INDUSTRIAL USE FOR THE "NIP-INDUCTED EFFECT" TO SEPARATE SHEETS

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ABSTRACT

This paper introduces an analytical method for the explanation of the nip inducted effect. This effect is known for a long term as a disturbance effect in the web handling industry. Here it is used for breaking bindings between the surface of sheets. The nip inducted effect causes a displacement of layers due to rolling a cylinder over a stack of sheets, known in the winding process of paper coils.

The developed model is based on the assumption that the kinematic processes of the nip inducted effect are explainable with a gear of hollow cylinders. It is shown how the geometry of a hollow cylinder is attuned. The geometry and the translation of the gear will be influenced by the material parameters of the promoted paper.

The analytical model will be discussed with the results of Pfeiffer and sorted in the existing knowledge about the nip inducted effect.

The model is explained on the example of a developed machine for breaking bindings between the surfaces of paper sheets.

Another focus is set on the measurement of the reversible extension of paper. These measurements are important for the industrial use of the nip inducted effect.

NOMENCLATURE

Symbol	Unit	Description
E	[%]	extension
$\varepsilon_{B\|n}$	[ ]	extension material n with tension σ_B
ε_{gesamt}	[%]	total extension
σ	[N/mm^2]	technical strain
σ_A	[N/mm^2]	strain at position A
σ_B	[N/mm^2]	strain at position B
Σ_{sheet1}	[N/mm^2]	strain in MD/CD sheet 1
Σ_{sheet2}	[N/mm^2]	strain in MD/CD sheet 1
ω_{oN}	[s^{-1}]	angular velocity upper nip roller
ω_{Rn}	[s^{-1}]	angular velocity ring n
a	[mm]	engagement of nip rollers to each other
a_A	[mm]	engagement of nip rollers at position A
a_B	[mm]	engagement of nip rollers at position B
$d_{A\|1\|b}$	[mm]	compressed height material 1 on position A
$D_{A\|b}$	[mm]	sum of compressed heights on position A
$d_{B\|n\|b}$	[mm]	compressed height material n on position B
E	[N/mm^2]	elastic modulus material
H	[mm]	thickness of rings in the gear of hollow cylinders
$R_{1\|au}$	[mm]	outer radius ring 1
$R_{1\|in}$	[mm]	inner radius ring 1
$R_{2\|au}$	[mm]	outer radius ring 2
$R_{2\|in}$	[mm]	inner radius ring 2
$r_{e\|n\|j}$	[mm]	j substituting radius material n
R_{ZW}	[mm]	radius centre cylinder
s/2	[mm]	distance between A0 and A1
v_0	[mm/s]	circumferential velocity centre cylinder ring 1 inner side
v_1	[mm/s]	circumferential velocity ring1 outer, ring 2 inner side
v_2	[mm/s]	circumferential velocity ring 2 outer side
$V_{sheet\|n}$	[mm/s]	velocity of sheets in the nip
$V_{sheet1o}$	[mm/s]	velocity sheet 1 upper side

INTRODUCTION

Everyone already had this problem: You take a stack of paper out of a photocopy machine and the sheets are not aligned to each other. To align the printed sheets, it is necessary to break existing fixations between the sheets and to bring air between them, which is all done manually with a characteristic movement. After that the stack of paper is rapped on the table, so that you gain an alignment of the stack on two sides.

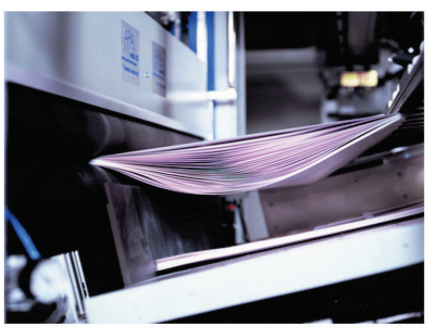
This working process is state of the art in industrial post processing after the sheet fed printing machines. It is completely done manually and turned out as the bottle neck of the post press processing. Increasing productivity of printing machines requires also a higher productivity and automation in the post press processes.

In the last 40 years many companies worked on the development for an automatic jogging machine which is aligning the sheets in the post press process but none was established in the market. [1,2,3,4]

The problem constitutes in breaking all bindings between the surfaces of every sheet to gain a precise aligned stack of jogged paper. This can not be ensured even in the manual process of aligning sheets by a repeatedly effected action.

Stacks of jogged paper are required in the post press processing to cut the sheets by guillotine. Applying a new mechanism of action the step towards the full automatic machine was succeeded, cause now you can be sure that all bindings between all sheets are broken.

In cooperation with the Chair of Printing Science and Technology (IDD) at Technische Universität Darmstadt, a full automatic jogging machine was invented. It is build by the company Baumann Maschinenbau Solms and the name BASA stands for "Baumann Automatische Schüttel Anlage".[5, 6]



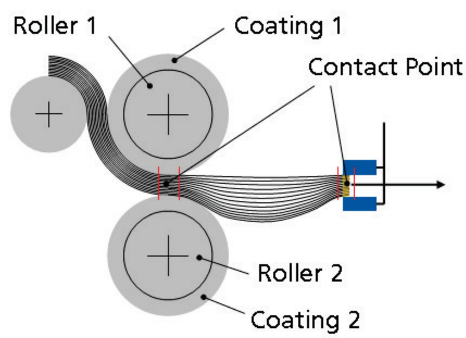


Figure 1 – Result of the new mechanism on the real machine and schematic figure of the new mechanism of action.

A stack of paper is formed and moved through the gap of two roles as shown in Figure 1. Due to the arrangement of these two roles with different coatings, as well as the movement of the pile through the nip, a define displacement between every sheet is achieved. The two contact points let the stack of paper shape in the characteristic way as seen in figure 1. This is necessary for braking the bindings and to bring air between the sheets.

There is a big challenge to indicate and to describe the physical background of the new mechanism of action for the industrial use of this effect.

This new mechanism of action is based on an effect of displacement of layers known in web handling processes for example during the winding process of coils. Normally it is a disturbing effect but here it is used for breaking the bindings between the sheets and bringing air between them.

This report is one of the first results of a doctoral thesis [7] out of the continual research at IDD. All its analyses are based on the research of Pfeiffer and Ärölä [8, 9]. They proved that this mechanism of action depends on the material behavior of paper in ZD-direction. The instantaneous centre of rotation of a roller over a stack of paper is located inside this stack. A analytical model describing the layer displacement in the nip was developed.

Basic approach for this new model is based on the assumption that the processes can be described as a gear where the gear transmission ratio is specified by the material parameters in the nip: paper and coatings of the rollers.

The analytical model is implemented in a graphical simulation tool and is successfully used for dimensioning and optimization of the BASA. The simulation tool needs the correct material parameters of paper. To determine these parameters in a reliable way, the IDD in Darmstadt developed new measuring devices for precise testing of paper in ZD-direction.[10]

The new devices are based on the scientific results of [11 – 18].

STATE OF THE ART: NIP INDUCTED EFFECT

In the last 40 years the nip inducted effect is subject of scientific research in the area of paper science. In literature this effect is treated as a disturbing effect during the winding process of coils. Older research and publications are almost always based on experimental results. Newer research are using Finite-Element-Modeling tools to analyze the nip inducted effect. The development of a consistent and satisfying analytical model is in progress. The commonality of all models (figure 2) is the influence of the force-deformation behavior of paper in Z-Direction.

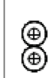
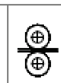
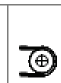
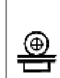
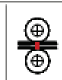
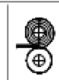
Results of research nipinducted effect author; year of publikation; reference ■ studied partial modell	partial modells					
	basic knowledge			enlarged knowledge		
						
Reynolds; 1876; [19]	■					
Hertz; 1882; [20]	■					
Bufler; 1961, 1969; [21], [22]	■					
Pfeiffer; 1970; [23]	■					
Glück; 1976; [24]	■					
Batra; 1980; [25]	■					
Hiss, Knothe, Wang; 1992; [26]	■					
Diehl, Stack, Benson; 1993; [27]	■					
Stack, LaFleche, Benson; 1995; [28]	■					
Böhm, Knothe; 1998; [29]	■					
Bentall, Johnson; 1968; [30]		■				
Soong, Li; 1981; [31], [32]		■				
Good; 1993; [33]		■				
van Haag; 1993; [12]		■				
Hinge; 1998, 1999; [34], [35]		■				
Jörg; 1979; [36]	■	■				
Jorkama, von Hertzen; 1999; [37]			■			
Rand, Errikson; 1973; [38]		■	■			
Humberg; 1996; [39]		■	■			
Pfeiffer; 1968; [40]				■		
Frye; 1985; [41]				■		
Amouri; 1989; [42]				■		
Ärölä, von Hertzen; 2003; [9]				■		
Pfeiffer; 1977; [43], [44]					■	■
Pfeiffer; 1993; [8]					■	■
Güldenberg; 2000; [11]					■	■

Figure 2 – Summary of scientific research for the nip inducted effect.

MODELLING OF THE NIP INDUCTED EFFECT

For modeling the nip inducted effect the following steps are important:

- The geometry in the nip explains the result of all materials in the nip.
  The compression of one material in the nip is compared to more materials.
- The kinematics in the nip is developed out of the geometry in the nip with the help of a gear of hollow cylinders.
- Measuring material parameters for paper in Z-Direction
- Proving the analytical model with results of the real machine

Geometry in the nip

The first step towards modeling the nip inducted effect is a pre-experiment. Some sheets are positioned on a flat surface. Located on top is a roller pressing into the stack of these sheets. It is a 2-dimensional experiment which showed that the geometry in the nip can be described by circles as shown in figure 3. Furthermore is the pressing tension in the middle of the nip throughout all sheets about the same value (position A).

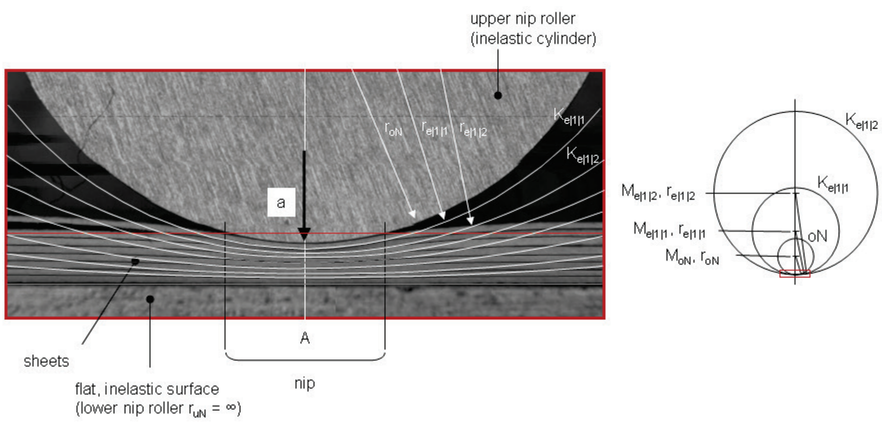


Figure 3 – Macroscopic picture of compressed sheets in the nip due to compression a.

The real geometry in the nip is specified by all materials in the nip. There are rollers with its different coatings and paper. Important for the model is the distribution of the pressure in the middle of the nip. It is set as a constraint that in the middle of the nip there is only one value of compressive stress throughout the whole material similar to the pre experiment shown in figure 3. The model's second constraint is the stiffness of the nip rollers in length (it is only a 2-dimensional problem) and the nip rollers are much more stiff then the promoted sheets in the nip. Also all materials in the middle of the nip adhere to each other.

For an easier understanding the explanation is done with an example like the pre experiment with the upper nip roller and a flat surface corresponding to a lower nip roller with an infinite radius. Figure 4 shows the different behavior of material in the nip to a flat surface due to its different modulus of elasticity. While moving material through the nip from position B to position A, material 1 is for example less compressed then material 2. The whole compression is marked as h_{oN} and is the difference of height s/2 besides the nip $D_{B|b}$ and the height in the middle of the nip called $D_{A|b}$.

The lower graphic in figure 4 shows the height of material 1 to material 2 in relation to the different pressure relations on position B to position A. With a given elastic modulus of every material in the nip and knowing the compressive stresses the calculation of the resulting height ($d_{A,B|1|b}$, $d_{A,B|2|b}$) can be done by

$$d_{A,B|k|b} = d_{A,B|k|u}\left(1 - \frac{E_1\left(\left(\sum_{i=1}^{n} d_{A,B|i|u}\right) - D_{A,B|b}\right)}{E_k\left(\sum_{i=1}^{n} d_{A,B|i|u} \cdot \frac{E_1}{E_i}\right)}\right) \qquad \{1\}$$

With $E = \frac{\varepsilon}{\varphi}$.

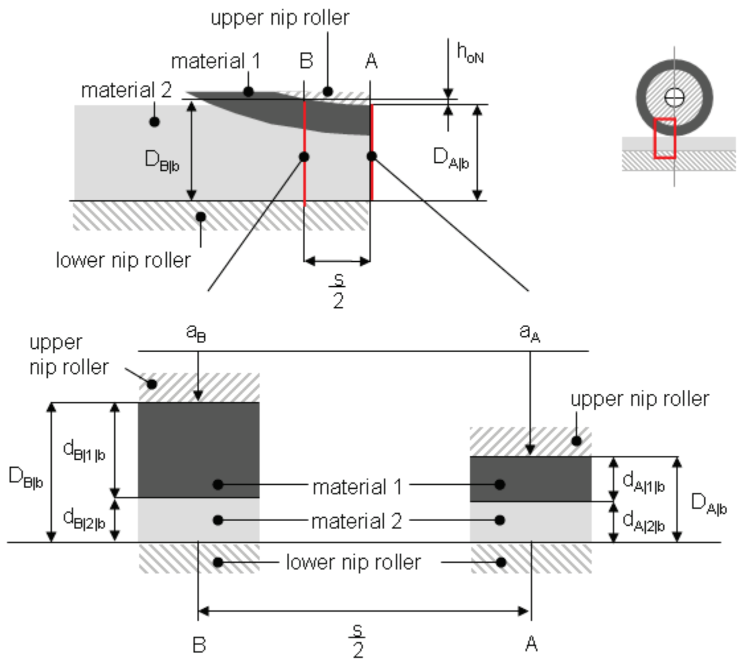


Figure 4 – Compressed material 1,2 due to a compression a_A, a_B. Position A is located in the middle of the nip. Position B is distant s/2.

These conditions of material behavior under compressive stresses are the basis for calculating the substituting radii shown in figure 5. Basis for these radii is the formula for a segment of circle.

In this formula all parameters can be calculated with the theorem of Pythagoras as shown in figure 5. First the height of segment of cycle h_{oN} of the upper nip roller is defined. Then the height of segment of cycle $h_{e|1|m}$ follows from the substituting circle ($M_{e|1|m}$, $r_{e|1|m}$). The substituting circle ($M_{e|1|m}$, $r_{e|1|m}$) follows from the height of segment of a cycle with the formula of a segment of a cycle with the substituting radius $r_{e|1|m}$.

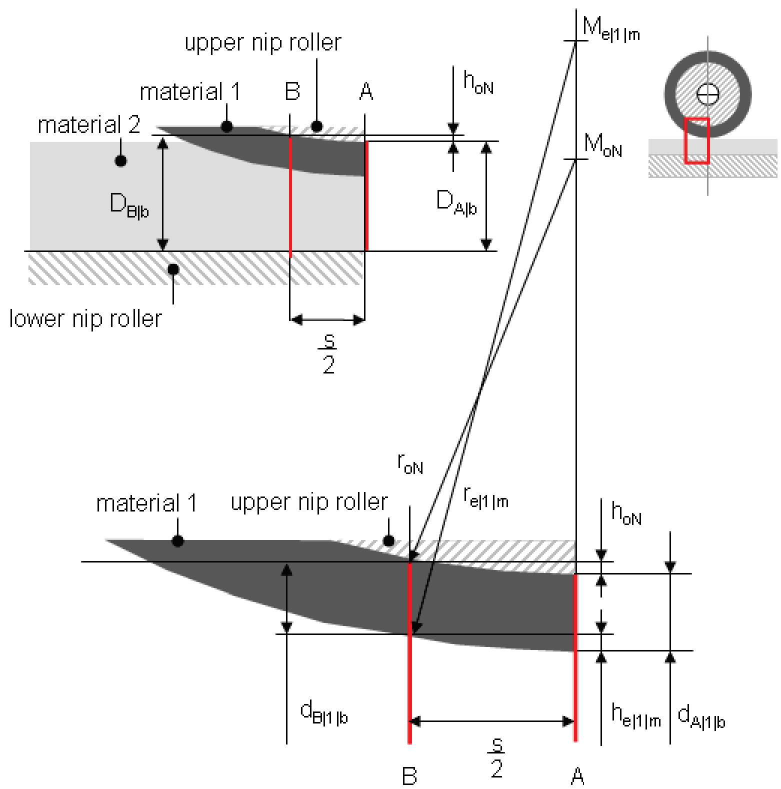


Figure 5 – Calculation of the substituting radii using the formula for a segment of circle. Shown are the heights of the segment of a cycle for the upper nip roller, for the substituting cycle and the compressed thicknesses of material on position A and B.

Here you have the ability to calculate with n materials in the nip {2}.

$$r_{e|n|m} = \frac{4 \cdot \left(h_{oN} + \sum_{i=1}^{n} d_{A|i|b} - \sum_{i=1}^{n} d_{B|i|b} \right)^2 + s^2}{8 \cdot \left(h_{oN} + \sum_{i=1}^{n} d_{A|i|b} - \sum_{i=1}^{n} d_{B|i|b} \right)} \quad \{2\}$$

To gain a higher accuracy of substituting radii, the different materials can be divided into m slices as shown in figure 6 and the resulting equation for n materials in the nip divided in m slices is {3}.

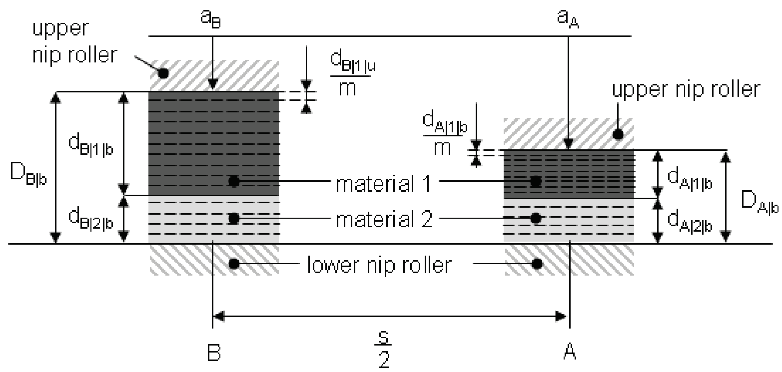


Figure 6 – Calculation of substituting radii within the materials. Shown are the divisions on position B and A with the compressed thicknesses of material.

$$r_{e|n|m} = \frac{4 \cdot \left(h_{oN} + \left(\left(\sum_{i=1}^{n-1} d_{A|i|b} \right) + j \cdot \frac{d_{A|n|b}}{m} \right) - \left(\left(\sum_{i=1}^{n-1} d_{B|i|b} \right) + j \cdot \frac{d_{B|n|b}}{m} \right) \right)^2 + s^2}{8 \cdot \left(h_{oN} + \left(\left(\sum_{i=1}^{n-1} d_{A|i|b} \right) + j \cdot \frac{d_{A|n|b}}{m} \right) - \left(\left(\sum_{i=1}^{n-1} d_{B|i|b} \right) + j \cdot \frac{d_{B|n|b}}{m} \right) \right)} \quad \{3\}$$

Kinematics in the nip

The following chapter will describe how to calculate the displacement of layers as a result of the nip inducted effect. The basic approach is the use of a gear of hollow cylinders. The functionality of a gear of hollow cylinders is shown in figure 6. It consists of a roller in the centre and two circulating rings, ring 1 and ring 2.

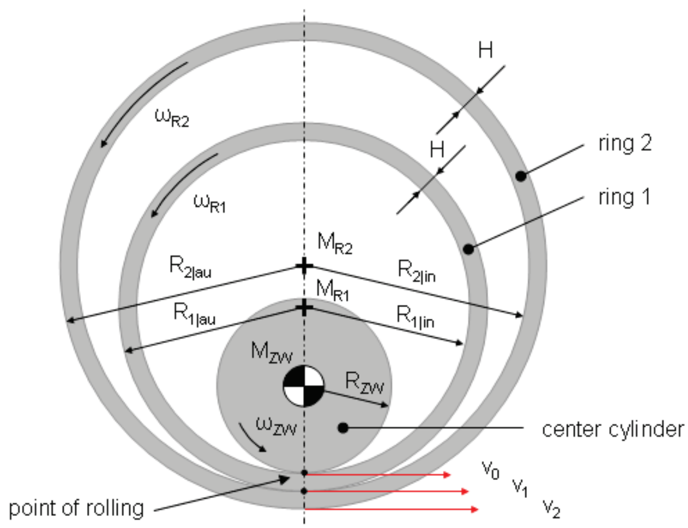


Figure 7 – Model of gear of hollow cylinders.

The roller in the centre has a known radius and circumferential velocity. The circumferential velocity of ring 2 need to be calculated. In addition the radii of ring 1 ($R_{1|in}$, $R_{1|au}$) and ring 2 ($R_{2|in}$, $R_{2|au}$) are given. The roller in the centre, ring 1 and ring 2 are not elastic, they show no deformation. The three elements, roller in the centre, ring 1 and ring 2 have contact in one point where they adhere. This point is called point of rolling. With these assumptions the following formula can be formulated. v_n is the velocity for calculation of ring n, H is the thickness of that ring and v_o is the circumferential velocity of the roller in the centre:

$$v_n = \frac{\prod_{i=1}^{n} R_{i|au}}{\prod_{i=1}^{n} \left(R_{i|au} - H\right)} \cdot v_0 \qquad \{4\}$$

Figure 8 shows the partitioning in n rings graphically. On the left side shown is the gear with one ring and shown on the right side is the gear with n rings. The resulting velocity v_n decreases with increasing gear ratio. The gear ratio is a function of the amount of rings.

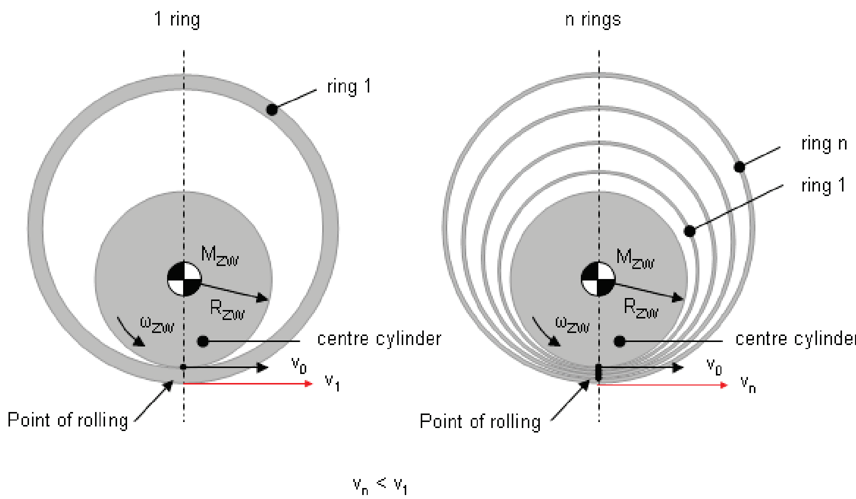


Figure 8 – Model of a gear of hollow cylinders. Left: A centre cylinder is surrounded by one ring. Right: the same structure, but the one ring is divided in n-rings. Result: Transmission is not single but multiple.

The functionality of a gear of hollow cylinders is now transferred to the kinematics in the nip. Basis is the calculation of substitution cycles. Figure 9 shows this graphically. The roller in the centre corresponds to the upper nip roller. The calculated substituting radii $r_{e|n|j}$ of the materials 1 and 2 in the nip corresponds to the outer radii $R_{n|au}$ in the gear of hollow cylinders. The thickness of a ring H of the gear of hollow cylinders is the minimum distance between two substituting radii in the nip and corresponds to the thickness of a material (coating of a roller or a sheet of paper).

With a known velocity of angle ω_{on} of the upper nip roller the calculation of any velocity for a substituting radius in the nip is possible. Figure 8 shows the calculated profile of velocity. Calculations showed the possibility of determining the velocity in the nip by reaching a limiting value while calculating the profile of velocity.

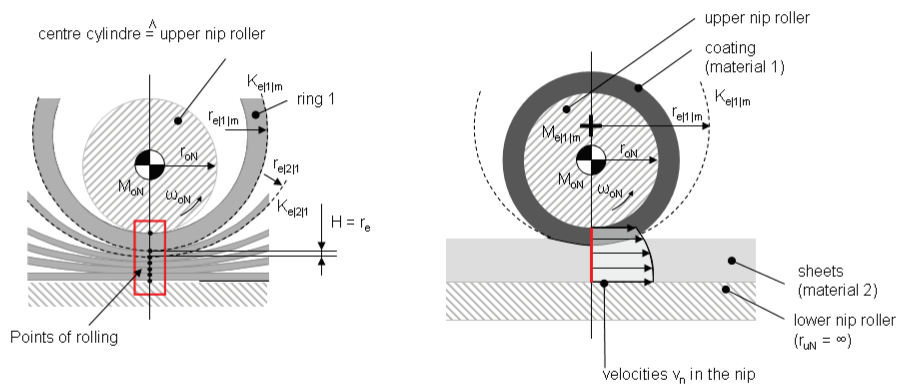


Figure 9 – Transferring the results of the gear of hollow cylinders to the kinematics in the nip. Left: outer radii are conform to the calculated substituting radii. Right: calculated velocity form in the nip. Basis was the circumferential speed of the upper nip roller.

To calculate the real velocity of a sheet of paper in the nip it is necessary to look closer to one sheet of paper in relation to its bending. Figure 10 shows the distribution of tensions inside one bended sheet around the upper nip roller. The velocity of the neutral fiber is the velocity of the sheet. Figure shows the velocity of the neutral fiber that has a value between the outer and the inner surface of the sheet. There is only one case for the neutral fiber being the median between the inner and the outer surface velocity: the elastic modulus of paper needs to be the same for tensile stresses and compressive stresses.

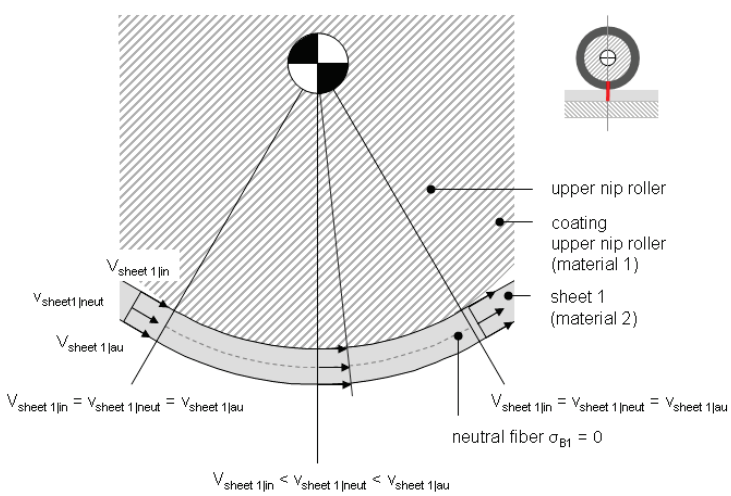


Figure 10 – Entangled nip roller by a sheet. Shown are the velocities at the moment for several points in sheet 1. Differences in velocity are the result of bending.

FORCE DEFORMATION BEHAVIOR OF PAPER

The end of the past chapter showed the importance of accurate material parameters for paper. Existing test equipment for measuring material parameters is designed for the test until failure. Comprehensibly the error of measurement results with these test equipment is high if it is not tested until failure. To gain high accurate results for tensile stresses of paper in Z-Direction the Chair of Printing Science and Technology at Technische Universität Darmstadt designed new test equipment. The main idea was adding an external travel sensor to the universal testing machine Zwick 050. This travel sensor is located behind the force sensor and the belted motor drive to achieve accurate data. Additionally a new test device for a high repeated preciseness was invented. Figure 11 shows this device. A hardened swimming stamp is set to the paper and adjusts itself on the top of the paper (1. – 2.). Hereafter a spherical calotte touches down and transfers the force to the sample.

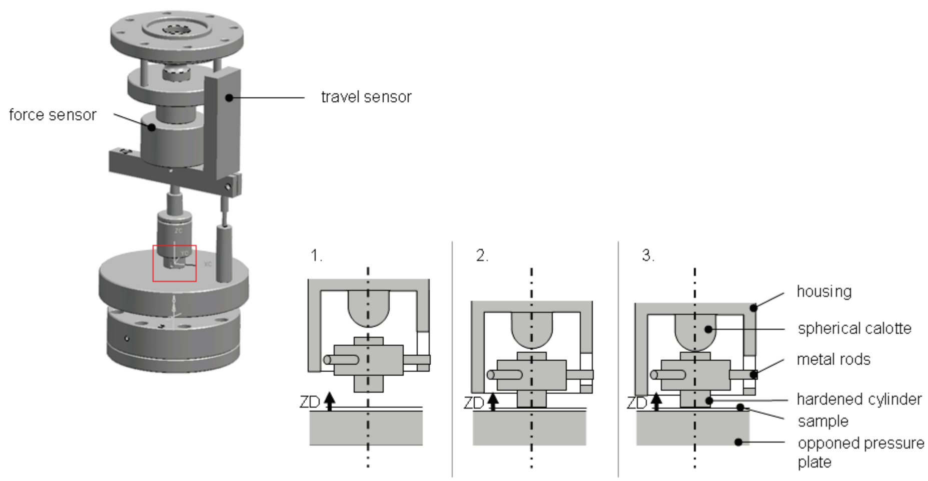


Figure 11 – Test equipment developed at IDD for compression tests in ZD.

The achieved results with this test equipment are shown in figure 12 . The shown force deformation curve points out the elastic material behavior after the first cycle of load. The first cycle shows a variant run due to planing the surface of the sample and setting actions. In figure 13 you can see the different material behavior of paper under tensile and comprehensive stresses.

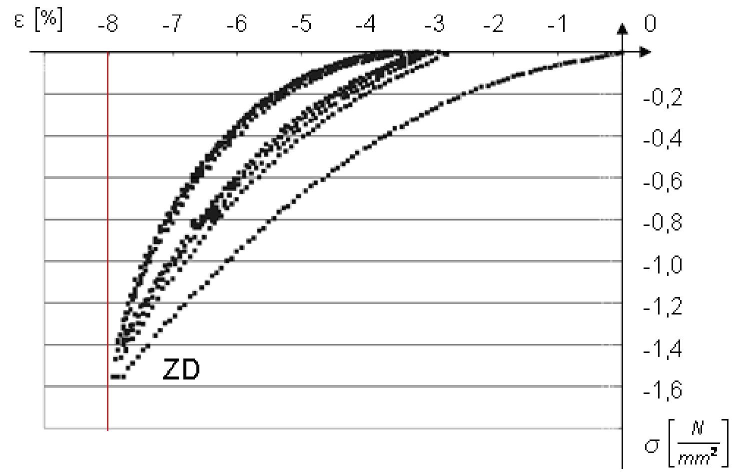


Figure 12 – Force deformation behavior under ZD compressive load. The sample was tested by 0,2% strain. Velocities of loading and releasing was constant 0,1 mm/min.

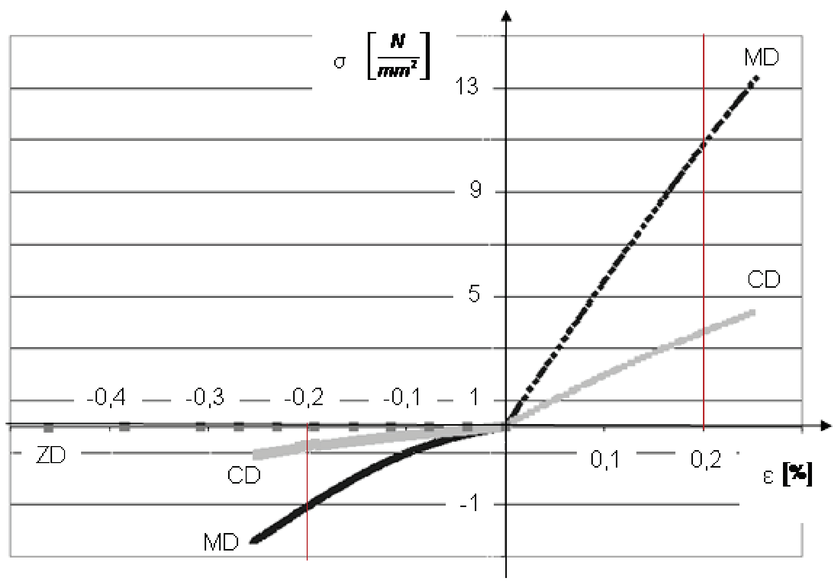


Figure 13 – MD CD and ZD tension strain diagram in the same scale for low strains up to 0,2%. Obvious noticeable is the anisotropy behavior of stiffness

Force deformation attributes of paper are not the same for tensile and comprehensive stresses. So it is proven that the neutral fiber of bended paper is not located in the middle of each sheet. For the analytical model presented in this paper it has no big effect but still it is an appearing factor. In addition the elastic behavior of paper in Z-Direction is proven under low stresses.

SIMULATION TOOL FOR THE NIP INDUCTED EFFECT

Aforementioned cognitions are summed up in a simulation tool with a graphical output. It calculates the displacement of sheets using the parameters for the paper, the radii of the nip rollers, the different coatings for the nip rollers and the pressure between the nip rollers, as well as the time for gaining the displacement of sheets using the difference of velocity of every sheet.

Figure 14 shows the graphical output of the simulation tool for the real process shown in figure 1. You need 2 nip rollers with different coatings. The upper nip roller has only one quite hard coating. And the lower nip roller exists out of 3 different coatings with different modulus of elasticity.

The simulation results were proved with the real process shown in figure 15. The real process shows a linear displacement. Feeding the simulation tool with the parameters of the real machine, the displacement of sheets is also linear and the amount of displacement has a low difference. The difference is about 14%. Simplification in the modeling as well as measurement errors of the force deformation behavior of the materials in the nip and the testing terms on the BASA are influencing the mentioned quantitative difference. Since the depending of force deformation behavior of paper on temperature and humidity is unknown the difference in measurement results between model and reality can not be calculated. Material parameters of paper were determined under repeatable clime conditions but the verification on the real machine was done in a normal industrial work floor.

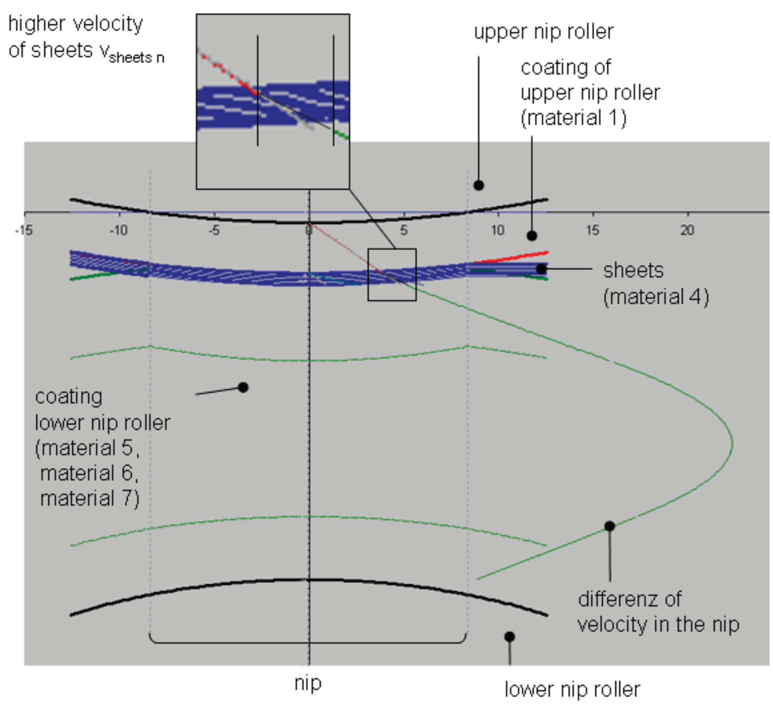


Figure 14 – Result of simulation for verification of the simulation tool. Displayed are the deformation of material as well as the velocities in the nip at a given circumferential speed of the upper nip roller

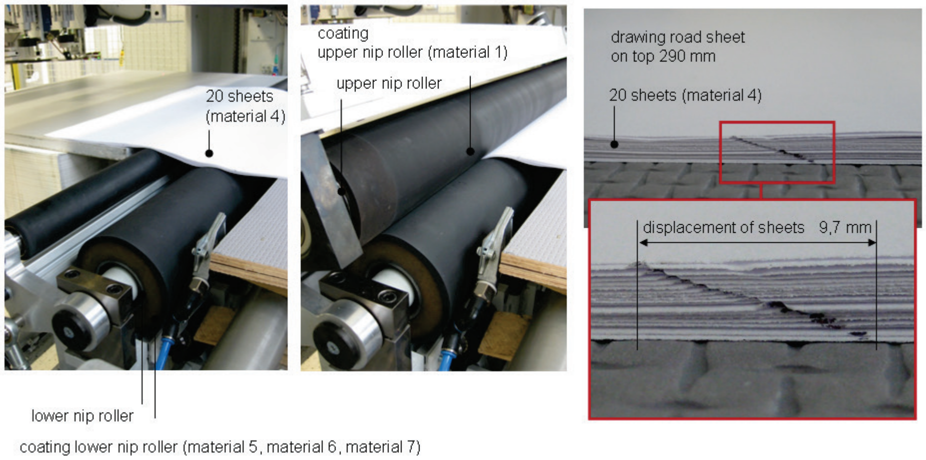


Figure 15 – Displacement of sheets in the BASA. Shown are the two nip rollers with 20 sheets of paper in the nip. A drawing road of 290mm of the sheet on the top results in a displacement of sheets of 9,7 mm.

DISCUSSION

There is a main difference between the analytical model and the nip inducted effect known from winding processes of coils. While winding coils all layers are fixed. For the analytical model all sheets are free and not clamped above the whole surface.

Normally a cylinder is rolling on the surface of a rigid body. A stack of paper is non-rigid. Pfeiffer [8] showed in his researches that there must be one instantaneous center of rotation in the layer of sheets.

The analytical model proved the existence of instantaneous center of rotation in the layer of sheets. It also ties up the research of Güldenberg [11]. Güldenberg's research was a test stand for watching the displacement of layers during the winding process of coils.

The analytical model for the nip inducted effect combines these researches and points out the existence of n instantaneous center of rotation in the layer of n sheets.

CONCLUSION

The paper showed a new way of interpretation the nip inducted effect and developed a simulation tool for designing and optimizing a machine for the real process of displacement of sheets to break bindings between sheets. The analytical model proves the existence of n instantaneous center of rotation in the layer of n sheets.

The processes of the nip inducted effect are explainable with a gear of hollow cylinders. The gear ratio is influenced by the material parameters of the promoted paper.

The analytical model matches with former research and was sorted in the existing knowledge about the nip inducted effect.

The development of paper testing devices in Z-Direction proved that force deformation attributes of paper are not the same for tensile and comprehensive stresses.

REFERENCES

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2. Patent - DE 2723162, "Vorrichtung zur Übergabe eines Teilstapels bedrückter Bögen von einem Gesamtstapel in eine Rüttelstation. "
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Industrial Use for the "Nip-Induced Effect" to Separate Sheets

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Name & Affiliation	**Question**
Volker Traudt, Inometa, Inc.	You consider the deformation of the paper, but your formula did not consider the deformation of the relatively soft covers that are used on nip rollers.
Name & Affiliation	**Answer**
Michael Desch, Technology University of Darmstadt	We tested coupons of the cover materials and produced charts of stress versus strain. From this data we extracted the elastic modulus which was then input to the simulation tool as the elastic modulus of the roller covering.
Name & Affiliation	**Question**
Volker Traudt, Inometa, Inc.	Have you shown the deformation of the cover in your results? Should the cover exhibit deformation?
Name & Affiliation	**Answer**
Michael Desch, Technology University of Darmstadt	The roller cover is quite hard. By design it flattens the paper and interacts with the surface of the paper. Even though this is quite a hard cover, it is still elastic. We studied both hard and soft covers. The nips with soft covers deform visibly but the deformations of the hard nip covers are minute. The deformation of the cover is modeled in the simulations.
Name & Affiliation	**Question**
Ron Markum, Oklahoma State University	In your results you show a stress-strain plot. This is Figure 13 in the report. You show CD and MD results. Was this data calculated or measured?
Name & Affiliation	**Answer**
Michael Desch, Technology University of Darmstadt	These results were data that were measured with our test equipment.