MOVEMENT OF LAYERS AND INDUCED TENSION IN THE NIP AREA BETWEEN DRUM AND PAPER LAYERS

By

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ABSTRACT

During paper manufacture and processing production losses occur during winding of machine-wide paper rolls and finished rolls due to winding faults. During the winding process at least one drum (steel or rubber-covered) is in contact with the winding roll and creates a nip area where tension and shifting of layers are induced. This process in the nip area with several layers of paper is not known in detail but the knowledge would be helpful to improve winding processes.

INTRODUCTION

Nip induced tension at a stack of paper and at wound rolls began appearing in the literature a long time ago. Winding models were created and helpful to understand the nip effect [1-8], but a calculation of induced tension is possible only in a narrow area.

In this presentation basic models were established where the deformation process in the nip area, movement of layers as well as induced tension were theoretically and experimentally investigated on a stack of 500 layers of LWC rotogravure paper and then transferred to the winding process (surface winding). Tests were carried out with a steel drum and, partially, with a rubber-covered drum.

EXPERIMENTS AND RESULTS AT A PAPER STACK

Deformation at the paper stack and winding roll for determination of a modulus of elasticity theoretically resulted, as a contact problem, in a smaller modulus as compared to compressibility measurements. Measurement of pressure distribution in the nip zone resulted in a higher distribution than assumed according to *Hertz*.

Rolling a drum over the surface of a lose paper stack results in shifting of layers within the stack which was calculated from geometric dimensions of deformation in connection with a static friction zone. The deformation caused a change in length of the half nip width. The half from this change of length move in rolling direction and the other half is fastened in the center of the nip and released during the rolling motion. Movement of the first layer results from the sum of movements of individual layers (Figure 1).

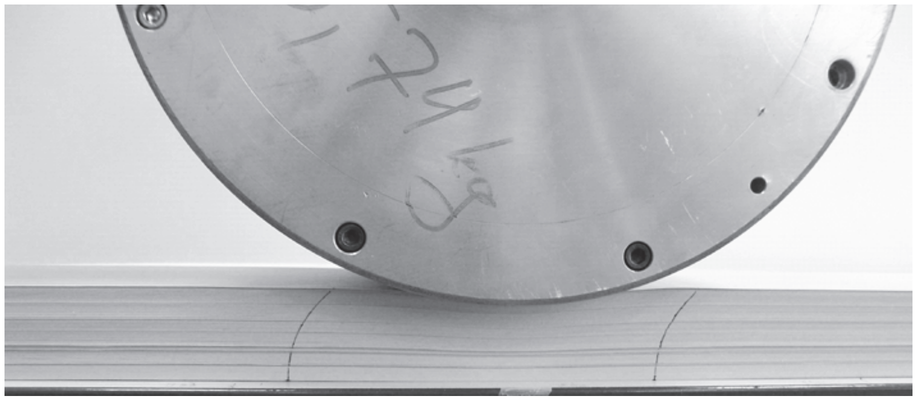


Figure 1 – Layer movement at a lose paper stack.

A measurement of induced tension on the first layer showed a difference between the lose stack and the situation when all layers are fixed (Figure 2). Change of length with reference to deformation in the nip area showed that only part of the deformation is transferred into tension. That means slippery effects are acting at the entrance of the nip area.

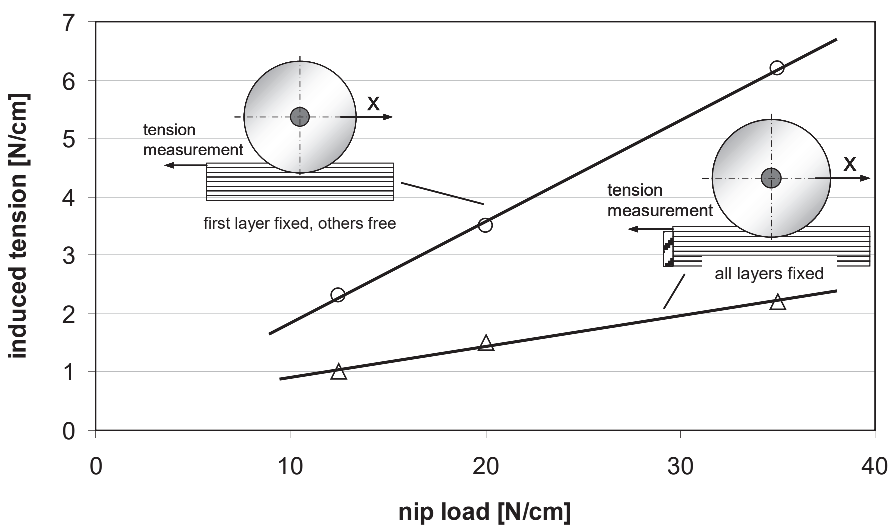


Figure 2 – Tension measurement at the first layer

If more layers of the paper stack are fastened, rolling of the drum induces tension within the layers, and highest tension occurs in the first layer. Subsequent layers show a reduction of induced tension; no more forces are measurable after the 10th layer. If pretension was exerted on the layers this resulted in a different induced tension, depending on the start point of the drum.

Induced tension occurs after a longer drum travel distance when all layers are fastened. Change of length resulting from deformation was summed up in dependence of the drum travel distance. This showed a direct dependence on the start point of the drum. The transferable tangential force is distributed to the underneath layers and reversal of force direction was found after the 8th layer (Figure 3). The sum of induced tension at the first 8 layers was identical with the induced tension in the first layer at the lose stack.

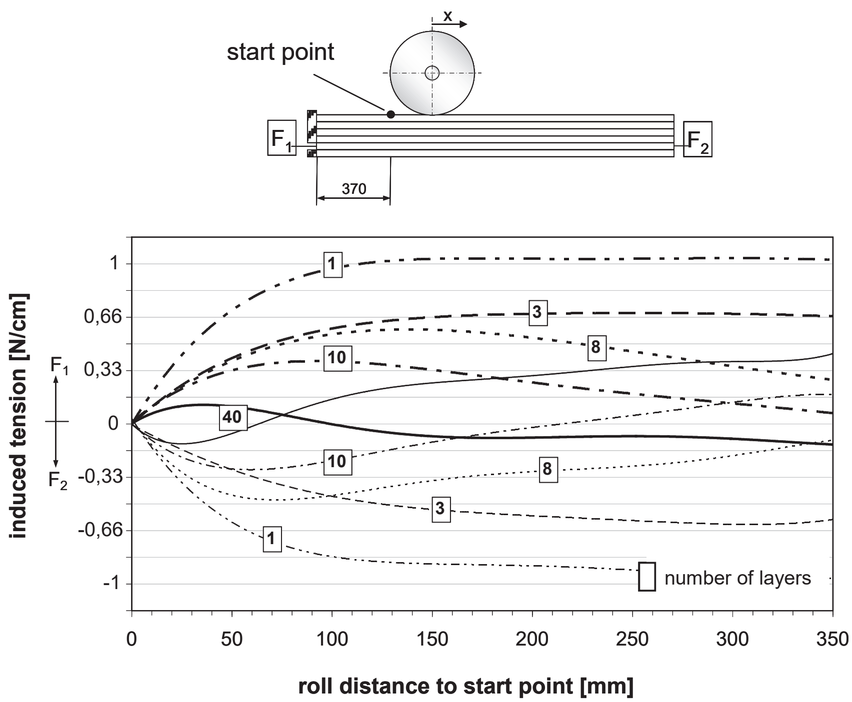
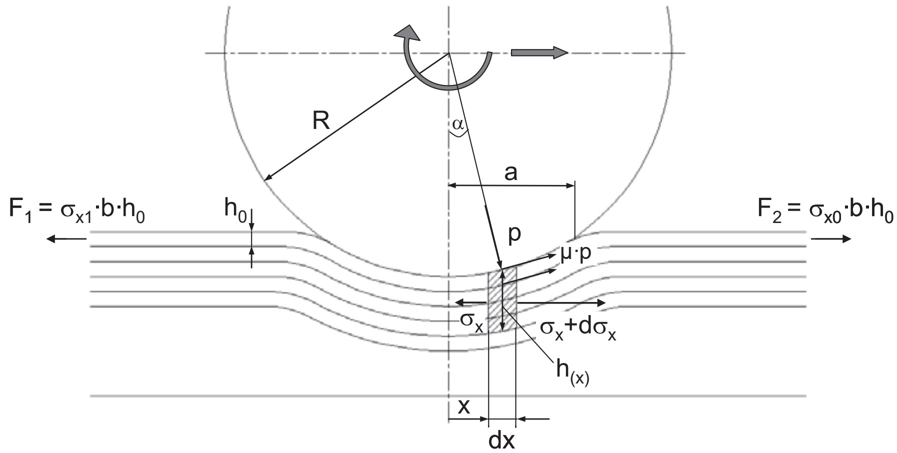


Figure 3 – Measurement of tension in different layers with pretension 2,5 N/cm

The tension-free 8th layer was assumed to be the instantaneous centre level. Layers above this level are "pushed" towards machine direction, hence inducing a change in length which is fastened in the center of the nip and released during the rolling motion as tension.

Induced tension in the nip area at the paper stack was calculated by a differential equation for the case that one and more layers are fastened in steps. The process is according to the shaping process during „rolling of sheet metal"[9], taking into consideration shape alterations (Figure 4).



$$\frac{d}{dx}\left(\sigma_x \cdot h_{(x)}\right) + p \cdot \sin\alpha + 2 \cdot \mu \cdot p \cdot \cos\alpha = 0$$

Figure 4 – Shaping process at a stack and differential equation

The equation shows the balance of force for the hachure volume element with the stress σ_x. The pressure distribution was statically measured with a foil sensor and showed a higher distribution according to *Hertz* (Figure 5).

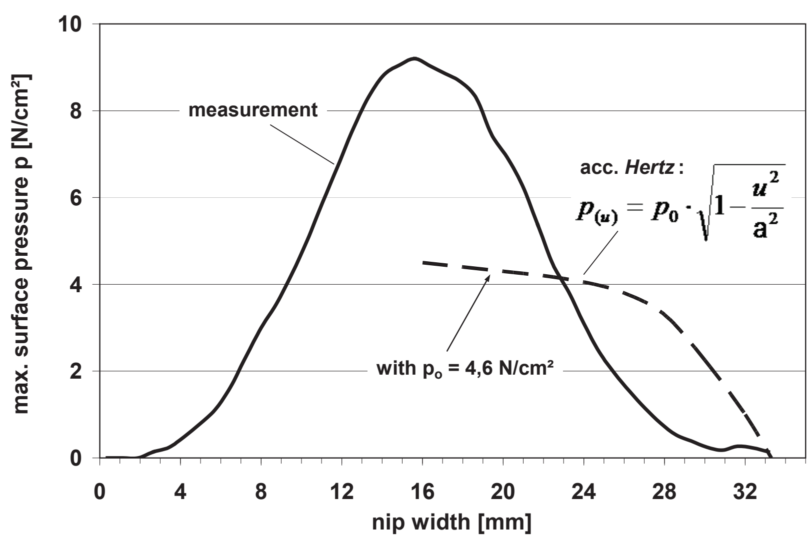


Figure 5 – Pressure distribution in the nip

The solution of the equation has one constant only but two conditions are required i.e. for the nip entrance one condition and one for the middle of the nip.

The calculation with the data (Table 1) and the pressure distribution yields two solutions which show a place of relative calmness at their transition point. Friction shear force tensions change their algebraic sign in this location. Solutions were identical for a quantity of 8 – 10 layers of the penetration depth (Figure 6). The figure showed that the nip induced tension is complete in the middle of nip area.

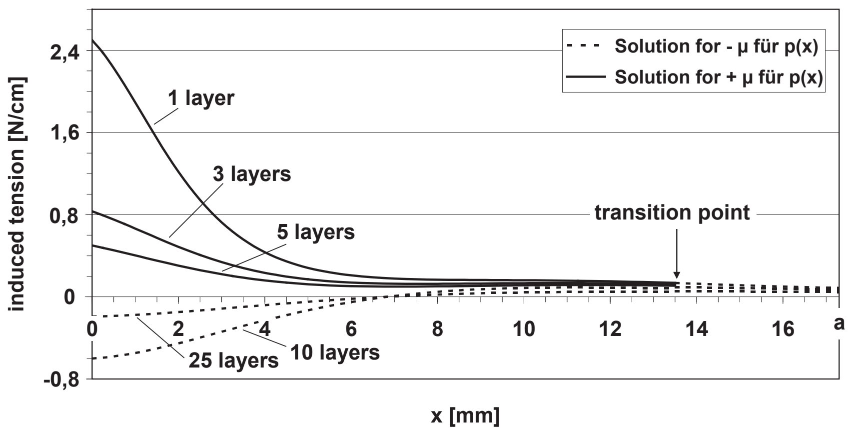


Figure 6 – Solution for different layers

Drum radius	R = 150 mm
Drum weight	150 N
Half nip width	a = 17,4 mm
Paper thickness	h_0 = 40 µm
Paper width	b = 120 mm
Friction coefficient	µ = 0,26
Penetration depth	1 mm

Table 1 – Test parameters

Progression of compressive load and shear force load during drum movement was recorded by two piezo-foil sensors on the drum surface. Dynamic measurements of a compressive load signal and a sum signal from compressive and shear force load were conducted where the shear force portion was measured for determination of difference (Figure 7).

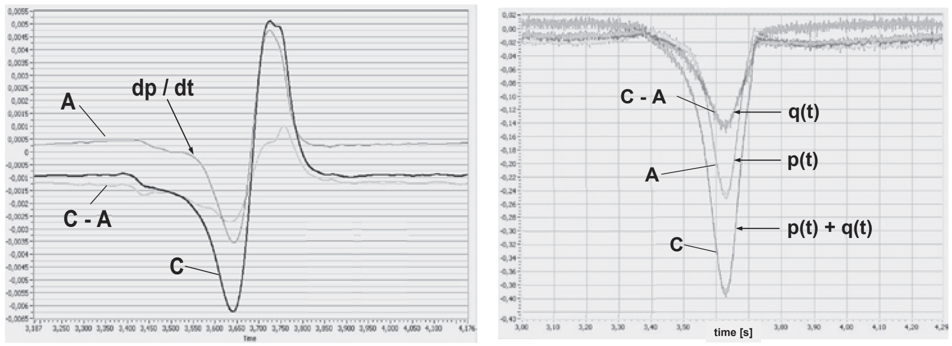


Figure 7 – Dynamic measurement of pressure (A) and shear force (C-A)
(left side-raw signal, right side-integrated signal)

Measurements at the lose paper stack showed a symmetric distribution of the shear force. Measurements at the fixed paper stack showed a rise in the shear force portion upon entering the nip area and zero occurred only in the compressive load zone. Upon entrance into the nip area the combination drum – winding roll yielded a steep rise in the compressive load portion with subsequent reversal, which leads to the conclusion that similar processes take place during winding and on a paper stack.

EXPERIMENTS AND RESULTS AT WINDING

Results from the paper stack tests were transferred to the winding process. Mechanisms of induced tension and movement of layers are similar to those in the paper stack. First, movements during the winding process are against machine direction of winding roll and lead to increased tension, referred to the winding roll as a spiral. Progression of movement of one layer shows that after two or three revolutions of the winding roll movement of this layer against machine direction comes to an end during one revolution. After further revolutions the movement migrates in direction of the winding roll and then again reaches the initial position (Figure 8). The trial was done on a wound roll with a new “window” after each one revolution.

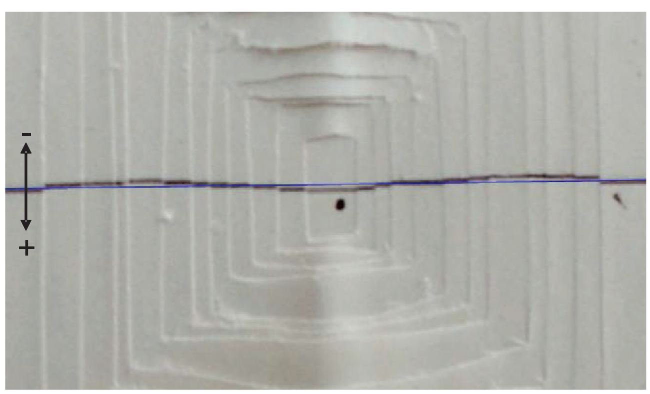


Figure 8 – Layer movement at winding roll (-) in opposite machine direction and (+) in machine direction, Nip load 130 N/cm

The evaluation (Figure 9) showed an increase of layer shifting with higher line load.

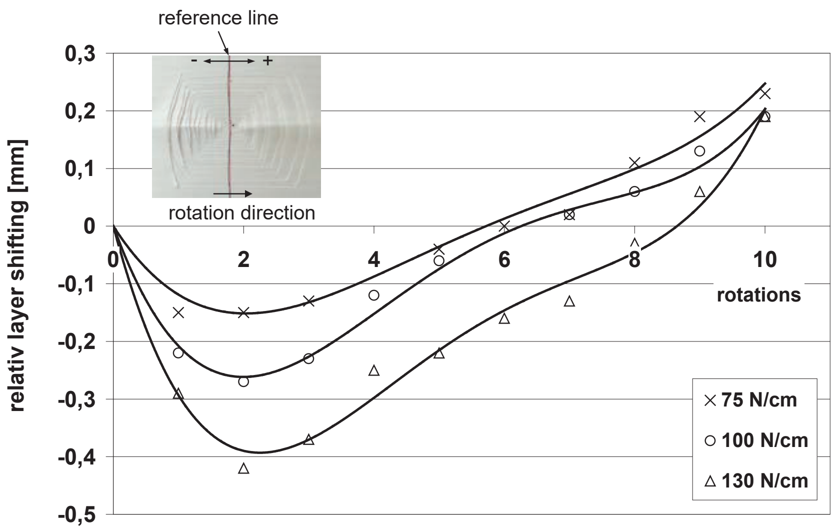


Figure 9 – Layer shifting with line load (75 – 130 N/cm)

Further movement in the winding roll occurs up to the depth where layers are deformed. Calculation of the deformation yielded a parabolic which explains the movements as a J-shaped line. With reference to the winding roll, movement towards the winding roll direction is a reduction in tension.

The static condition of one layer during a revolution as well as reversal of direction leads to the conclusion that an instantaneous centre exists. While tension reversal on a paper stack led to a tension-free layer, reversal on the winding roll causes maximum tension.

Circumferential velocity of the winding roll was determined considering an instantaneous centre course where the velocity is equal to that of the drum. It is larger than the circumferential velocity of the drum (Figure 10).

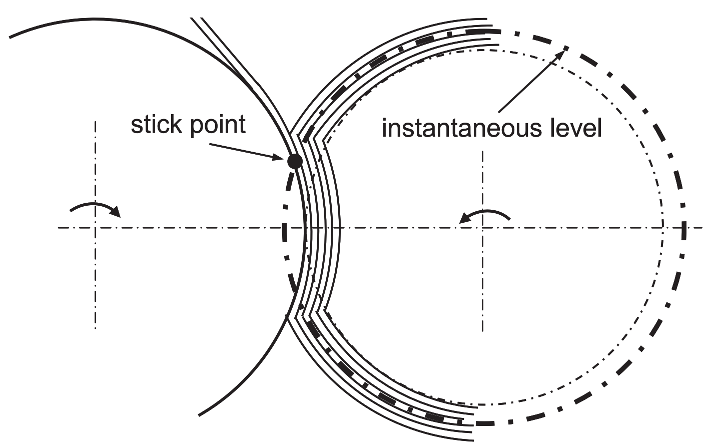


Figure 10 – Instantaneous level for one revolution

Regarding tension progression a differential equation with the winding parameters was established similar to that for the paper stack (Figure 11).

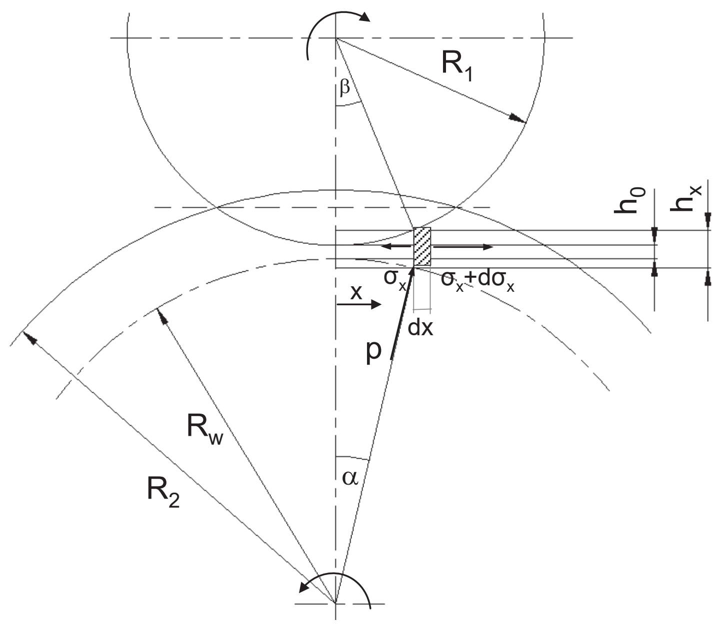


Figure 11 – Shaping process at wound roll

Similar as for the stack two resolutions are necessary. Both solutions yielded a common intersection which is in agreement with the position of the instantaneous centre (point x0 in Figure 12). With the data in Table 2 and the measured pressure distribution the calculation results showed that a reduction of tension occurs in front of or at the entrance into the nip area, both for the arriving web tension as well as for the layers on the winding roll up to the third layer. The induced tension including the web tension is named WOT (wound on tension). In the middle of the nip the WOT is complete similar to the paper stack.

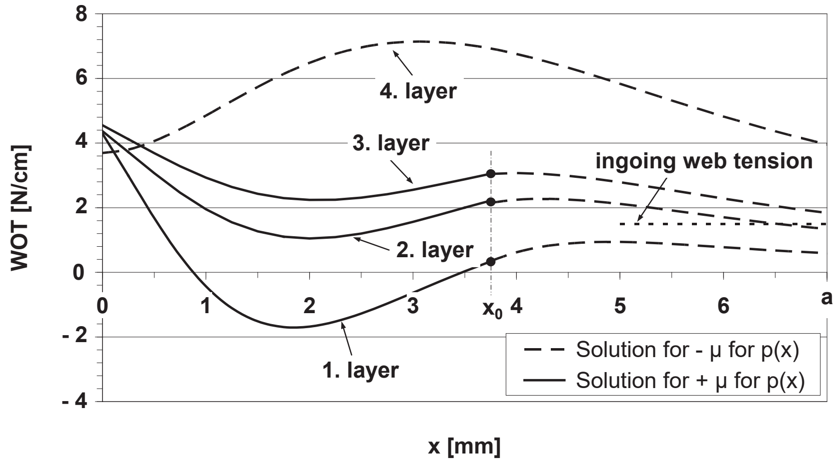


Figure 12 – Calculation of wound on tension

Drum radius	R = 150 mm
Roll radius	Rw = 150 mm
Half nip width	a = 7 mm
Paper thickness	h0 = 40 μm
Web tension	1,5 N/cm
Friction coefficient	μ = 0,26
Penetration depth	0,32 mm
Line load	75 N/cm

Table 2 – Test parameters

At a winding equipment the WOT was measured and controlled with the “Gap”–test (Figure 13).

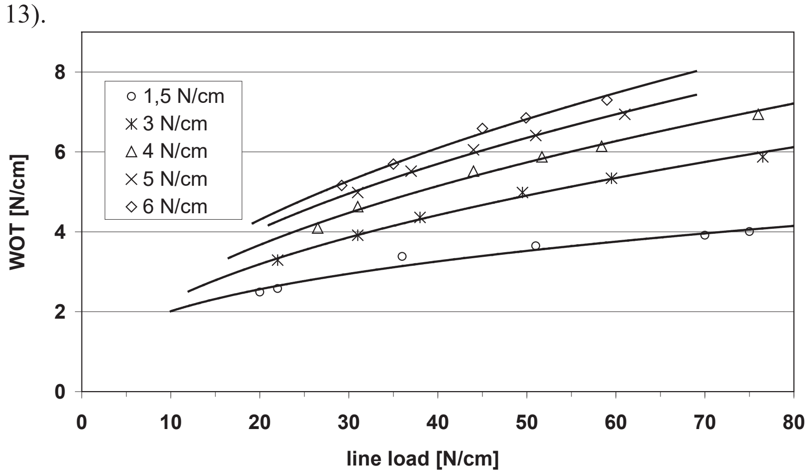


Figure 13 – WOT – measurement with web tension (1,5 – 6 N/cm)

This measurement is helpful in practice for the winder parameters to avoid winding faults.

CONCLUSION

The movement of layers and the induced tension in the nip was experimentally and theoretically analysed on a stack of paper and in winding. The movement on the stack was calculated from the geometric dimension of deformation in the nip area. The induced tension was calculated from the shaping process and showed two solutions which are equal on one point. This point is identical with the instantaneous level on a stack and a course in winding. The level is a tension free layer on a stack and the course a maximum tension in winding. Additional to the theoretical understanding of the nip process usable results for practice could be developed.

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Movement of Layers and Induced Tension in the Nip Area between Drum and Paper Layers

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Name & Affiliation	Question
Bob Lucas, Winder Science	When you were doing your horizontal bench test, to what extent after each test were you changing the paper samples and putting fresh paper down? I would be inclined to think that if you made multiple tests using the same samples, there would be some conditioning of the sheets that would affect the results.
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	Yes, this is definitely true. You need to use new stacks of papers for new experiments to produce repeatable results. The samples were stored in an acclimatized room for different amount of hours before the tests were done.
Name & Affiliation	**Question**
Keith Good, Oklahoma State University	This afternoon there will be a lab tour and we have set up an on-line demonstration of wound-on-tension. If you like, you can make a few comments downstairs, OK?
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	I'll try. Peter Hoffman would be the right person to do it.
Name & Affiliation	**Question**
Neal Michal, Kimberly Clark	On your last graph, Figure 13, you show a wound-on-tension curve. It appears that you are using a gap test. Could you briefly describe that? You are cutting the web, measuring the gap, calculating the strain and then calculating the tension using the modulus? Is that what you are doing? You are showing it in Newtons per centimeter but you are measuring a gap.
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	The complete computation behind that test was done by Peter Hoffman, so I'm not the right person to ask.
Name & Affiliation	**Question**
Neal Michal, Kimberly Clark	It appears that you are running the Cameron gap test and inferring the tension from the measured gap.
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	Yes.

Name & Affiliation	Question
Dilwyn Jones, Emral Ltd.	Can you comment on what rolls were driven in your experiments? In both the stack and the winding experiments? Was the nip roll free to rotate on a bearing or was it driven with a motor so that it rolled across?
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	You have the weight on the nip roll and the roll was driven by hand.
Name & Affiliation	**Question**
Dilwyn Jones, Emral Ltd.	On the winder, was the nip roll driven in that case? Or was it like a paper winder where it the drum was driven?
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	It was an experimental setup and was not a real winder. I think only the wound roll was turned.