Cellulose fibers swell when wetted, and shrink when water is removed. This dimensional change is less along the axis of the fiber than across the axis. Paper is formed from aqueous suspension in the wet end and de-watered through pressing and drying to a moisture level of typically 5 – 7 %. As a result, it shrinks by several percent. No shrinkage occurs in the initial de-watering in the forming section and presses, as the water content is too high and fiber bonding is weak. As soon as the sheet has sufficient fiber bonding strength to support itself, shrinkage will accompany further de-watering.

However, the paper web is dimensionally restrained for part of its journey, being supported and transported by fabrics, which impose frictional constraints on shrinkage. It is completely supported through the forming and pressing section, but open draws occur thereafter. When subsequent de-watering occurs to these fabrics, the sheet receives an increment of strain, which can be relaxed only when it is an open draw, where it is less constrained in dimension. If the sheet is sufficiently wet, the strain is generally plastic (no stress is included), or viscous (stress depends on rate of deformation, rather than on amount). This is the case in the forming and pressing sections, and in the initial drying stages. Strain due to constrained shrinkage when the sheet is drier is generally elastic – it induces a stress or tension. The elastic strain will be maintained if suitable tension is applied and will relax otherwise.

The sheet is under MD tension in open draws, to support the mass of the web, stabilize its path, provide forces needed to detach it from fabrics and cylinders, and to overcome aerodynamic drag. Local MD tension prevents relaxation of strain in the sheet in the MD. However, if the strain can relax in the CD, this leads to local Poisson or Poisson-like elongation in MD, and results in a lower local MD tension. There is no externally applied CD tension per se, but the sheet is dimensionally restrained in CD at each end of the draw, and the length of the draw is typically much shorter than the sheet width. As a result, there is a CD tension profile induced in the open draw as a result of the straining due to de-watering. This CD tension is much less than the MD tension, and falls essentially to zero at the sheet edges, which are less restrained than the sheet center. Thus, although the sheet stretches in the MD both plastically and elastically, more than countering the effect of shrinkage in MD, it shrinks overall in the CD, and the shrinkage is greater at the edges than in the middle of the sheet.

Local MD dimensional change is the sum of local elongations due to the CD shinkage, local plastic strain, and local elastic strain. The amount of local elastic strain largely determines the local web tension (together with the local elastic modulus of the sheet). In an open draw, the total MD dimensional change is the same at all locations across the sheet, and reflects the difference in speed of the upstream and downstream rolls. The MD tension profile will reflect the balance at each point between cumulative MD plastic strain, cumulative MD elongation due to CD shrinkage, current plastic or viscous straining, and cumulative elastic straining at a given speed difference.

In the initial drying, where the strain tends to be viscous or plastic rather than elastic, non-uniform MD elongation due to non-uniform CD shrinkage does not affect the tension profile. In the later drying, where strain tends to be elastic, non-uniformity in MD elongation causes a tension profile, due to the process described above. There is gradual transition between these two regimes, occurring during the initial stages of drying. In the presses and before the first open draw, strain is plastic in both MD and CD, and no dimensional change occurs.

The basic principle of web elongation control is to change the evolution of the CD shrinkage profile, so that the CD shrinkage non-uniformity occurs mainly in the initial drying, where the plastic strain of the sheet will match MD elongation due to CD shrinkage. Shrinkage in the later drying is then more nearly uniform, so that the MD elastic strain (and hence MD tension) are more uniform.

Since the evolution of the shrinkage profile is determined by the evolution of the moisture profile, web elongation control is carried out by non-uniformly dewatering the sheet in the wet end. The intention is that parts of the sheet which tend to shrink more in the CD are dewatered more in the plastic regime. Ideally, this is achieved using a steam box or other suitable CD moisture actuator in the forming section or presses. Since this also causes a non-uniform moisture profile entering the dryers, it may adversely affect the moisture profile at the reel. Preferably, there is also another CD moisture actuator situated close to the reel to correct the moisture profile. If this latter actuator is close to the reel, then its effect on subsequent shrinkage, elongation, and tension is small. However, if it is distant from the reel, its effect on elongation and tension may be significant.

WEB ELONGATION-MOISTURE CONTROL SYSTEM

Fig. 8 shows a block diagram of the web elongation-moisture control system. In this solution, the first CD moisture actuator for the steam box in press section is governed to control the web elongation profile and the second CD moisture actuator rewet is governed to control the moisture profile. The control of the steam box employs an optimization, which includes the operating state of the rewet actuator. Thus, control of web elongation using the steam box actuator is not allowed to force the rewet actuator outside set limits. Hence, the moisture profile is given precedence over the web elongation profile.

Elongation and/or Tension Target Management

When no online shrinkage or elongation information is available, the target for the controller must be provided from the tension measurement. In the first phase of the implementation, Target Management comprises of two layers:

1. Tension Reference optimization, and
2. Tension Target optimization.

The Tension Reference optimization layer maintains the reference level, which will be updated if process measurements such as change of the web spreading angle will change the shape of the measured tension profile. Tension Reference is needed when calculating tension difference for the controller. The Tension Difference measurement is included in the optimization.

An operator can change the Tension Target from the Tension Controller Operator display, Fig. 9. He defines how much we want to improve the tension difference profile shape by using moisture actuators.

Multi-Profile Optimization

The controller works by minimizing a quadratic objective function by means of a gradient method modified for constrained optimization. The objective function is composed of terms for each controlled profile and terms for the actuation system:

$$\begin{aligned} Objective &= \lambda_A P_A^T Q_A P_A + \lambda_B P_B^T Q_B P_B + \lambda_C P_C^T Q_C P_C + \ldots \\ &+ \lambda_{UX}(M_X U_X)^T (M_X U_X) + \lambda_{UY}(M_Y U_Y)^T (M_Y U_Y) + \ldots \end{aligned} \qquad \{1\}$$

in which λ_A, λ_B, λ_C, λ_{UX}, and λ_{UY} are positive scalar weighting factors. Q_x, Q_y, M_x, and M_y are weighting matrices. More general form is given in [8].

For a multiple actuator systems multiple error profiles P_A, P_B, and P_C, etc. and actuator profiles U_X, Uy, etc. may be appended to form composite profiles, with a block response matrix:

$$P = \begin{bmatrix} P_A \\ P_B \\ P_C \end{bmatrix} \qquad R = \begin{bmatrix} R_{AX} R_{AY} \\ R_{BX} R_{BY} \\ R_{CX} R_{CY} \end{bmatrix} \qquad U = \begin{bmatrix} U_X \\ U_Y \end{bmatrix} \qquad \{2\}$$

The algorithm above can be applied to the composite system, with suitably constructed composite operators. For instance, if the relative weights for the three profiles are λ_A, λ_B, λ_C, and the relative weights for actuator functionals M_X, M_Y are λ_{MX} and λ_{MY}:

$$Q = \begin{bmatrix} \lambda_A Q_A & & \\ & \lambda_B Q_B & \\ & & \lambda_C Q_C \end{bmatrix} \qquad \{3\}$$

$$M = \begin{bmatrix} \lambda_{MX} M_X & \\ & \lambda_{MY} M_Y \end{bmatrix} \qquad \{4\}$$

Using terms, which penalize deviations from a reference state is essential in control of actuators which have opposite responses, and which have a cost related to their state.

Each controlled profile has its own target shape, which can be modified by the operator. The scalar weighting factors for the profile errors may be supplied by a grade parameter package, and may be changed by the operator. Scalar weighting factors for the actuator terms may be fixed during commissioning or may be operator entered.

CONTROL PERFORMANCE

The multi-profile tension-moisture controller was commissioned in a newsprint machine with a production speed that can reach over 1800 m/min. The newsprint contains over 70% recycled fibers.

In web tension-moisture control, the steam box controls both moisture and tension. When dedicated to curl control, rewet has a smaller profiling capacity and therefore controls only moisture in this installation. Fig. 11 and 12 show the control performance of the on-line tension profiles obtained when tension was optimized by decreasing moisture at the edge roll areas, Fig. 10. Results from the controlled tension and moisture profiles are compared to a situation in which only moisture was optimized and the target shape for the moisture profile was flat, despite the fact that a totally flat moisture profile has not been the main target in the machine for some time.

DISCUSSION AND CONCLUSIONS

The development of the elongation and moisture profile controller that includes tension profile measurement in its optimization was discussed. Controlling tension, which is a property of the papermaking process, was not the main target in developing this controller. Properties of the paper web, such as elongation and shrinkage and a decrease in their non-uniformity, were the main goal.

To be able to attenuate shrinkage non-linearity, new solutions in the paper machine are needed. Optimizing moisture profile requires a greater number of profiling actuators with more capacity than are nowadays typically found in paper machines. After construction improvements are implemented in the machine, we can achieve all the benefits from the kind of controller discussed here.

Nevertheless, results of this study also show, for example, that the whole truth is not always to have a flat moisture profile from press to dryer section. Based on our experience in commissioning both tension measurement as well as the controller utilizing it, we can see that over-dried edges improve the runnability of the paper machine. A rewetting actuator at the end of the dryer section allows us to achieve improved runnability while preserving optimum moisture.

ACKNOWLEDGEMENTS

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ILLUSTRATIONS

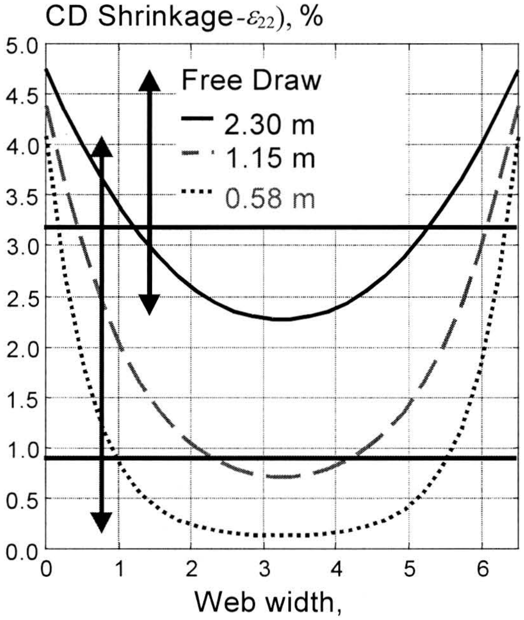


Fig. 1 Simulated Shrinkage Profile for Different Lengths of the Free Draw [4]

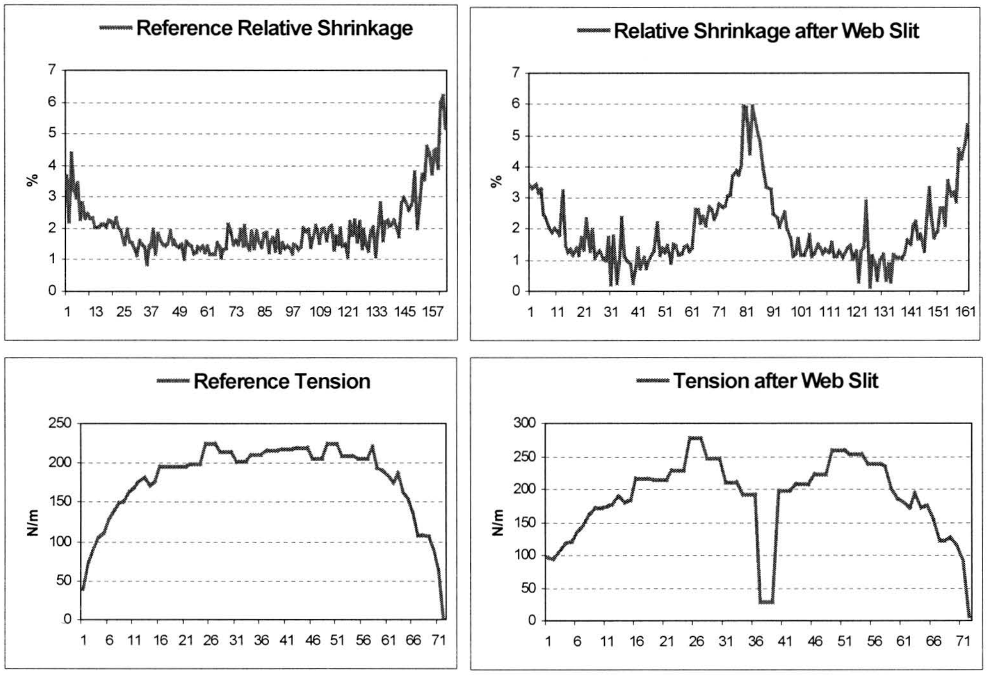


Fig. 2 Shrinkage and Tension Profiles Before and After the Web Slit

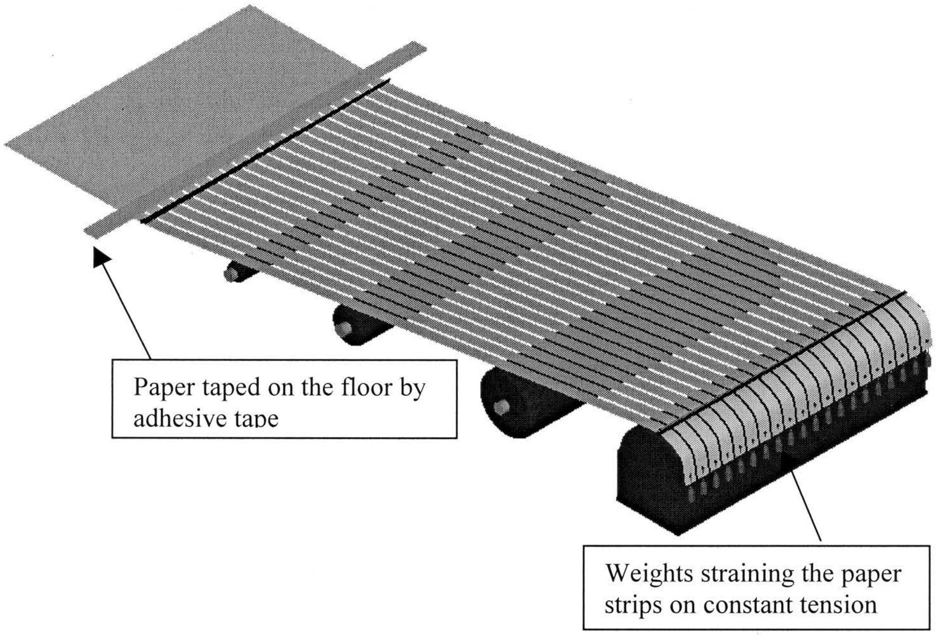


Fig. 3 The Basic Arrangement for the Paper Web when Measuring Elongation Changes

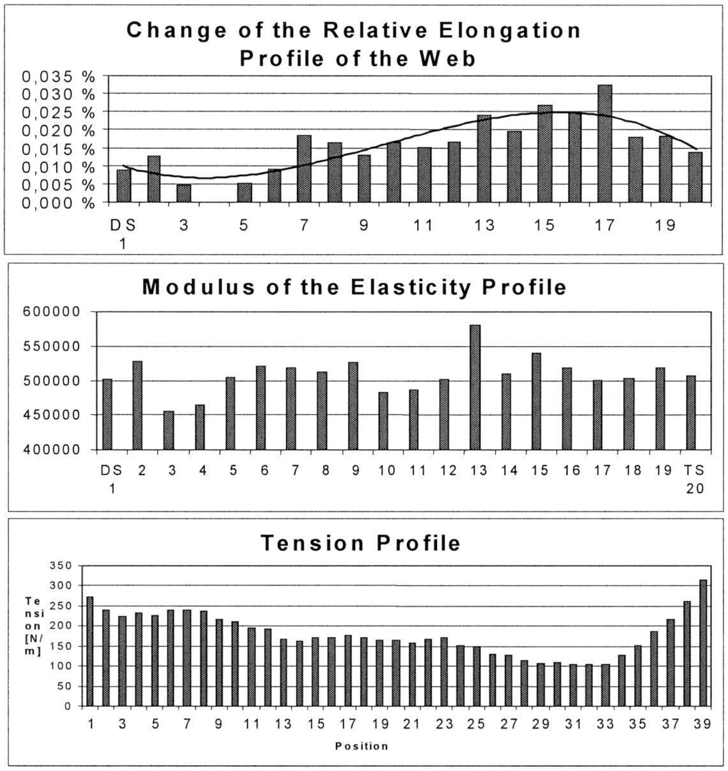


Fig. 4 Elongation-Tension Relationship based on Pilot Machine test

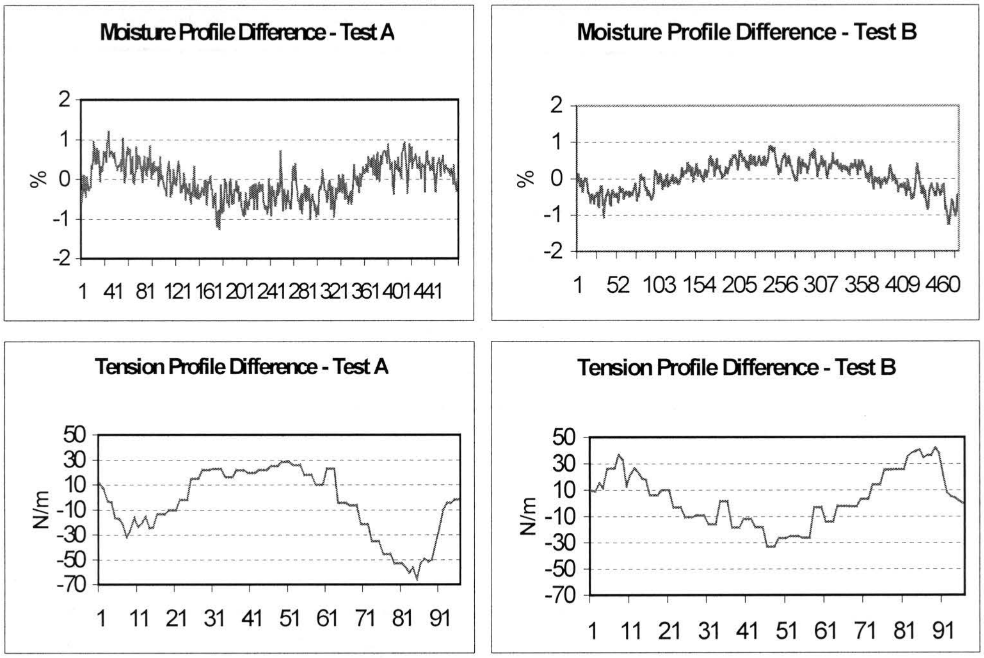


Fig. 5 Moisture and Tension Profile Changes Made by Steam Box in the Presses

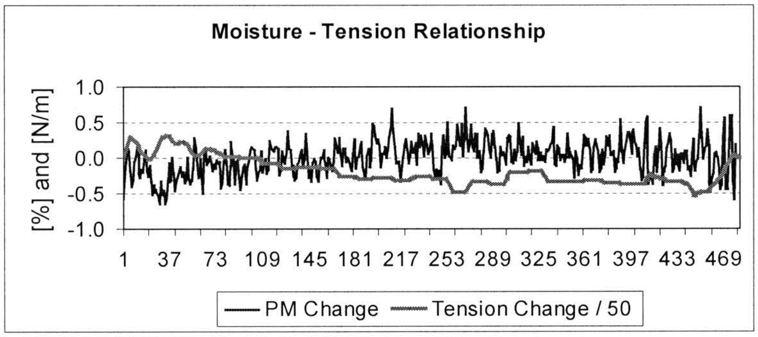


Fig. 6 Tension and Moisture Changes Following a Break

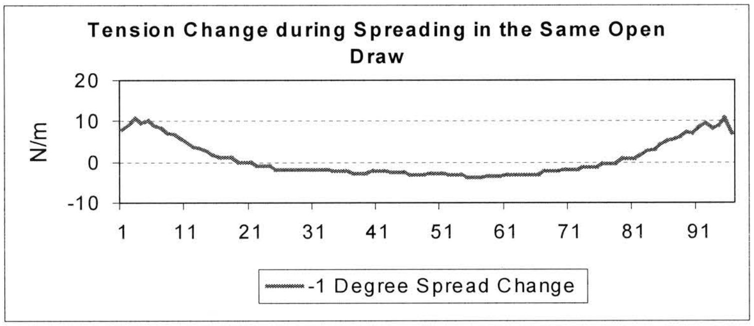


Fig. 7 Web Spreading Changes Locally Tension

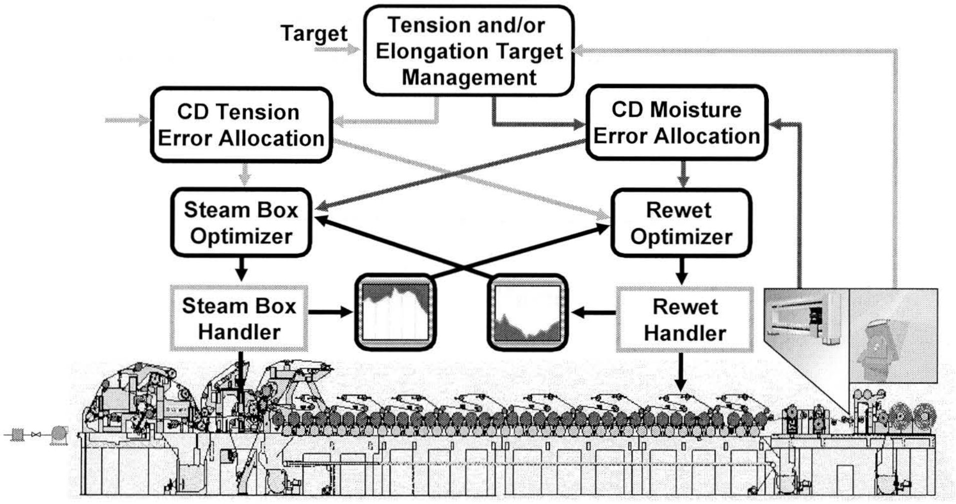
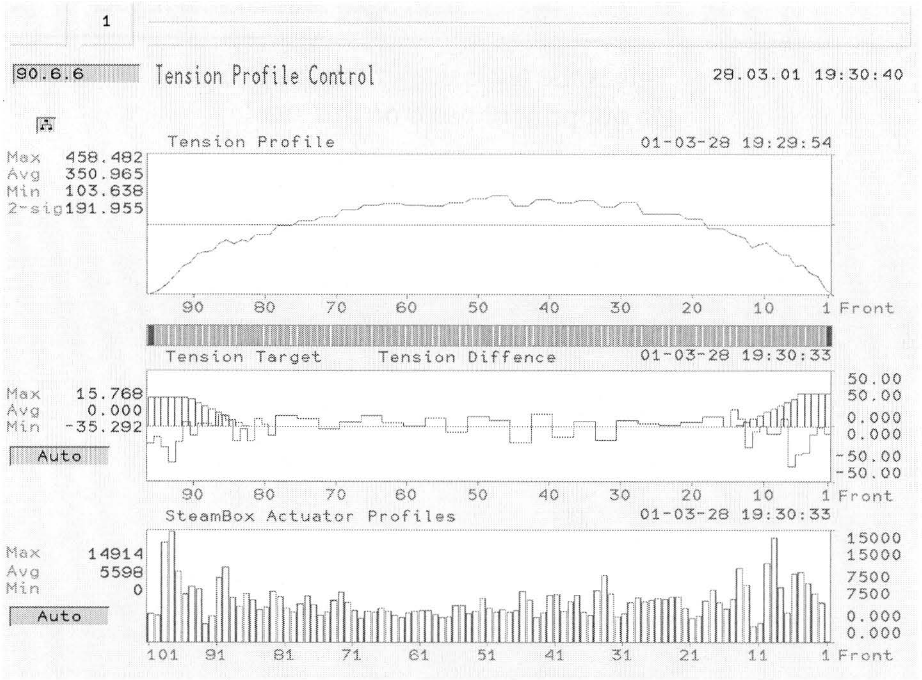


Fig. 8 On-line Web Tension Profile Control via Web Moisturization


1

90.6.6 Tension Profile Control 28.03.01 19:30:40

Tension Profile 01-03-28 19:29:54

Max 458.482
Avg 350.965
Min 103.638
2-sig 191.955

Tension Target Tension Diffence 01-03-28 19:30:33

Max 15.768
Avg 0.000
Min -35.292

Auto

SteamBox Actuator Profiles 01-03-28 19:30:33

Max 14914
Avg 5598
Min 0

Auto

Fig. 9 Operator Display for Web Tension Profile Controller

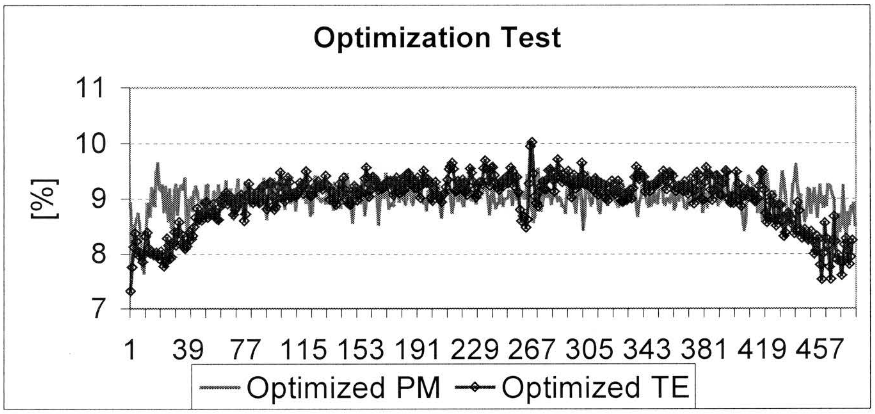


Fig. 10 Moisture Profiles when Moisture or Tension Optimized

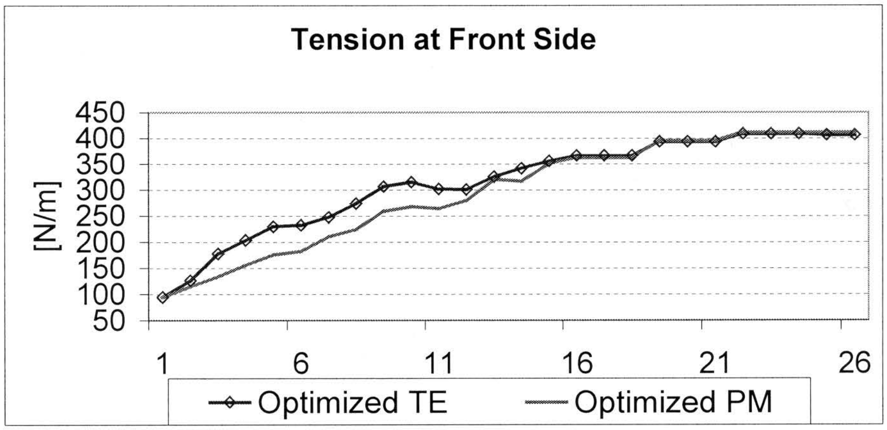


Fig. 11 Tension Profiles at the Front of Web when Moisture or Tension Optimized

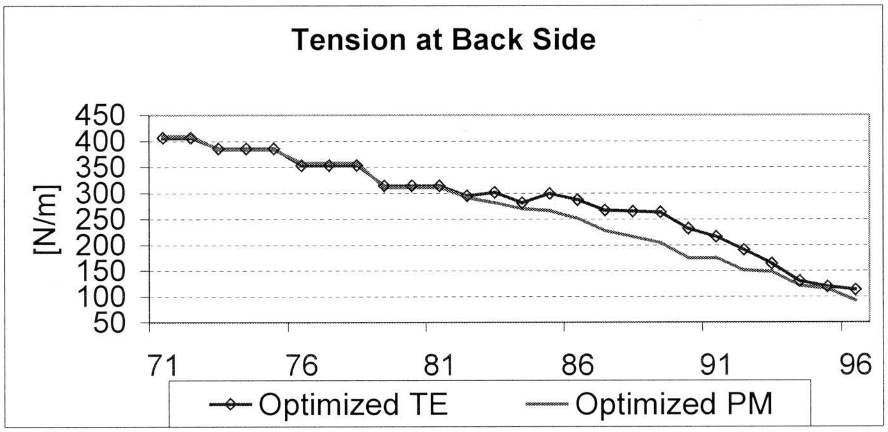


Fig. 12 Tension Profiles at the Back of Web when Moisture or Tension Optimized

On-line Tension Profile Optimization via Moisture Profile Controls on the Newsprint Papermaking Process

J. Kniivila – Metso Paper Automation, Inc., Finland

Name & Affiliation	**Question**
J. Hamel – Paprican	Could you expand upon you description of how you performed the shrinkage measurement?
Name & Affiliation	**Answer**
J. Kniivila – Metso Paper	The shrinkage was measured in the Metso Paper Laboratory. The measurement is based on wire marking technique.
Name & Affiliation	**Question**
D. Pfeiffer – JDP Innovations, Inc.	What is the definition of the measurement of relative elongation that was at the top of your figure of bar graphs? Was this measured by recording the elongation of the web resulting from hanging weights on the web?
Name & Affiliation	**Answer**
J. Kniivila – Metso Paper	Perhaps in the figure a better title than relative elongation change would have been relative length. Relative length was calculated for each strip in reference to the length of the shortest strip.
Name & Affiliation	**Question**
D. Pfeiffer – JDP Innovations, Inc.	Under what conditions were the measurements made, were these strips 2 cm wide with weights hanging on the end?
Name & Affiliation	**Answer**
J. Kniivila – Metso Paper	The width of the strips was 5 cm. Measurement of the length profile is difficult because of the very small differences. The measurements were made without weights.
Name & Affiliation	**Question**
D. Pfeiffer – JDP Innovations, Inc.	The second part of the same chart shows a profile of the modulus of elasticity. Was that a laboratory measurement?
Name & Affiliation	**Answer**
J. Kniivila – Metso Paper	Yes. We calculated the elastic modulus profile based on the change in length of each strip when subjected to four different stress levels.
Name & Affiliation	**Question**
D. Pfeiffer – JDP Innovations, Inc.	So, the fact you didn't get a good correlation might have been due to the measurement technique?
Name & Affiliation	**Answer**
J. Kniivila – Metso Paper	The accuracy would have improved if we had a dedicated measurement for the modulus of elasticity profile available. Based on our studies, there is not good correlation between modulus of elasticity and tension.