MODELING OF EDGE ROLLS DEFECTS

by

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ABSTRACT

Based upon Hakiel's nonlinear orthotropic model for wound rolls, a model has been developed which takes into account widthwise variations in web properties . The model includes widthwise variations in the elastic modulus in the machine direction and it includes the effect of slack edges which is modeled as a widthwise variation in initial strain. Both variations can typically be found in paper and they are possible causes of soft outer edges on wound rolls. The variations are included by modifying the outer boundary condition in Hakiels model. Calculations show that in-roll pressure decreases towards the edge if there is a slack edge or the elastic modulus has a lower value at the edge than elsewhere. This is consistent with empirical observations.

NOMENCLATURE

E	MD elastic modulus, Pa
h	web thickness, μm
P	in-roll radial pressure, Pa
s	peripheral radius (outer radius), m
T	web line tension, N/m
w	width of web, m
y	widthwise position, m
σ	web line stress, Pa
ε	web strain
ε_0	initial strain

INTRODUCTION

Wound roll quality is important in the relationship between manufacturer and customer. Bad quality will not sell in a market where competitors are ready to provide rolls of better quality. Rolls that are described as poor rolls, are often edge rolls. With edge rolls we understand the leftmost and rightmost rolls in a roll set. These rolls typically produce a tension profile with greater widthwise variation. If these variations are too bad the rolls will behave badly in printing presses with different kinds of runnability problems. These rolls are often characterised by outer edges that are softer than the other parts of the roll. Traditionally this has been explained by low web thickness on the edges[1]. Some manufacturers even provide sertificates for their winders which guarantee good roll quality as long as the thickness profile is acceptable. In the following sections we will see how rolls with poor quality may be produced even with acceptabale thickness profiles. This we will do by the means of a mathematical model.

THEORY

Modeling of stress and strain in wound rolls dates back to the late 50's when Gutterman[2] and Catlow & Walls[3] published articles on calculations of wound roll stresses. Several other wound roll models have been published since then. Today the most used model is the model of Hakiel[4] which incorporates orthotropic and nonlinear material behavior. The model adds up the pressure contribution from each layer wound on to the roll. While the roll has an outer radius s during winding, the pressure P underneath the outermost layer is given by

$$P = \frac{h}{s}\sigma \tag{1}$$

where h is web thickness and σ is web line stress. This is the outer boundary condition of Hakiel's model.

Since the reason for soft outer edges are suspected to be some kind of widthwise variation in web properties, this has to be included in Hakiel's model. The effect of widthwise variations in web thickness has been included by Cole & Hakiel[5], but many paper rolls have soft outer edges in spite of good thickness profiles. Thus other web properties need to be considered. Two properties that may affect the roll hardness are elastic modulus and web slackness. Any widthwise variation in these properties will yield a widthwise variation in the incoming web stress. The incoming web stress is then a function of the widthwise position y. The outer boundary condition is modified to

$$P(y) = \frac{h}{s}\sigma(y) \tag{2}$$

accounting for widthwise variations in elastic modulus and slackness. By assuming that all drums and rollers in the winder are parallel, the total strain ε (machine direction) is constant across the width, and the web stress is given by

$$\sigma(y) = E(y)\left\{\varepsilon - \varepsilon_0(y)\right\} \tag{3}$$

where E is the elastic modulus and ε_0 is initial strain representing slackness. Due to its bending stiffness, paper has a very low ability to carry compressive forces in the machine (or cross) direction. Therefore we make the restriction that stresses cannot be compressive.

This restriction and Eq.(3) yield the following expression for the web stress:

$$\sigma(y) = \begin{cases} E(y)\,\{\varepsilon - \varepsilon_0(y)\} & : \ \varepsilon > \varepsilon_0(y) \\ 0 & : \ \varepsilon \leq \varepsilon_0(y) \end{cases} \tag{4}$$

Total web strain ε is not a given or measured quantity. Thus it needs to be calculated from the web line tension T, which is known from on-line measurements. Mathematically the relation between web line tension and web strain is given by

$$T = \int_0^w \sigma(y)\,dy \tag{5}$$

The combination of Eqs.(4) and (5) will yield a value for ε and thus a known expression for the local web stress $\sigma(y)$. Inputs are web line tension and profiles of elastic modulus and initial strain.

Application of Eqs.(2) and (4) as the outer boundary in Hakiel's model, transforms this model from a one dimensional model to a two dimensional model. The extended model enables calculations of stresses in wound rolls as a function of radius *and* widthwise position.

WEB PROFILES AND WIDTHWISE ROLL VARIATIONS

Initial strain and elastic modulus as functions of the widthwise position are input parameters to the model. Assuming that initial strain propably is less than 0.5% we realize that it is not straightforward to measure. Publications of elastic modulus measurements show profiles with edge values that are typically 10% less than the average value. For really poor edge rolls the edge value may be even lower, but it is very unlikely that any paper mill will go public with such profile measurments. Due to these difficulties we will look at examples with assumed web profiles.

First we will study the effect of variations in elastic modulus. To single out the effect of these variations we neglect initial strain. For paper the variations in elastic modulus are mainly a result of cross directional variations in the fibre orientation. This is caused by settings in the headbox and forming section of the paper machine. As mentioned above edge values of elastic modulus are typically 10% less than the values in the center of the web. Since we are looking for poor rolls, we will assume that there is a reduction in elastic modulus of 20% at the edges. Such a profile is plotted in Fig.1. For sets of rolls wound at a web tension of 400N/m with no initial strain, variations in elastic modulus as in Fig.1 and other properties as in Table 1, we calculate an in-roll radial pressure as represented by Fig.2. We see that the outer edges are softer than the center region. In Fig.3 we compare the in-roll radial pressure between edge and center position. The ratio between the *edge pressure* and *center pressure* is about 0.88.

Next we study the effect of initial strain, and thus we assume no variations in elastic modulus. For paper, initial strain or slackness may be caused by widthwise variations in moisture throughout the paper machine, especially in the drying section. Parts of the paper which dry relatively early in the drying section tend to have a larger in-plane physical dimensions compared to those parts drying later[6]. Edges dry relatively early, and thus the edges tend to be longer than the central parts. This is the reason for the slackness which we model as initial strain. Values for initial strain is not known in the litterature, so an assumption needs to be made. We believe that a moderate value for initial strain would be 0.005%. Applying an initial strain profile as in Fig.4, a constant elastic modulus and other properties as in Table 1, we get in-roll radial pressure as in Fig.5 for a set of rolls wound with a winding tension of 400N/m. Comparing the radial pressure at the edges with the pressure at the center (see Fig.6) we find a ratio between the edge pressure and center pressure at about 0.76.

The combined effect of widthwise variations in elastic modulus and initial strain is demonstrated by making a calculation with both variations. With an elastic modulus profile as in Fig.1 and an initial strain profile as in in Fig.4, we get results as in Figs.7 and 8. The ratio between the edge pressure and center pressure is about 0.67. We see that in-roll pressure decreases towards the edge if there is a slack edge or the elastic modulus has a lower value at the edge than elsewhere. This is consistent with empirical observations. Thus we find that soft outer edges is caused by not only thickness profiles, but also by slackness and widthwise variations in elastic modulus. One could try to compensate for this by extra straining at the edges or applying a harder nip pressure at the edges. This should in theory enable production of rolls without soft edges. However, the slackness and widthwise variation in elastic modulus will still be present in the web when the rolls are unwound at printing mills. As long as the web has significant widthwise variations in these properties, the roll will not behave well even if the roll structure is good. We are therefore dealing with a web defect and not a roll defect.

Comparing the effect of widthwise variations in elastic modulus and initial strain show that initial strain is the most significant of the widthwise variations assumed here. Note that the variations in elastic modulus were assumed relatively high and the initial strain was given a moderate value compared to what we might expect. Thus one might argue that in general slackness or widthwise variations in initial strain is more significant than widhtwise variations in elastic modulus for the soft outer edge phenomenon. Care should however be taken with this conclusion since no real measurements of initial strain is known. Future work should focus on measuring the slackness or initial strain.

CONCLUSION

A mathematical model have shown that soft outer edges in a set of wound rolls will be the result of slack edges or an elastic modulus that is decreasing towards the edge. The effect of slackness seems to be more significant than the effect of widthwise variations in elastic modulus.

ACKNOWLEDGMENTS

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REFERENCES

[1] Smith,R.D. Roll and Web Defect Terminology. TAPPI Press, 1 edition, 1995.

[2] Gutterman,R.P. "Theoretical and Practical Studies of Magnetic Tape Winding Tensions and of Environmental Roll Stability". U.S.Contract No. DA-18-119-SC-42, 1959.

[3] Catlow,M.G. & Walls,G.W. "A Study of Stress Distributions in Pirns". Journal of Textile Institute Part 3, pages T410–429, 1962.

[4] Hakiel,Z. "Nonlinear Model for Wound Roll Stresses". TAPPI Journal, 70(5):113–117, 1987.

[5] Cole,K.A. & Hakiel,Z. "A Nonlinear Wound Roll Stress Model Accounting for Widthwise Web Thickness Nonuniformities". In Proceedings of the 1992 Winter Annual Meeting of the ASME, Symposium on Web Handling, pages 13–24, 1992. AMD-Vol.149.

[6] Thun,M. The Influence of Drying Strategies on the Mechanical Properties of Paper. PhD thesis, KTH, 1980.

elastic modulus [GPa]	3.5
Poisson's ratio	0.01
core modulus [GPa]	1.5
core o.radius [m]	0.05
web thickness [μm]	70
radial modulus [kPa]	$488.3 + 29.5P$ $-0.043P^2 + 0.0000349P^3$

Table 1: Roll and web properties.

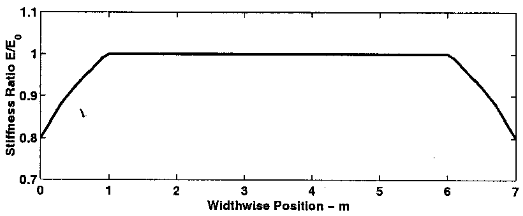

Figure 1: *Widthwise variations in elastic modulus.*

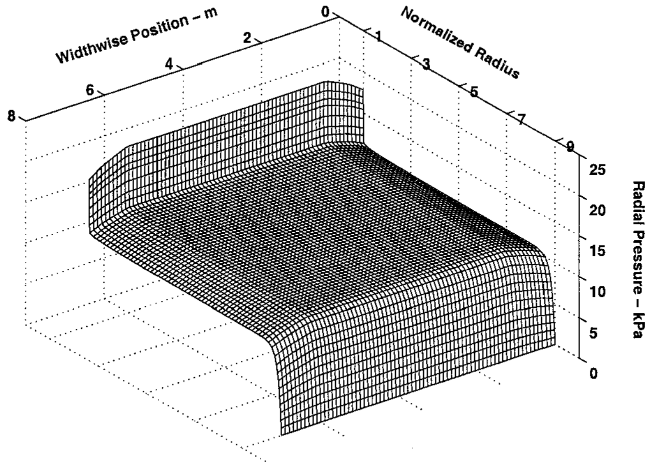

Figure 2: *In-roll radial pressure as a function of widthwise position and in-roll normalized radius due to widthwise variations in elastic modulus.*

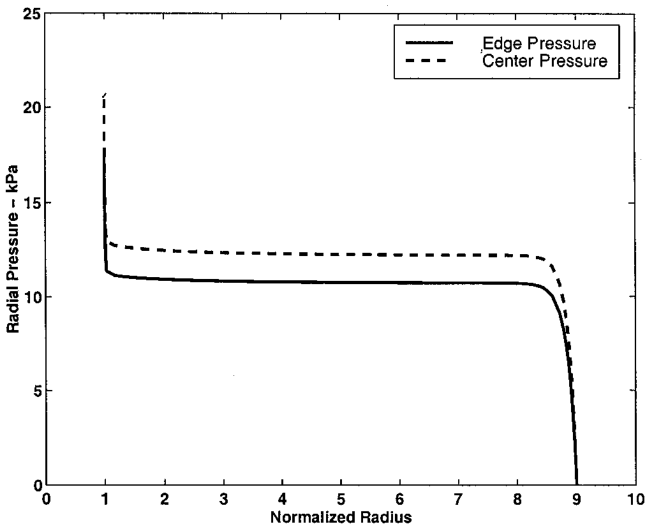

Figure 3: *In-roll radial pressure as a function of in-roll normalized radius for edge position and center position due to widthwise variations in elastic modulus.*

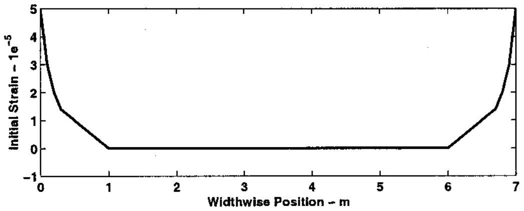

Figure 4: *Widtwise variations in initial strain.*

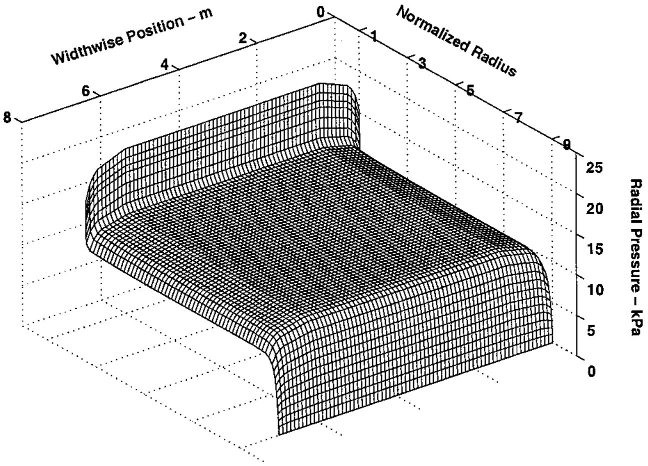

Figure 5: *In-roll radial pressure as a function of widthwise position and in-roll normalized radius due to widthwise variations in initial strain.*

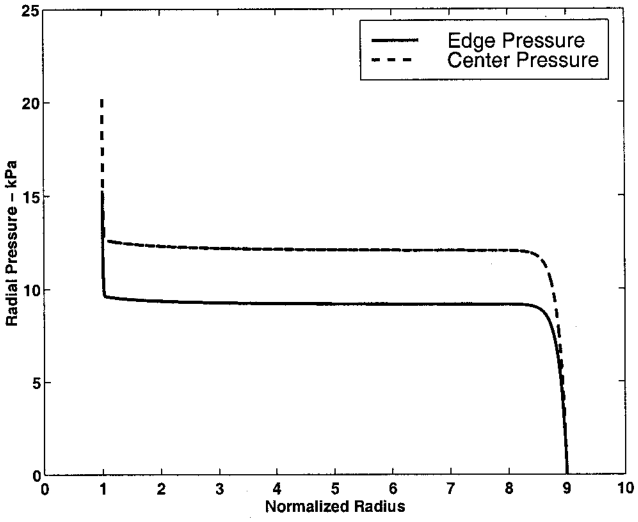

Figure 6: *In-roll radial pressure as a function of in-roll normalized radius for edge position and center position due to widthwise variations in initial strain.*

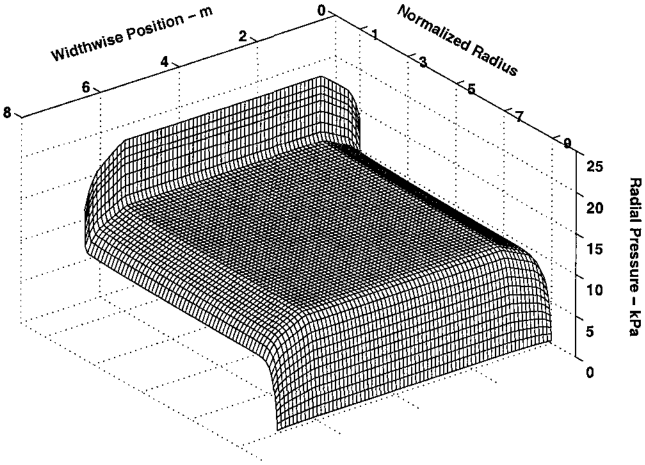

Figure 7: *In-roll radial pressure as a function of widthwise position and in-roll normalized radius due to widthwise variations in initial strain and elastic modulus.*

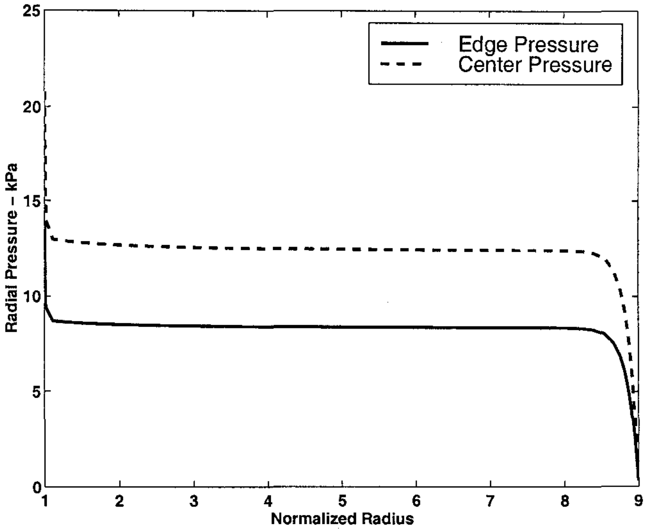

Figure 8: *In-roll radial pressure as a function of in-roll normalized radius for edge position and center position due to widthwise variations in initial strain and elastic modulus.*

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Modeling of Edge Rolls Defects
6/7/99 Session 1 10:35 – 11:00 a.m.

Question - David Roisum, Finishing Technology Inc.
I'm a little puzzled about your Figure 4 both in the magnitude and the direction of the assumed initial strain. My understanding is the web edges are typically slack in comparison to the center and that would be a negative strain or more negative than in the middle. Yet that Figure 4 shows more positive. The other thing that is puzzling is the magnitude, when we see edges that are floppy they are actual in compression and its not unusual to have edges so floppy that you can pull the web to failure and still not pull the floppy edges tight. In other words more than 1% strain instead of a tiny percent positive strain. Could you clear up my confusion on that?

Answer - Jan Erik Olsen, PFI
Your first question; the slack edges infer a greater length dimension. Thus Figure 4 should be correct.
We don't have much data, but in the examples that I've been running, I have run examples that always stretch out the paper. The stress is positive in the entire width. If you have webs that have very slack edges and you are still seeing the fluttering while you're winding; you have to do something more theoretically. Due to this you have to take into account more than the outer boundary condition. You are putting through paper that is longer at the edges into the rolls at the same radius with paper that is shorter in the center of the rolls and in this case you will actual get harder edges.

Q- Dave McDonald, Paprican
You mentioned the solution to this is uniform profile in modulus and initial strain. What would you do on the paper machine? What changes would you make in the dryers and press action in order to get that?

Answer - Jan Erik Olsen, PFI
This is not my field of work but I've seen a lot of papers presenting solutions how you can keep the edges in the dryer section more moist. It used to be that the edges become very dry compared to the center position and there are several technical solutions to this. If there is someone here from the paper industry they could answer this better than me.

Answer - Dick Adams, Beloit Corporation
What happens as the sheet dries, as it is running down the dryer section, the edges is allowed to shrink in a greater proportion than the center. Then as it shrinks more, the initial strain to pull that shrinkage back out is going to be more than the profile across as you have it there. The solution to that is not to allow the freedom to shrink differentially at the edges relative to the center. This approach has been taken to minimize the problem.

Comment - Bob Lucas, Beloit Corporation
To get some information on this particular strain I can give you a test that can be conducted very easily in the mill. Basically you take a log of paper on the machine and you very carefully scribe a knife cut that is two wraps deep down into the winding roll. Then take that single wrap; which represents one perfect single circumference around the log and then you cut that sheet into 25 mm wide strips in a stress free environment. The

sheet is then properly conditioned at its free length, and you'll be surprised that the free length will vary a great deal. That's a very tedious process but you get some very interesting data.

Question - Rolf Bosse, Munich
Do you have any idea at what initial strain the printer should reject these rolls?

Answer - Jan Erik Olsen, PFI
We need a way to measure the initial strain, as long as we don't have a standard way to do this I don't think paper mills will be focusing on this. One option is to monitor tension problems or skew tension, and compare edge rolls from different paper mills. Paper mills supplying edge rolls with high skew tension could be taken off the list of suppliers.