WINDER VIBRATION; CAUSES, DEFECTS, AND REMEDIES

By

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ABSTRACT

Web process machines employ various winder types depending on the web being wound. These winders have various rolling contacts between machine elements and the winding roll which give rise to complex vibration phenomena. Consequences of the vibration vary from wear of the machine elements and web material defects to wound rolls being thrown catastrophically from the winder. The type of the vibration excited is very much dependent on the web material properties. Hence, the remedies for vibration problems can differ depending on the web. Despite recent advances in reducing the vibration, roll vibration continues to be the major obstacle to increasing winding equipment speeds.

The web properties which contribute to vibration sensitivity are discussed as well as various mechanisms which can cause wound rolls to become out-of-round and compound vibration problems. When the basic dynamic features of the winding process are studied with elementary or more detailed mathematical models the influence of the damping enhancement of the winder components can be simulated. Some typical vibration types are described together with commercially available solutions.

INTRODUCTION

In recent decades the annual average speed of paper machines has increased considerably. The average speed of winder has not been able to keep up with the paper machine speed. Instead the major capacity enhancement has been reached by shortening the set change time, parent reel change time, acceleration and deceleration time etc. Great improvements have been achieved but eventually also the winder average speed needs to be increased. The biggest obstruction to this is the vibration.

Vibration can limit the winder average speed because of the need to reduce the speed preventively in beforehand known vibration areas or due speed reductions done by vibration watch dogs. Also the greater amount of debris and cleaning work after a paper break at higher speeds are limiting the operator willingness to run at high speeds.

Influence of the enhancements on the winder structure can be simulated with FE or other mathematical models. First the problematic vibration modes have to been identified and then measures to dampen these modes should be sought by simulations. Using this technique several major improvements have been achieved. Solutions to some important winder vibration types are described in the following.

PRACTICAL SOLUTIONS

It was only after 1850 when the paper machines started to deliver paper in a form of rolls instead of sheets. Very soon, as the speed picked up, roll quality problems emerged. One of the worst problems was that large rolls were too softly wound. The next step in the winder evolution was the Bischof-winder, which operated separate from the paper machine. In this winder the winding took place in the top of a support roller and the slitters cut directly from the set [1]. The appearance of the nip between the wound rolls and support roller introduced immediately a new problem - namely vibration. This happened around 1870. Since then vibration has been a major problem of winders. Especially this applies to winder types where the nip load is mainly determined by the wound roll mass, i.e., two-drum winders.

Some improvement has occurred as the winder speeds have increased from speeds less than 100 m/min to over 3000 m/min during past 130 years. However, winder vibration is still severe problem causing loss of capacity, reject, wear, dust etc. Why is it so difficult to deal with nip induced winder vibration? Why is this still an unsolved problem after great advancements over past century in material technology, control systems, automation etc.?

Obviously the core of the problem can be attributed to the tricky mechanical behavior of the wound roll. In addition to the elastic deformation in the nip, wound roll is easily affected by the irreversible nip deformations, i.e., the wound roll may become out-of-round. Understandably the wound roll is newer perfectly round. Now, when this, let's say 1 μm, out-of-roundness induces some nip pressure oscillation during winding, some areas of the roll periphery become more deformed than the other parts. Since the oscillation is due to the wound roll out-of-roundness, an even deformation pattern is created on the roll periphery. The incremental permanent deformations during one rotation of the roll are tiny (order of μm's or less). However, since the roll rotates 10 – 30 times in a second, relatively large deformations of order 0.1 – 1mm will be developed very quickly. Typical forms of out-of-roundness are off-center core, oval shape and quadratic shape.

In practice it has been observed that in general the "vibrating paper grades" are bulky and have very high layer-to-layer friction coefficient. Bulky means that each individual paper layer has a lot of "deformation capacity" left from the calender or other phases of the paper manufacturing and finishing processes. When compressed hard in the winder nip, some permanent changes in the internal structure of the paper are induced and, hence, some proportion of the deformation is not recovered when the loading is removed. High layer-to-layer friction contributes to the vibrations as follows: Due to the high nip load, the paper layers at the nip slide slightly relative to each other and after exiting the nip the high friction COF prevents the layers from sliding back to their original positions. Hence, a permanent deformation is developed on the roll periphery.

With a special damping bearing house the damping capacity of the drums has been more than tripled. The increase of the damping is especially advantageous for winders running WFU because the resonance vibration of the drums is effectively attenuated. Figure 1 shows the bearing vibration of the winding drums before and after damping drum rebuild at running speed 2400 m/min. Before the rebuild the drums started to resonate heavily at roll diameter 1150 mm and the strong vibration last up to 1400 mm. After rebuild this resonance vibration has disappeared thanks to the increase of the damping of the drums.

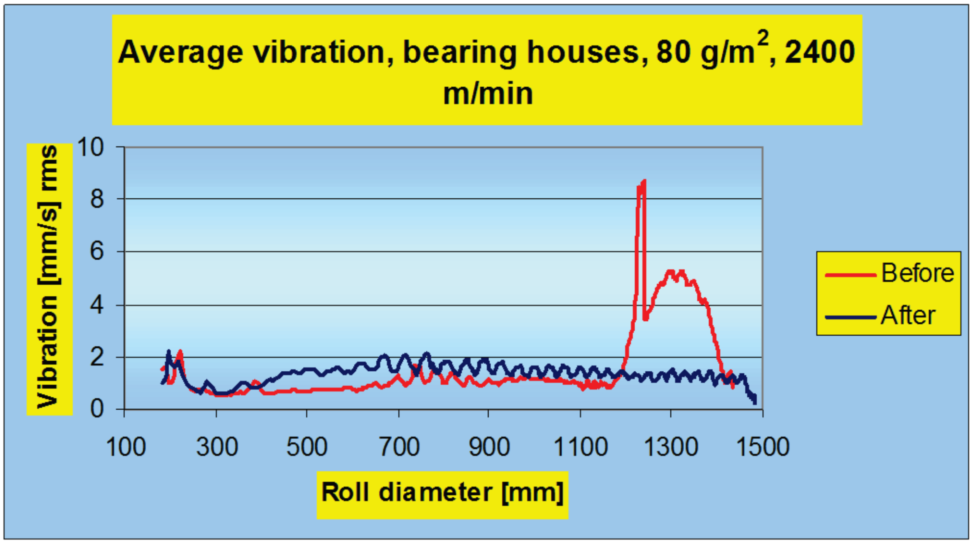

Figure 1. Winder vibration with and without drums equipped with damping bearing houses.

Two-drum type of winders running double coated or other high density, low permeability paper grades sometimes experience strong vibration when the winder is accelerated. This occurs because the natural frequencies of the paper rolls are excited by multiples of the paper roll rotation frequency. The natural frequency of the paper rolls is partially determined by the compliancy of the wound roll in the front and rear drum and rider roll nips and partially by the roll mass and inertia properties. The natural frequencies decrease from appr. 150 Hz to 5 Hz, corresponding the situations when the rolls are lightest and heaviest. At certain diameter during the acceleration the excitation frequency and the natural frequency will match, creating a resonance vibration. As a consequence of the vibration the rotative tangential traction capacity decreases causing the paper rolls to slow down temporarily. This, in turn, leads to slack web and roll offset. This may happen to several rolls or just one roll depending on the vibration mode shape. Simple way to avoid this to happen is to program very low acceleration rate or increase the speed in steps. For capacity critical winders this is not tolerable solution. More detailed information of the special features of winder vibration can be found in references [2] and [3].

There is, however, practical solution to the above described initial acceleration vibration – namely compliant rider roll technology (**Figure 2**). With careful design of the compliancy and the properties of the soft cover it is possible to shift the natural frequency so that the resonance is attenuated to a level which is not causing problems. The important input for determining suitable cover properties is the paper grade and its mechanical properties. The mechanical properties of the paper can be measured in the laboratory. This information together with wide database of running installations of various paper grades provides the necessary data for the cover selection.

Figure 2 – Winder equipped with compliant rider rolls

Another type of two-drum winder vibration is called *bouncing.* This is clearly the most serious vibration problem for two-drum winders nowadays. Typically, the grades experiencing this problem are easily wound up to the roll diameter 500 – 700 mm but then, little by little, rolls start increasingly develop eccentricity. The paper grades with a tendency to the above-mentioned vibration include DIP newsprint and bag paper. This corresponding vibration mode occurs always at the roll rotation frequency and is hence not accompanied with audible sound. On a two-drum winder the rolls are seen to bounce in a more or less irregular pattern from drum to drum. Due to the roll eccentricity, also the core chucks are vibrating heavily. The mechanism and mode for this type of vibration is quite complex, involving interplay of the adjacent rolls due to the edge contact and frictional forces.

Over the years numerous attempts to eliminate this problem have been tried. These include adjusting the winding parameters: web tension, rider roll load and torque, various rider roll load control strategies, soft roll covers on drums and rider rolls etc. At best only minor improvements have been achieved with these measures. The only 100 % sure method has perhaps been too obvious that it has only recently been fully recognized. This is, of course, imitating shafted two-drum winding. In some paper mills this is done with inserts or plugs connecting the adjacent cores. This usually requires some manual work before and after the winding. Couple of years ago fully automated way to ensure co-axial rotation of the set was introduced by Metso Paper. This patented solution is based on machining shallow male and female grooves on adjacent core ends (Figure **3**). The grooving station is implemented conveniently in conjunction with the core saw. The depth of the grooves is so small that the rolls are separated easily after winding.

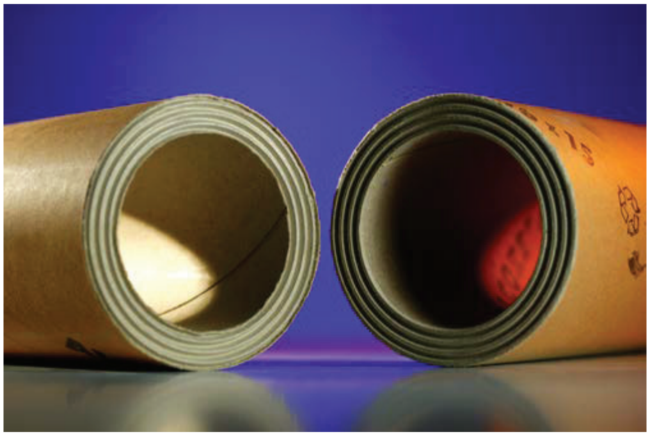

Figure 3 – Grooved core ends

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Keynote Presentation – *Winder Vibration: Causes, Defects, and Remedies*

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Name & Affiliation	**Question**
Dave Wager, DuPont Teijin Films	Regarding the tendency to get deformation of the roller and vibration: Do you find that changes to the nip load or the roller, the nip diameter can actually influence the formation of vibration?
Name & Affiliation	**Answer**
Marko Jorkama, Metso Paper	Do you mean by changing the drum diameter?
Name & Affiliation	**Question**
Dave Wager, DuPont Teijin Films	I'm talking about changing the nip roller diameter or changing the nip loading.
Name & Affiliation	**Answer**
Marko Jorkama, Metso Paper	If you change the nip loading then you also change the roll structure. That can help if you want softer or harder rolls, but the impact on vibration is limited. I'm not sure that will solve any severe problems.
Name & Affiliation	**Question**
Clarence Klassen, KlassEngineering	Having experienced this, I applaud your efforts to solve it at the source. If we have roll bounce and web break occurs, have you a recommendation for the type of stop to be implemented? Would it be a rate of speed change, a torque limit stop, reduced torque limit, would both drums have the same torque limit?
Name & Affiliation	**Answer**
Marko Jorkama, Metso Paper	There are different opinions on this. I think we are increasing the rider pressure a little bit after the break. Regarding the drums: Some prefer running in speed control so that they will not accelerate during a web break. That is one way, but I don't know if that's the only way – speed control.

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).

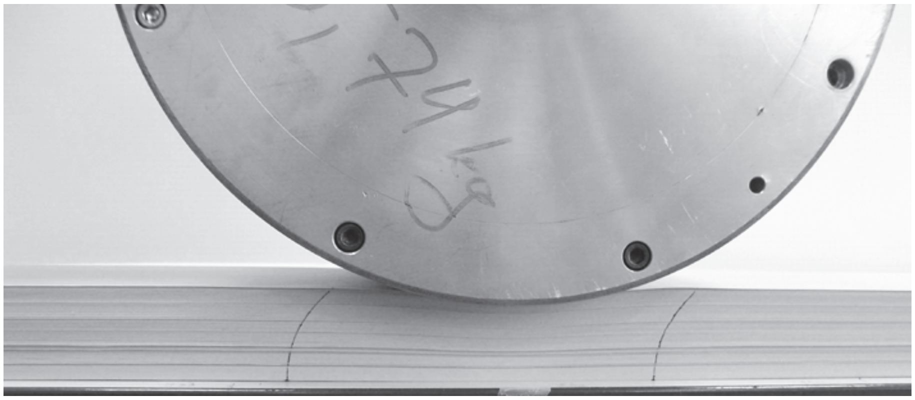


Figure 1 – Layer movement at a lose paper stack.

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.

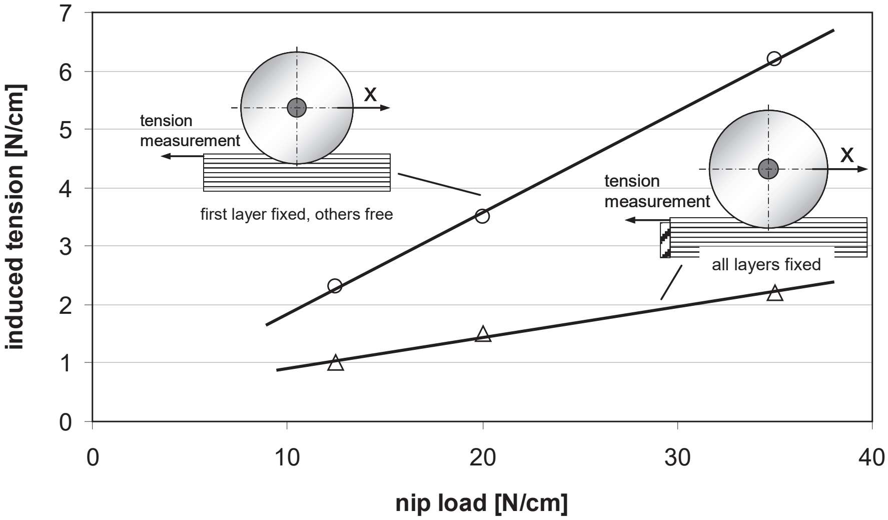


Figure 2 – Tension measurement at the first layer

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.

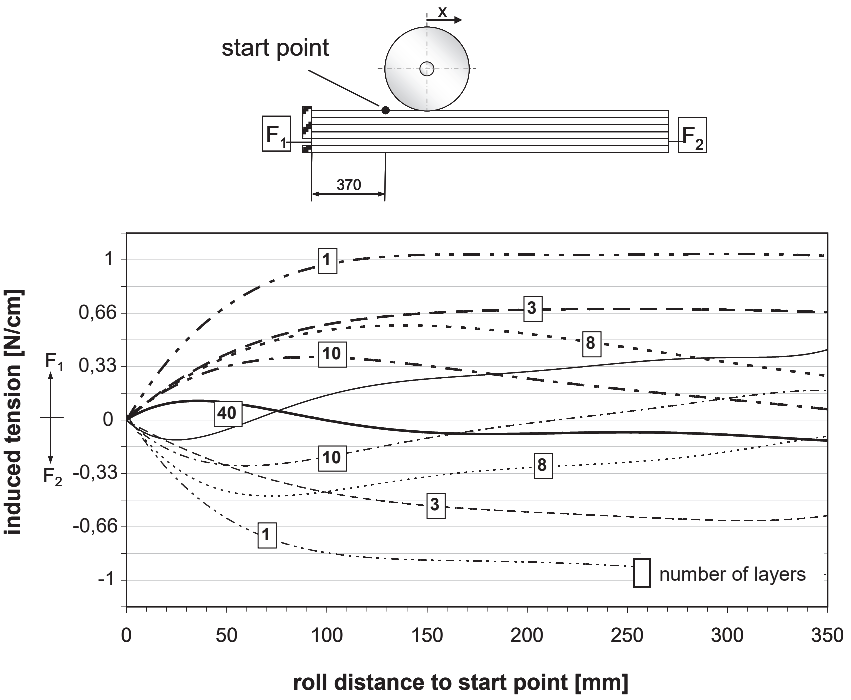
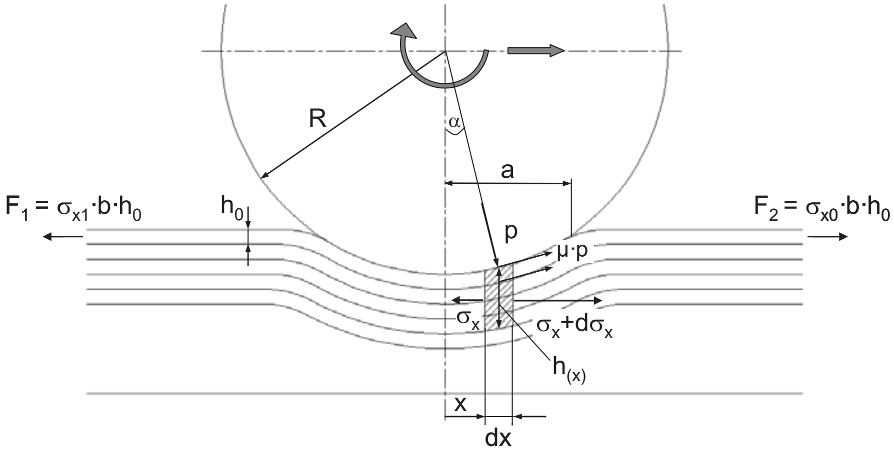


Figure 3 – Measurement of tension in different layers with pretension 2,5 N/cm

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).

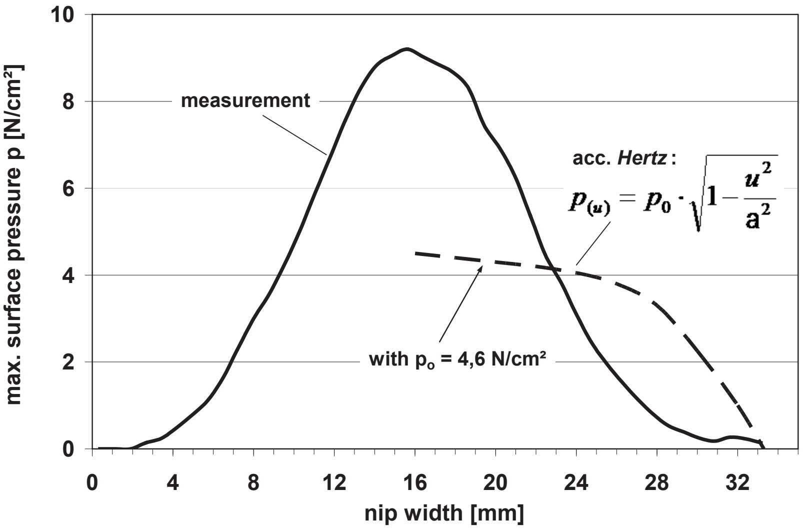


Figure 5 – Pressure distribution in the nip

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.

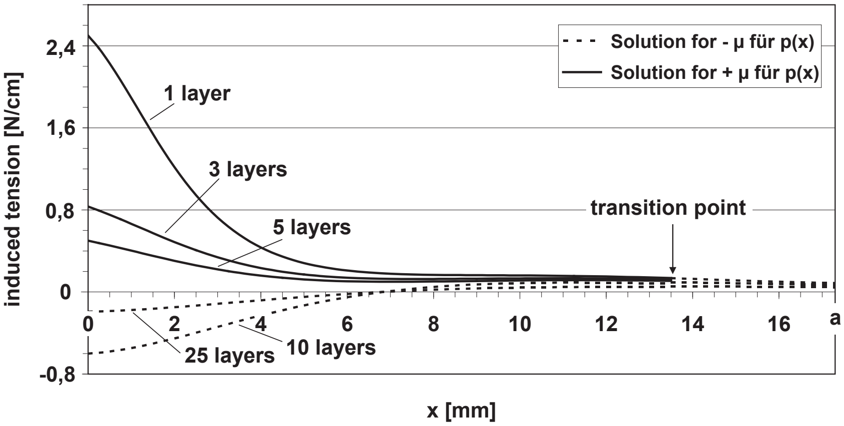


Figure 6 – Solution for different layers

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).

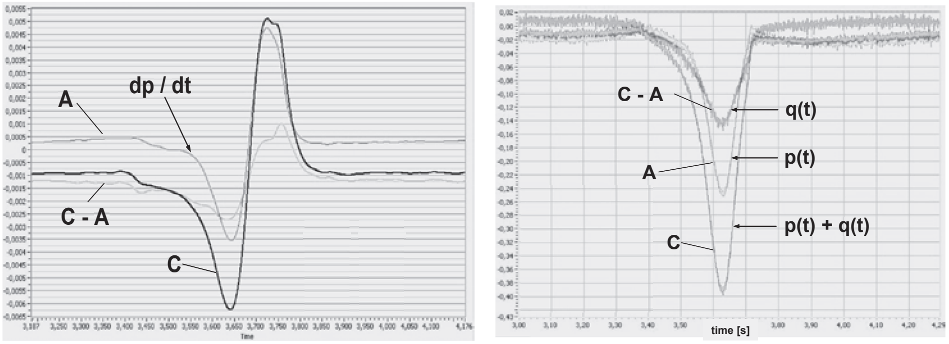


Figure 7 – Dynamic measurement of pressure (A) and shear force (C-A)
(left side-raw signal, right side-integrated signal)

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.

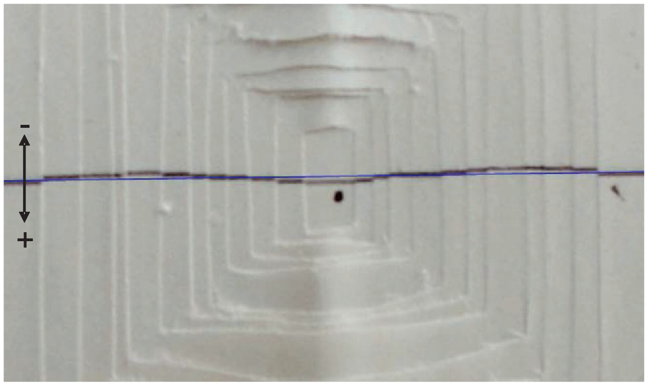


Figure 8 – Layer movement at winding roll (-) in opposite machine direction and (+) in machine direction, Nip load 130 N/cm

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

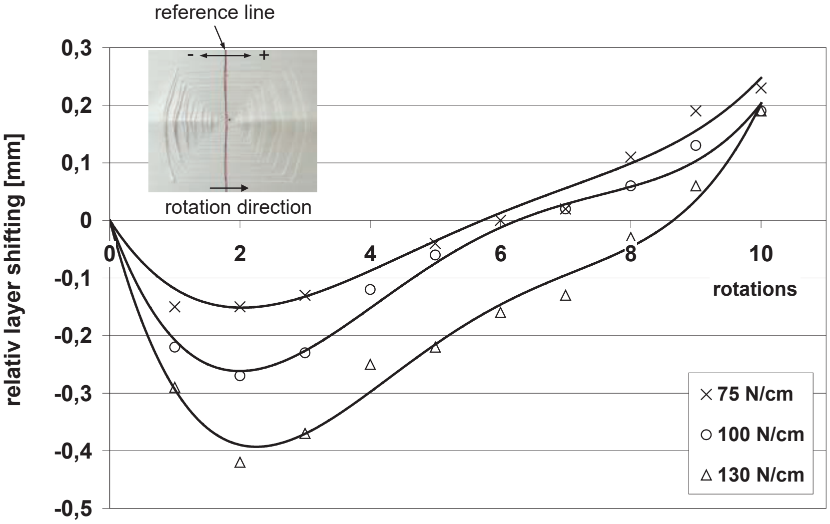


Figure 9 – Layer shifting with line load (75 – 130 N/cm)

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).

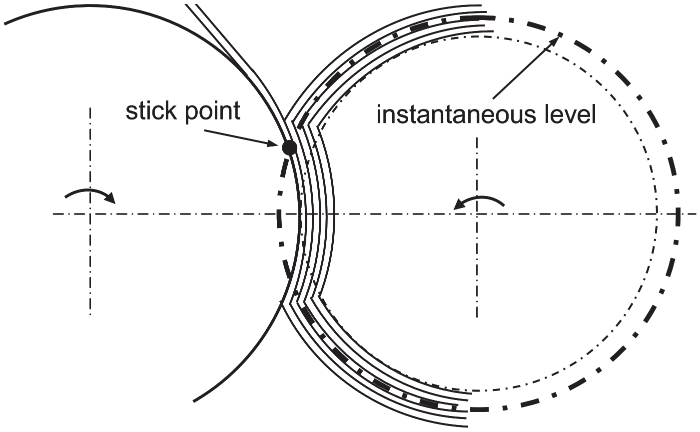


Figure 10 – Instantaneous level for one revolution

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

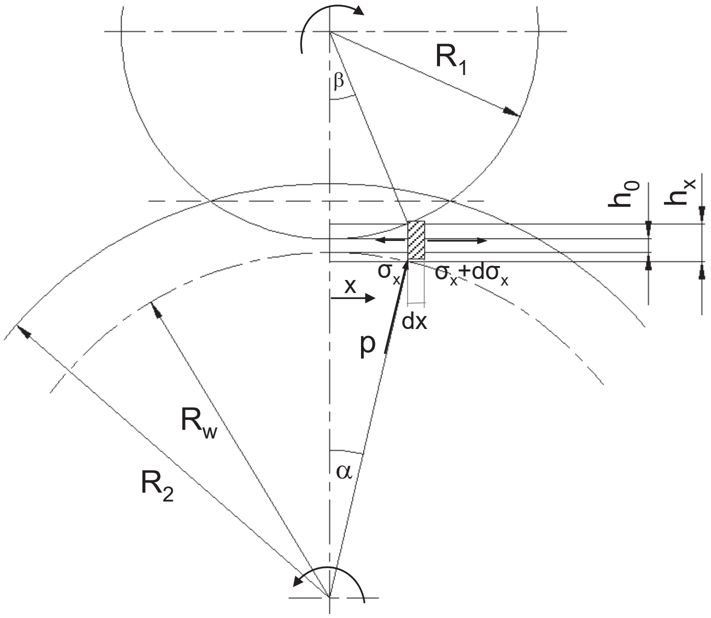


Figure 11 – Shaping process at wound roll

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.

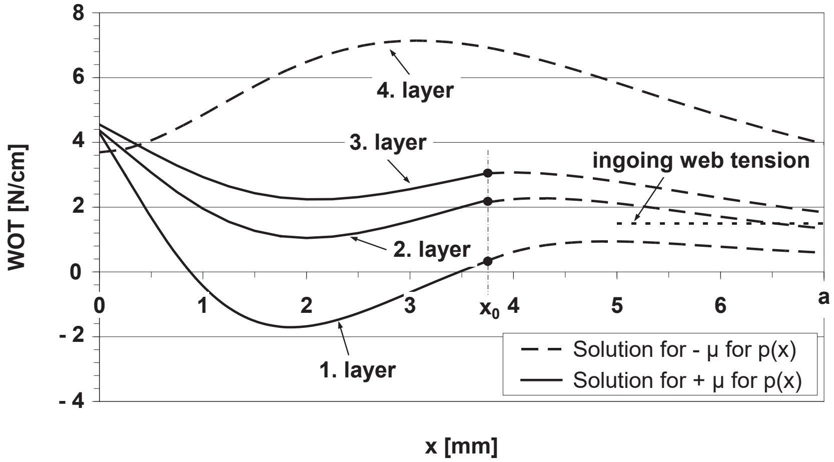


Figure 12 – Calculation of wound on tension

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).

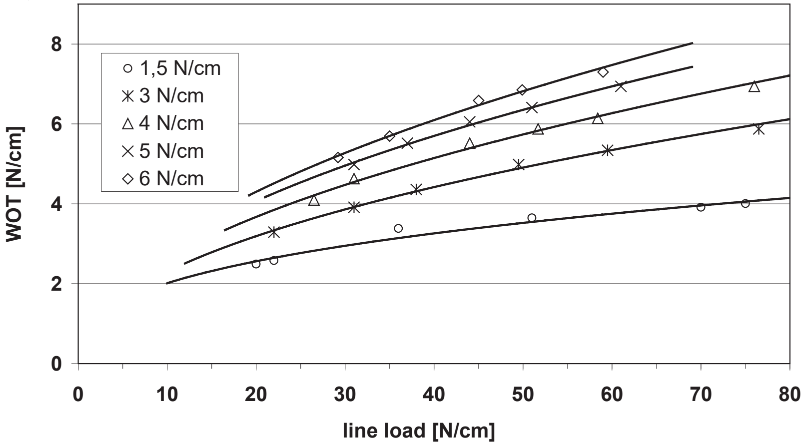


Figure 13 – WOT – measurement with web tension (1,5 – 6 N/cm)

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 Bob Lucas, Winder Science	**Question** 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 Michael Desch, Technische Universität	**Answer** 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 Keith Good, Oklahoma State University	**Question** 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 Michael Desch, Technische Universität	**Answer** I'll try. Peter Hoffman would be the right person to do it.
Name & Affiliation Neal Michal, Kimberly Clark	**Question** 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 Michael Desch, Technische Universität	**Answer** The complete computation behind that test was done by Peter Hoffman, so I'm not the right person to ask.
Name & Affiliation Neal Michal, Kimberly Clark	**Question** It appears that you are running the Cameron gap test and inferring the tension from the measured gap.
Name & Affiliation Michael Desch, Technische Universität	**Answer** 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.