DETERMINING THE AMOUNT OF SHEETS IN A STACK OF PAPER BY USING A PRESSURE STAMP

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ABSTRACT

The paper will investigate the quality of an easy measuring procedure for determining the amount of sheets in a stack of paper.

One of the central questions is the comparability of the height of a loaded stack consisting of a single sheet, a small stack or a high stack of sheets. Here two approaches were examined to constitute the different deformation behavior of a single sheet and a stack of paper.

Experiments showed that deformation of the lowest and the highest surface of paper is not relevant and can be neglected if the stack of paper has more than 20 single sheets. Also experiments with different pressure stamps showed the spreading of a punctual charged load in the form of a cone to a bigger area while going down in the stack of paper. This has a high influence to the deformation allocation inside a stack of paper.

The interesting reference factor - thickness of a loaded sheet - for the measuring procedure will even in high stacks not converge to a constant value. Analysis of the measurement data certifies this effect. Measuring the height of a stack of paper is not possible in required accuracy with the procedure due to the low quality of the measured reference factor.

While comparing the calculated amount of sheets with the correct amount of sheets, a linear correlation between these values is conspicuous. Upgrading the easy measuring procedure with this linear correlation guides to a satisfactory measurement result. The use of the respective regression parameters is needed. The deviation to the exact amount of sheets can be lowered compared to the easy measuring procedure for example at 400 sheets, by factor 10 to 0.2 percent.

The procedure can be used for measuring the amount of sheets in a stack of paper with a high accuracy.

INTRODUCTION

In view of economic development in printing industry market participants are required to handle the exact amount of sheets. This demand appears at the paper manufacturers. These should take the exact number of sheets out of their stock to perform the orders. Furthermore this problematic is relevant in all post press processes. Dimensioning of forces while cutting or die cutting or even the fast determination of the number of sheets for configuring the post press machines after taking away the misprinted paper are actual examples for this purpose. Reducing costs as well as reduced ecological damage step in foreground due to the high consumption of water and energy while manufacturing of paper.

Out of these reasons there is a high demand in industry to determine the exact amount of sheets in a stack of paper with high reliability.

STATE OF THE ART: MEASURING SYSTEMS IN THE MARKET

Commonly industry offers three measuring principles for determining the amount of sheets in a stack. In the following, these will be described.

Optical Measuring System

A self-adjusting system is used for optical determination of the amount of sheets inside a stack. A known amount is scanned in advance and the picture is analyzed. The data of this analysis is used to auto-calibrate the system. Once the parameters are determined for one product the system accepts only scan files, which are almost identical to the original. Bigger spaces between stacks are ignored and have no influence to the count result. Bended material can be counted when the edges can be scanned clearly.

Main advantage of this process is the touch less determination. So a single sheet cannot be damaged. Some facts can influence the result negatively. These are the disadvantages of that process. Enumeration of these facts: bad cut edges, very fibrous material, sheet splitting and bad alignment of the sheets in the stack. [1][2]

Gravimetrical Measuring System

A scale is used for the gravimetrical measurement of the amount of sheets. Here a reference stack is weighed to determine the mass of one sheet. Now the amount of sheets in a stack is calculateable out of the actual weight and the reference measurement.

Such a scale can be integrated in a jogging machine. Here the alignment and the determination of the amount of sheets can be done parallel. Also this process touches not every single sheet. No marks are left back on the sheets. [3]

Mechanical Measuring System

Another process for determining the amount of sheets in a stack of paper is the mechanical measurement. Here every sheet is touched in its corner. The stack of sheets is held by a pin. Then the count head grabs the first sheet with vacuum and moves it below the pin. Then the count head releases the first sheet and takes the next sheet. This system has a performance up to 2500 sheets per minute.

Besides that there is another counting system on the market. It works similar but with a rotating disc. Here you gain less marks on the sheets. No further details can be specified due to intellectual properties. [4][5]

THEORETICAL FUNDAMENTALS TO THE DEFORMATION BEHAVIOUR OF SHEETS AND STACK OF SHEETS IN Z-DIRECTION

Here a short introduction to the topic will be given in advance to the experiments and the presentation of the results. Especially the difference in deformation behavior of single sheets and a stack of sheets are of interest.

Paper and Its Strength Properties

Paper is an inhomogeneous material made of natural cellulose fibers. These are connected by hydrogen bridges. In addition to the cellulose fibers there can be processed several other ingredients like lignin and hemi cellulose. According to the intended use of the paper there can be added inorganic materials to the texture to compact the mterial or to influence optical or mechanical attributes.

So the paper contains several components. These cause in interrelation heterogeneous deformation behavior. Different load directions (CD, MD and ZD) cause viscous-elastic behavior in varying characteristics. With increasing the load plastic deformation turns up.

Fibers inside the paper are hygroscopic. Their humidity is in balance with the humidity in the air. Several characteristics in particular the mechanical strength of the paper are influenced by humidity. Mechanical characterization is done inside a climatised laboratory with a relative humidity of 50% at a temperature of 23°C. [6][7][8]

Paper and Its Strength Properties

The term **paper thickness** is the distance between two parallel-oriented plates between which the paper is in contact. For thickness determination a large number of measurement data used due to the inhomogeneity of the fiber meshwork and thus the variance of measurement data.

Because of the compressibility of the medium a defined pressure force of 20 N is applied to a circular area of 200 mm² (0.1 N/mm²). So reproducibility of results is guaranteed. [6][7]

Loading a paper sheet with a compressive force in z-direction causes a compression of the sheet structure. This results in a reduction of the thickness of the paper. After discharging the load a delayed forming back to the initial thickness occurs due to the viscous-elastic behavior.

Some of the compression goes into a plastic deformation due to a very high load which results in a permanent loss of thickness. In this case of deformation behavior in thickness direction, paper sheets may be modeled by a system of three springs in series. This spring system results, as illustrated in figure 1 from the thickness of the fiber network and the roughness at the top and bottom. The heights of the surface layers are defined as two times the arithmetic mean roughness value R_A. To the tips on the surface a reduction of the cross-sectional area persists. This results in an increased deformation by applying a load. Therefore the compression path is not uniform running through the paper structure in the thickness direction. In the figure 1 this fact due to the different stiffness of the springs is shown [9]. [10][11]

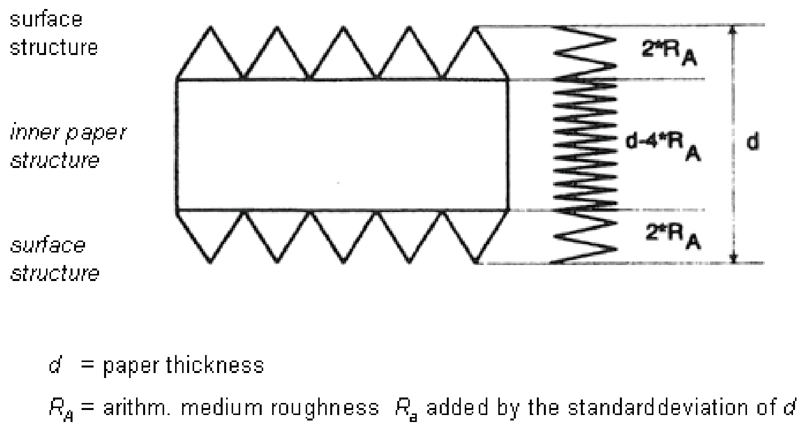


Figure 1– Easy model for the force deformation behavior of paper in z direction [12]

Transferring this model to the behavior of a stack of sheets at one pressure load, it is not describable as a series of these three springs of a single sheet. The height of a stack of paper cannot be directly calculated from the thickness of a loaded single sheet. The measurement of several sheets results in a reduced deformation compared to the mathematical product of the number of sheets and the height of a loaded sheet. In figure 2, this effect is shown on the basis of a stack of 20 sheets of paper. Also is to recognize that the relationship between force and travel in the case of paper is not linear [13].

There is a significant increase in the stiffness while increasing compression stress. As a result the maximum deformation diverges after a complete compression of the components of the paper in z direction against a limit [14].

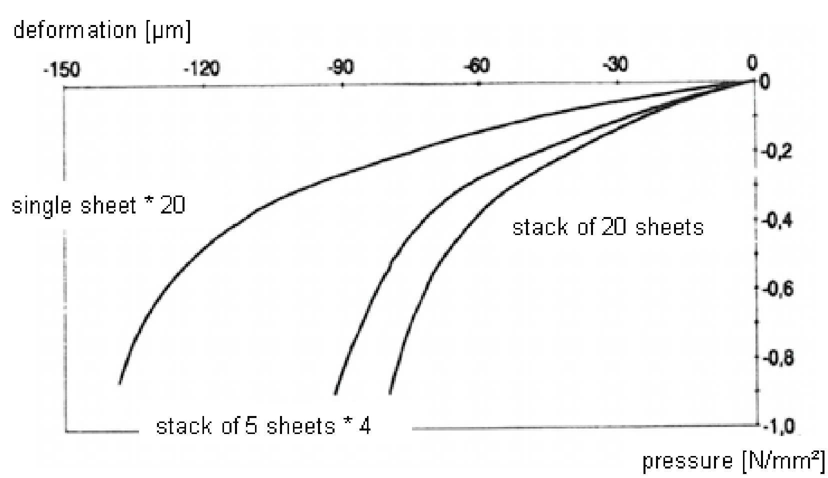


Figure 2 – Deformation behavior of a single sheet and a stack of sheets [12]

If a single sheet of paper is pressed in z-direction, two contact surfaces results between paper and the top or bottom of the pressure stamp. Additional contact surfaces arise in the case of a stack of paper between the individual sheets.

On the contact paper-stamp a lower friction occurs due to the smoothness of the stamp which favors the deformation in the thickness direction. Increasing the number of sheet in the stack, this effect is seen relatively less. This decreasing percentage of the total deformation is shown in figure 3.

The contact points between the individual sheets contribute significantly to the compression with increasing height of the paper stack. The surfaces show - as shown in the model - a lower stiffness due to the roughness than the inner structure of the paper. However the roughness tips in a paper stack can be pushed partially into each other. Thus increases the stiffness of the interlocking contact points between the layers of paper and the compression decreases. As a result, a stack of paper under equal pressure conditions can be less deforming.

In the figure 3, it is still clear that the proportion of deformation of the inner structure of paper in the stack converge to a limit [12][13].

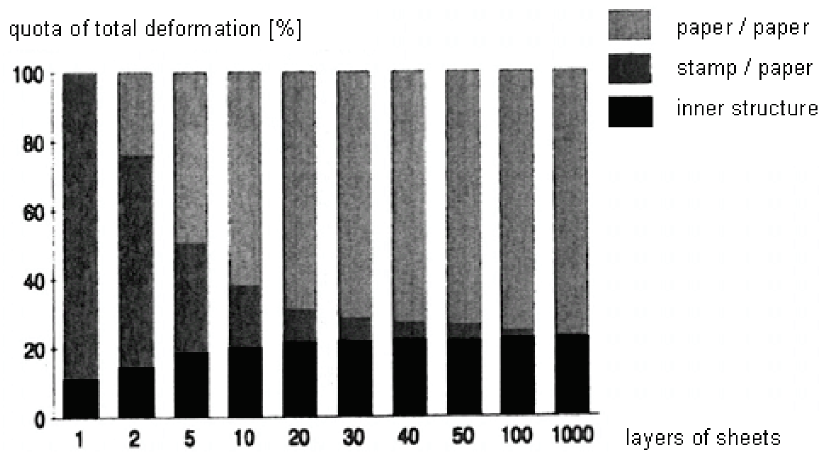


Figure 3 – Quota of the single components to the total deformation of a paper stack [12]

EXPERIMENTS FOR THE EVALUATION OF THE PRESENTED MEASURING PRINCIPLE

This project conducted a series of tests. These will show the results the measurement procedure presented in the introduction. On the one hand, the attempts focused on the deformation behavior of stacks of paper and on the other hand on the measuring quality of presented process. The actual experimentation is based on some preliminary considerations. The test program was created and defined by these.

The Test Implementation Considerations

The proposed measuring procedure is based on a very much simplified mechanical model. The idea to determine the height of a deformed sheet of paper from a reference measurement with ten sheets and to determine the exact number of sheets using this reference level and the height of the stack to be measured is based on the assumption that the individual sheets in the stack act as a series connection of a large number of identical, mass less springs. Still, it is assumed that in a stack of paper, which is exposed to a defined load, each are equally deformed. But at the same time this last condition requires that the load on the paper stack spreads down straight and is not distributed in the form of a pressure cone on an even larger area.

Influence of own weight. In first considerations, it was assessed whether the influence of weight has an influence on the measuring results and thus must be considered. In a paper which has a thickness of 100 µm and has a weight of 100 g/m², a sheet performs 0.981 N/m² pressure to the lower layers. The stack to measure should be up to 15 cm height (1500 sheets). In a stack of this amount, a pressure of 1471.5 N/m² weights on the bottom sheet by the weight of the rest of the stack. This corresponds to 0.0014715 N/mm² or 0.014715 bar. Taking into account that winding paper cause strains in the order of 1 N/mm² (approx. 680 times the load of the weight) and the charges carried out in the experiments were in this size, so the influence of weight [12] can be neglected.

Series connection of identical springs - influence of surface roughness. The theoretical understanding of the deformation behavior of stacks of paper shows that the total deformation of a stack of paper is made of three components: the deformation of the internal matter of the paper, the deformation of contact surfaces between two sheets and the two contact surfaces with the pressure stamp and the counter pressure plate. The first two components can be considered in accordance with the literature as a series of identical springs, while the third component with increasing number of sheets decreases influence. Literature also posits that the deformation per sheet due to this influence was subject to the respective pile height [12]. Because this effect has also an effect on the quality of the reference measurement, this will be closer examined and its impact evaluated on possible measurement errors.

Distribution of the pressure force - training a pressure cone. Another important aspect, which affected the quality of the reference measurement, is the distribution of the introduced force. The basic idea of the measurement procedure is that the initiated pressure in the stack is distributed straight and thus to any position of the stack, an identical cross section of paper is charged with the given power. Only this way would ensure that independently to the stack height to each equally deformed sheet on the stack and so the height of a sheet is independent of the stack height.

To doubt this assumption in advance some practical examples are given. The designs of bolt connections of two parts by tension a pressure cone and the distribution of the tension force on a larger cross section are expected. According to VDI 2230 calculation explicitly is done with a cross section (Figure 4). Also during a compaction of material in the soil with a so-called polygon bandage, forming a pressure cone in the floor and a related decrease of compressive stress in the earth's interior taken into account (Figure 4). It is however to note that in a stacking of an inhomogeneous material such as a stack of paper distribution of compressive stress is different from the distribution in a massive, homogeneous material such as steel.

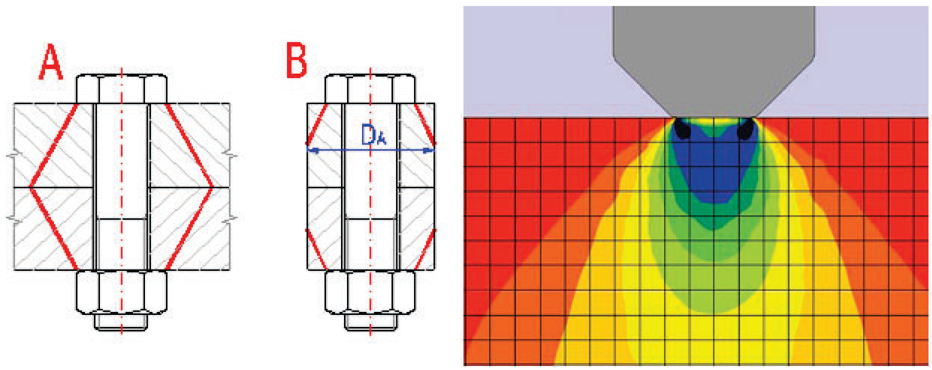


Figure 4 – Formation of a pressure cone (left: screw connections [15], right: in soil with polygon bandages [16])

Development of Testing Program

A total of six series of tests were carried out on the review of the just discussed considerations and assessing of the measuring procedure. All tests were made to a material testing machine of Zwick/Roell Company. In all trials, the machine table, on which was the paper stack, was driven to reach a particular force against the stamp. Then, the machine table with a constant speed was moved further upwards, until the desired load was reached. To maintain a potential creep of the paper stack, the maximum load was applied a defined time. The exact test parameters in the respective tests are available in tables in the next chapter:

1) In a first test the influence of the contact surfaces between paper and stamp or counter plate surface should be examined on the deformation behavior of stacks of paper. According to the considerations the comparatively high deformation of top and bottom of a paper stack to a rising number of sheets spread with increasing stack height. So the deformations of the sheet loose influence and converge to a constant value. To prevent the development of a pressure cone, the stack was loaded on the full surface.

(2) The influence of pressure distribution should be reviewed in the second test. For reasons of comparability, the stack heights from test 1, were adopted. Exposure to a given compression stress was however not fully but selectively.

(3) In test three, the suspected and closer studied pressure cone in test two should be visualized. Here paper stacks of different heights were loaded punctually. At regular intervals carbon paper was inserted to visualize the formation of the compressive stress. This test was carried out with copying and double-sided coated paper. Preliminary tests have shown that for the development of marks higher compressive stresses are required than in the previous tests (see the test parameters)

(4) In tests four and five, the quality of the measuring procedure should be estimated. To do this, in test four we measured heights of stacks of paper with up to 1000 sheets and calculated the measurement error when using different reference levels for the height of a loaded sheet. Also this test was again performed with copying and double-sided coated paper.

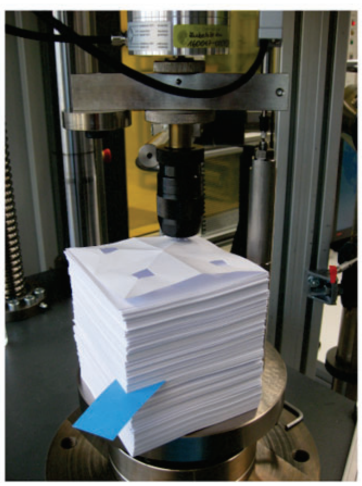
(5) In test five, it was reviewed whether a precise determination of the number of sheets from the height of a stack of loaded paper is possible when knowing a proper reference for the amount of a loaded sheet with the featured processes. To do this, heights of paper stacks with 500, 501, 502, 503, and 504 sheet of copy paper were measured and from an average size of reference, the number of the sheets is calculated. In particular, it

should be determined whether the featured principle is able to detect fluctuations in the order of a single sheet.

(6) During test six final trials were conducted, what other influences on the measurements can be identified. One hand, the velocity of the testing machine was modified and on the other hand the holding time of the maximum load was varied. From these results, a dependency of the measurement results of the test parameters should be estimated.

Implementation of Attempts and Presentation of Test Results

As already mentioned, a test consisted of three successive phases. In the first phase, the machine table with the paper stack was driven so far against the pressure stamp until a predetermined pressure force test was applied. This force was chosen for reasons of comparability. So a bias in the cross section of 0.106 N/mm^2 was loaded (cross section of the top layer of paper). It should be ensured that no more air is located in between the individual sheets in the entire stack. So the individual layers lay already flat on top of each other at the beginning of the measurement. How far this has been achieved with the chosen bias, is available in the discussion of results. In the second phase of the measurement, the machine table was driven with a constant speed against the pressure stamp until a desired force has been reached. This force was chosen (except for test 3) that the compressive stress in the loaded cross section including the bias was 1.106 N/mm^2. So, the compressive stress was increased by 1 N/mm^2. After reaching the desired compression stress it was held during the third test for 60 seconds (except in test 6).



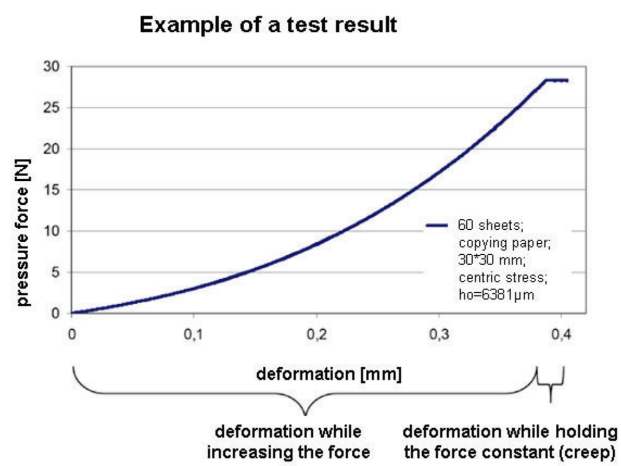


Figure 5 – Test stand (left) and exemplary discussion of results (right)

During the second and the third phase of the measurement, the software logged the deformation of the sample, the measured force of pressure and time. The distance of the pressure stamp from the surface of machine table at the start of the second phase specifies the height h_0 of the paper stack at preload. From the evaluation software the deformation of the paper stack Δh can be read. Finally, the difference of both sizes is the height of the loaded paper stack $h1$. From these values the needed sizes for the evaluation can be calculated: "Deformation per sheet" and "Height of a loaded sheet". Figure 5 shows the test set-up, as well as the results obtained with the software for an exemplary test. This example shows two important aspects. On the one hand, the curve shows a non-linear deformation behavior. So with further loading the deformation converge to a constant value [14]. And a significant creep of the paper stack can be recognized in the holding time of 60 seconds. So, the deformation continues growing under constant loading conditions.

In the following the results for the carried out tests are presented and the respective test parameters are listed in detail. Standard copy paper was used for the tests (basis weight 80 g/mm²) and on both sides smooth coated offset paper (weight 135 g/mm²). During the experimentation was ensured that a sample was not used twice. So always a fresh sample was used for a measurement or an already loaded stack was loaded in a different position.

Test 1:

For the estimation of influence of two contact areas between paper and metal on the deformation behavior of paper stacks, a square copy paper with an edge length of 25 mm was fully charged by a stamp of 65 mm. To calculate the size of "Deformation per sheet", the deformation of the test setup was subtracted from the entire measured deformation. This was done for this measurement, as well as in all other measurements. The deformation of the test setup was previously found in a test without sample and under the specified test parameters. From the diagram in figure 8 can be read that the height of a loaded sheet first increases with increasing the stack height. A number of 20 sheets the curve commutes at a value of 95 µm and is subject only to low fluctuations. The curve of the deformation of a sheet is falling. As predicted in the model, presented in the last chapter, the deformation of the top and bottom surface at low stack heights has a relatively large impact on the total deformation. By increasing the number of sheets, this influence is distributed on more and more sheets. The value of the deformation of a sheet is nearly a constant value from a stack height of 30 sheets. Also it is confirmed that no inference on the deformation of a stack of paper can be drawn from the deformation of a single sheet. To be noted for further tests, the deformation of the top and the bottom surfaces of the paper have an influence on the deformation behavior of a stack of paper. This is negligible from a pile height of 20 sheets. Thus, for a first intermediate result it appears to use as a measurement reference not 10 but at least 20 sheets. Here the relevant size "Height a loaded sheet" has left only small fluctuations and has no discernible trend.

Test 1	
Paper format [mm]	25*25
Paper type	Copy paper
Diameter of stamp [mm]	65.0
Bias [N/mm²]	66.3
Load [N]	0,106
Load [N/mm²]	625
Total load [N/mm²]	1,106
Position of load	Full surface
Duration of load [sec]	60
Velocity of the stamp [mm/min]	0.1
Deformation of the test machine [µm]	3.1

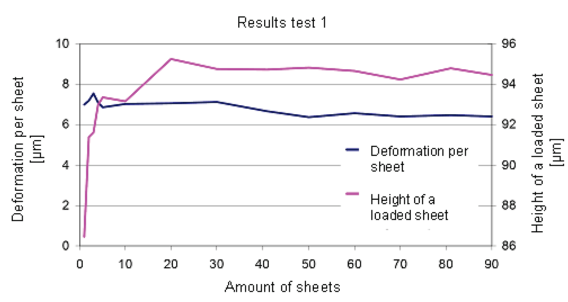


Figure 6 – Parameter and results of Test 1

Test 2:

In this experiment, the stack height and other parameters were taken from experiment 1. But the compressive stress of 1.106 N/mm² was applied with a 6 mm stamp, which is set to the samples center. Because of the smaller diameter of stamp the force had to be reduced to preserve the compressive stress. The results in figure 7 show significant differences to the results of test 1. While the calculated deformation per sheet continuously decreases, the height of a loaded sheet grows steadily. A state of equilibrium is not visible in a pile height of 100 sheets. These two curves can not be justified solely with the deformation of the top and bottom surface in contrast to the results of test 1. These curves are different, as figure 8 shows in direct comparison.

The results of the experiment suggest that in addition to the influence of the surface roughness, the formation of a pressure cone affects the deformation behavior in a stack of paper. The distribution of a punctual applied force to an ever-increasing material diameter causes an even larger decrease of the compressive stress as lower as a sheet lays in the stack. Accordingly, in higher stacks of paper the lower layers are less deformed. This effect would explain the increasing run of the curve in figure 7, and would have a serious impact on the practicality of the measuring principle.

Test 2	
Paper format [mm]	30*30
Paper type	Copy paper
Diameter of stamp [mm]	6.0
Bias [N]	3
Bias [N/mm²]	0.106
Load [N]	28.2743
Load [N/mm²]	1
Total load [N/mm²]	1.106
Position of load	Concentric
Duration of load [sec]	60
Velocity of the stamp [mm/min]	0.1
Deformation of the test machine [µm]	0.6

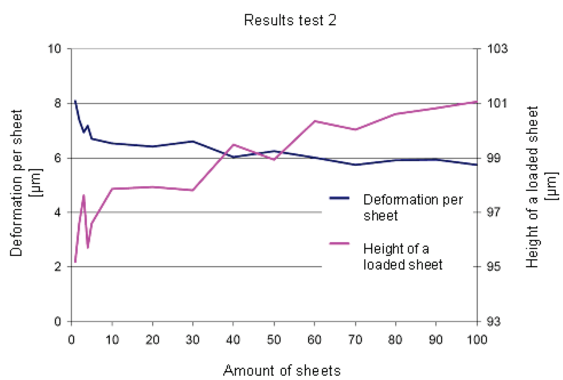


Figure 7 – Parameter and results of Test 2

Test 3:

To confirm the suspected forming of a pressure cone the distribution of the pressure force depending on the height of the stack and the associated decrease of pressure stress was tried to visualize. To do this, two stacks of paper were examined: normal and double-side coated paper. In a stack of 100 sheets of paper a carbon paper was inserted all ten sheets and in the stack with 250 sheets all 50 sheets. The decline of compressive stress in the direction of the thickness of the stack can be estimated on the basis of the size and the intensity of carbon prints. The force had to be increased strongly in an attempt to achieve visible imprints. In the tests the 100 mm * 100 mm stacks were charged by using a 6 mm stamp with a compressive stress of 21.33 N/mm². The feed rate was this 1 mm/min. Figure 9 shows the test set-up and a selection of results.

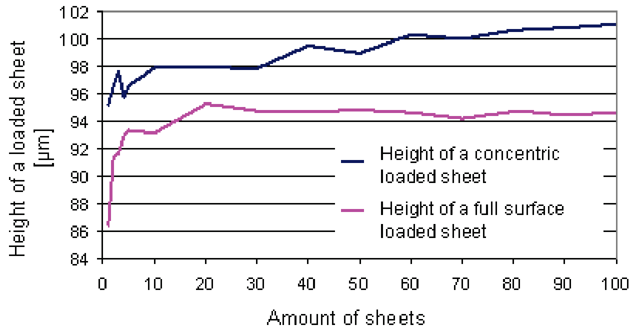


Figure 8 – Comparison of the results from Tests 1 and 2

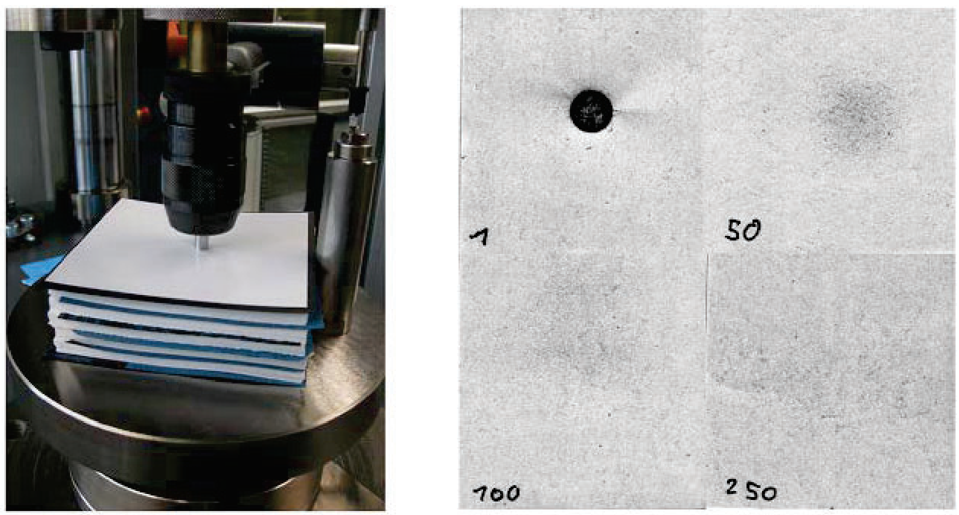


Figure 9 – Test stand for test 3 (left) and results for double side coated paper at 1, 50, 100 and 250 sheets

Test 4-1	
Paper format [mm]	100*100
Paper type	Copy paper
Diameter of stamp [mm]	6.0
Bias [N]	3
Bias [N/mm²]	0.106
Load [N]	28.2743
Load [N/mm²]	1
Total load [N/mm²]	1.106
Position of load	20 mm of a corner
Duration of load [sec]	60
Velocity of the stamp [mm/min]	0.5
Deformation of the test machine [µm]	1.38

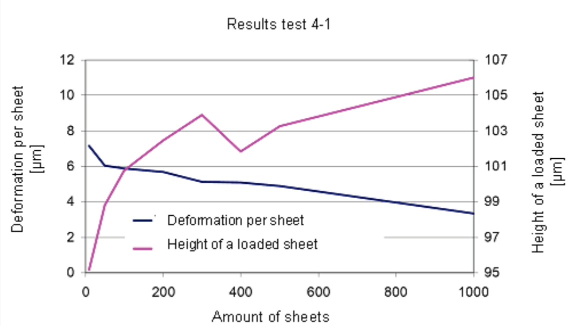


Figure 10 – Parameter and results of Test 4 for copy paper

You can see clearly that already after a few layers the intensity of coal marks takes off strongly and its size increases at the same time. After about 100 layers, no more significant carbon footprint is detectable for both types of paper. This indicates that from this stack height the punctual force evenly has spread to the entire paper. The formation of a pressure cone hereby is sufficiently proven. The effect on to inter seeking measurement methods are discussed the next chapter.

<u>Test 4:</u>

After the basics of deformation behaviour of paper have been tested in the tests one to three, the stack height increased in the test four and five to up to 1000 sheets. Thus, the accuracy and practicality of the measuring procedure should be explored. Examined was copying paper with a pile height of up to 1000 sheets and on both sides coated paper with a height of up to 500 sheets. The stacks of the format 100 mm * 100 mm were loaded by a stamp of 6 mm. The loading point was 20 mm away from the corner (see figure 5). This experimental setup should be used to simulate conditions in a real measurement in the practice.

Both results for copy paper (fig. 10), as well as for double-side coated paper (fig. 11) show that the height of a loaded sheet increases up to stack heights of 1000 sheets. The formation of a pressure cone plays a significant role even in these stack heights and influences the quality of a previously determined reference measurement. The results of these tests are used in the next chapter for an error assessment of the measuring procedure for the application of different reference measurements. The curve of a deformed sheet has a contradictory effect at test 4-2. Expected was a steadily decreasing as in the previous tests. One reason for this behaviour could be, that from a critical pile height the individual layers in the preloaded stack lay no more plan on top of each other due to the pressure cone.

Test 4-2	
Paper format [mm]	100*100
Paper type	Double side coated
Diameter of stamp [mm]	6.0
Bias [N]	3
Bias [N/mm²]	0.106
Load [N]	28.2743
Load [N/mm²]	1
Total load [N/mm²]	1.106
Position of load	20 mm of a corner
Duration of load [sec]	60
Velocity of the stamp [mm/min]	0.5
Deformation of the test machine [µm]	1.38

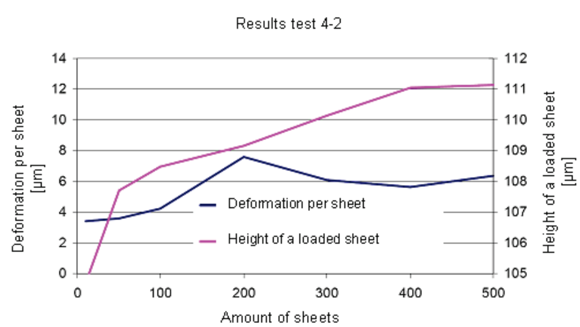


Figure 11 – Parameter and results of Test 4 for double side coated paper

The measure h_0 and the total deformation Δh have no big significance. Thus, only the height h_1 for the total load and the amount of a loaded sheet are relevant for a later evaluation. The history of the force-deformation diagram from the said series showed this. In some points, the force suddenly dropped to a lower value. We can assume this is the result of a "pressing flat" of wavily paper. Figure 12 shows a snippet of a chart in which the mentioned effect occurred.

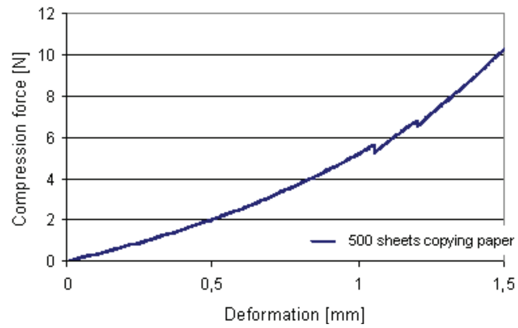


Figure 12 – Dropping of the force in high stacks

<u>Test 5:</u>

This experiment was made on the basis of copy paper to estimate the accuracy of the measurement procedure. Stacks of 500-504 sheets are examined and calculated the differences of the heights h_1 in µm and in sheets. The parameters were the same as in test 4-1. The results show that the height h_1 increases between 321 µm and 15 µm when a single sheet is added. Calculating with an average reference size of 105.21 µm per sheet, this corresponds to an increase of 0.1 to 3.1 sheets. The number of sheets in the stack is finally calculated according to the formula $n = h_1/a$, where a is the reference "height per loaded sheet". Figure 13 shows the measurement results and compares the actual number of sheets to the calculated values. With the method of measuring the number of the sheets in the stack with a known reference size, we can gain an accuracy of 1.6 sheets. This corresponds to an accuracy of 0.3%. Restrictive remains it should be noted that the size of the used reference from the results of the test series 4 was calculated itself. A reference measurement with 500 sheets is however unrealistic in practice. The quality of the measuring procedure for the use of other reference is examined in the next chapter. However, remains to be noted that the results when using a good reference is very accurate despite the inhomogeneous structure of paper stacks.

Amount of sheets in a stack	Calculated amount of sheets
500	499,2
501	499,9
502	501,5
503	504,6
504	504,7

Figure 13 – Comparison of real and calculated amount of sheets

<u>Test 6:</u>

In the last experiment, two test parameters were varied to identify their influence on the displacement behaviour of stacks of paper. In a first experiment, the velocity of the machine table has been increased. In a further experiment, the holding time of the maximum load has been increased from 60 to 300 seconds to characterize the creep behaviour of the samples. Figure 14 shows the results of the two final tests. The left part of the figure shows that deformation under a higher feed rate is low. This is possibly because of a lower speed the sample has time during the longer loading phase to creep. For the measurements, it is important that the reference measurement as well as the actual measurement will take about the same amount of time. The right side of the figure reflects the creep behaviour of the samples. It turns out that most of the creep deformation is completed in the first 100 seconds. So it is important for the measurement to ensure that the results are always read after unitary time.

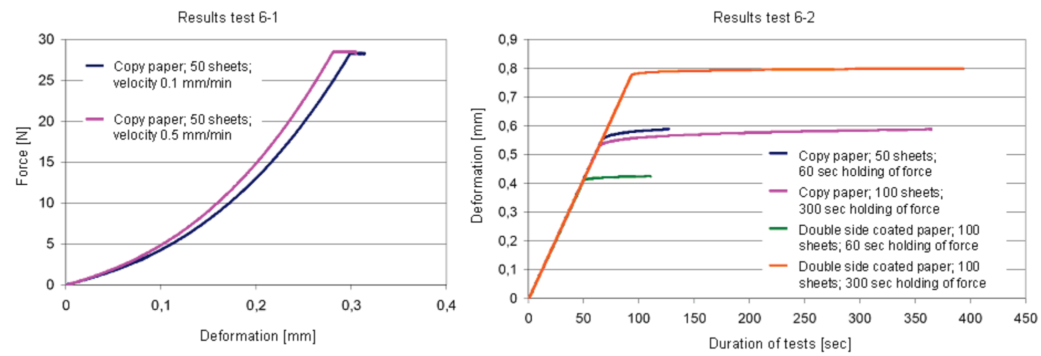


Figure 14 – Results of Test 6

ASSESSMENT OF THE PRESSURE MEASUREMENT PROCEDURE ON THE BASIS OF THE TEST RESULTS

Develop of the Measurement Rules

The recommendations on the measuring rules take into account the test results presented in the last chapter. An optimization of the measuring principle is made in the next chapter.

Measuring equipment. In the test series 4 and 5, the force was applied with 6 mm stamp on a paper stack with the format of 100 * 100 mm. In this size, the compression force is applied to about 0.3 % of the total area. It is about the relationship, if a sheet of the format 700 * 1000 mm will be loaded with a 60 mm stamp. Therefore a diameter of 60 mm for the stamp is recommended for practice.

Compressive stress / pressure force. During tests the paper stack was loaded with a bias of approximately 0.1 N/mm² and was subsequent loaded with a stress of 1 N/mm². These values were chosen because the same stresses occur while wrapping paper on roles. Also they are used in common analysis concerning the compression behaviour of paper. After the tests with the specific load, an imprint of the stamp is clearly visible and sensible on the top sheet of the stack. This undesirable consequence of pressure makes it clear that the compressive stress can not be increased without increasing the waste paper. In addition, the load with a lower compressive stress is also not to recommend. Figure 12 shows the behaviour of a stack after application of the bias. The "edges" seen on the picture suggest that the bias was not high enough to push all air out of the pile out. The layers begin at the additional load to slip on each other. This process of "pressing flat" must be completed before measurement because only then the correct height of the stack can be measured. At low compressive stresses, this would be but not guaranteed. Therefore the selected load in the tests with 1.1 N/mm² makes sense for the measurements although the top sheet is damaged. However to keep in mind the force must be adjusted when using a larger pressure stamp.

Mathematical determination of the number of sheets. The amount of sheets *n* is determined with a simple formula. From the height of loaded stack h_1 and the reference for the level of a loaded sheet the number of sheets is calculated according to the regulations:

$$n = \frac{h_1}{a}$$

The reference *a* is calculated out of the reference stack:

$$a = \frac{h_{ref}}{n_{ref}}$$

In this formula h_{ref} is the height of the reference stack and n_{ref} the amount of sheets in the reference stack.

Number of the reference sheet. The results of the tests show that a recommendation is almost impossible for the forming of pressure cone. Only the influence of the deformation of the top and bottom surface can be reduced. This requires a reference measurement with at least 20 sheets. For reasons of practicality, but not more than 50 sheets should be used for the reference measurement.

Duration of the measurement. From the results of test 6, we can see that the velocity of the stamp and the duration of the exposure play a negligible role, as long as the reference measurement conditions persist for all measurements. A duration of the pressure force between 30 and 60 seconds is recommended.

Resolution of distance sensor. It can be assumed that the height of an sheet depending on the variety is between 200 µm and 50 µm. Therefore a travel sensor with a resolution of 25 microns is required to measure differences in the magnitude of a sheet. However, the use of a travel sensor with a resolution of approximately 10 µm is recommended.

Review and Assessment of Measurement Rules Based on the Results of the Tests

The developed measuring rule should be applied with the results of the carried out tests. This is done as follows: under application of different reference levels, the number of the sheets are calculated according to the above formula from the height of a stack. The data is from the test 4. For copy paper the respective reference size *a* is calculated using the measurements of 10, 50, 100, 200, 300, 400 and 500 sheets. From the height of the measured stack of 1000 sheets the reference size of *a* the number of the sheets is calculated and compared with the actual value. For the double-side coated paper the height of 500 sheets of the stack is used. As reference levels work the calculated values from the stack heights 10, 50, 100, 200, 300 and 400 sheets. Figure 15 shows the error, which is made by using the measuring rule. The diagram is to read as follows: If the calculation for the double-side coated paper (blue curve) with a stack of 500 sheets is done with a reference determined from a measurement of 50 sheets, so an amount of 516 sheets is calculated, which corresponds to a measurement error of 3.2 %. Should the reference be determined from measurement with 100 sheets and the amount sheets in a 1000's stack of copy paper (pink curve) is calculated, the measurement error is even 5.2%. From the figure a central connection can be read which has an impact on the quality of the applied measuring rules: the measurement error is less, if the reference measurement is closer to the actual stack height. To compare that with test 4, the height of a loaded stack is increasing with increasing amount of sheets and the curve takes a concave course. So, if the stack height for reference measurements differs more from the actual height, the measurement error is bigger. This is due to the forming of a pressure cone studied in the tests of 1 to 3.

For practice, it is however unrealistic to adapt the reference to the to be measured stack height. It is also impractical to use a reference stack of more then 50 sheets. The effort to do this and the possibility of errors in the counting would be too large. The developed measuring rule is not for the exact determination of the number of sheets in a stack paper applicable in this form. In the following chapter two modified approaches are examined and assessed.

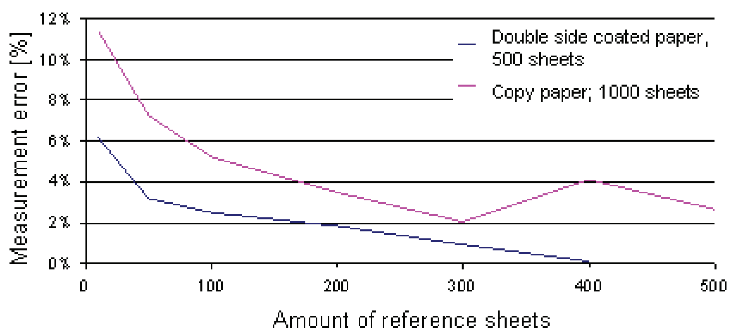


Figure 15 – Error calculation for different reference values

Approach for the Optimization of the Measuring Process

The first approach to the optimization of the measuring principle concerns the measuring geometry. As shown in test 1, a full-surface load of sample stack largely prevents the forming of a pressure cone. Accordingly, the curve for the height of a loaded sheet also quickly converges to a constant value. The impact on the quality of the measurement of the process is shown in Figure 16. The data are taken from test 1. The reference *a* is determined by a measurement with 20 sheets (see results of test 1). With this size and the height h_1 of the stack with 30, 40, 50, 60, 70, 80, 90 and 100 sheets, the number of sheets according to the measuring procedure is calculated and compared with the actual amount. The results show that deviations are significantly lower than for a selective load. Loading a full stack would reduce the measuring error and results are of acceptable quality. This optimization approach is impractical in practice. The mobility and ease of handling would be lost if the pressure stamp would have a format of 70 cm * 100 cm or greater.

Amount of sheets in a stack	Calculated amount of sheets	Deviation in %
30	29,8	-0,5%
40	40,8	-0,6%
50	49,8	-0,5%
60	59,6	-0,6%
70	69,3	-1,1%
80	80,6	-0,5%
90	89,3	-0,8%
100	99,3	-0,7%

Figure 16 – Quality of the rule

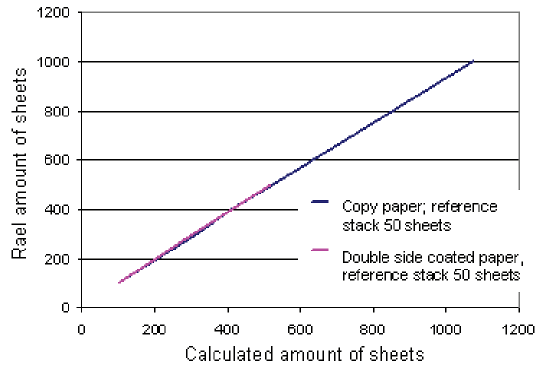


Figure 17 – Comparison: calculated and real amount of sheets

The second optimization approach concerns not the measurement geometry but the calculation rule. The data for the following examination is taken from test 4. The reference *a* is calculated for both types of paper from the measurement of the 50's stack. The with this reference calculated stack heights are compared to the actual stack heights in figure 17. Result is a linear relationship for both papers. Adding each a linear trend line in the form of $y = m \cdot x + b$ to the graph and combine this trend line with the measurement rule of the last chapter, so the following formula for the amount of sheets *n*:

$$n = m \cdot \frac{h_1}{a} + b \qquad \text{results.}$$

The results of applying this formula to the measured values from test 4, are shown in Figure 18. It was still calculated with the reference of the respective 50's stack. Just the results for the double-sided coated paper point to high quality. By combining the trend line with the measurement rule of the last chapter the effects of a pressure cone can be compensated. With such an extension of the measurement rule, the measuring procedure even in a selective load is practical. Necessarily is the previously correct identified parameters *m* and *b* for the type of paper to measure with the desired height of the reference stack.

Copy paper		
a=98,81	m=0,9267	b=10,107
Amount of sheets in a stack	Calculated amount of sheets	Deviation in %
100	104,59	4,6%
200	202,29	1,1%
300	302,47	0,8%
400	392,18	-2,0%
500	494,28	-1,1%
1000	1004,18	0,4%

Double side coated paper		
a=107,71	m=0,9613	b=4,1869
Amount of sheets in a stack	Calculated amount of sheets	Deviation in %
100	101,01	1,0%
200	199,05	-0,5%
300	299,07	-0,3%
400	400,63	0,2%
500	500,18	0,0%

Figure 18 – Quality of the modified measurement rule

SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

The carried out research examined the quality of a simple measuring method for the determination of the amount of sheets in a stack of paper by means of a pressure stamp. Two approaches were considered, which justify the differences in the deformation behaviour of paper and paper stacks. The tests revealed that the in a first explanation, the deformation of the top and bottom surface, plays a minor role and can be neglected from a pile height of 20 sheets. Still, the tests revealed that the distribution of the selectively initiated force spreads to an ever-increasing cross section inside the stack. The related decline of compressive stress has a much larger influence on the deformation behaviour of a paper stack. The relevant value "height of a loaded sheet" for the measuring principle doesn't converge even at very high stacks against a constant value. The evaluation of the test results confirmed eventually, that due to this effect and the resulting low quality of the size of the reference *a* measure of the amount of sheets with the here transmitted measuring rule is not possible.

The comparison of the calculated number of sheets with the actual number of sheets is however in a linear relationship between these two sizes. An extension of the measurement rule with knowledge of the respective regression parameters, with this linear context, leads finally to a satisfactory measurement with small deviations of the actual amount of sheets.

Remaining results:

- The reference "height per loaded sheet" of the measurement of a stack with 20 sheets is transferable to higher paper stack.
- The simple proposed measurement rule is not operating exactly to determine the exact number of sheets in a stack due to the formation of a pressure cone.
- By knowledge of the correct reference the pressure measurement methods works with a sufficient satisfaction to determine the number of sheets, but is impractical.
- Correction of the calculated number of sheets with a linear function with knowledge of the correct regression parameters leads to satisfactory results.

Tests should be carried out to determine definitively the function and marketability of the measuring procedure:

- The linear relationship between calculated and actual number of sheets should be checked for other types of paper and stack heights.
- The applicability and accuracy of the measuring procedure should be verified with a prototype with paper sizes used in practice

REFERENCES

1. Website: http://www.vacuumatic.de (Viewed 13.02.2009).
2. Website: http://www.functioncontrol.com/content/view/16/22/ (Viewed 13.02.2009).
3. Website http://www.baumann-mbs.de/web/de/sites/produkte_detail.php?subkat=5 (Viewed 13.02.2009).
4. Website. http://www.dyneticsengineering.com/psc-plastic-sheet-counter.html (Viewed13.02.2009).
5. Website: http://www.wecount.com/images/Max-Bantam.pdf (Viewed 13.02.2009).
6. Bos, J.H., Veenstra, P., Verhoeven, H., and de Vos, P.D., Das Papierbuch – Handbuch der Papierherstellung, EPN Verlag, 3994 DB Houten, Niederlande , 1. Auflage, 1999.
7. Böck, A., Schäfer, W., and Zerler, D., Prüfung von Papier, Karton und Pappe, Greiser Druck GmbH & Co.KG, 76437 Rastatt, 3. Auflage, 2004.
8. Kaulitz, T., "Highly Accurate Material Characterization of Paper for the Simulation of Printing Processes," Iarigai – Proceedings Vol. XXXV of Advances in Printing and Media Technology, Valencia 2008.
9. Weinig, B., "Untersuchungen zum Kompressionsverhalten von Papier in z-Richtung an Einzelblättern und Blattstapeln," Diplomarbeit, Technische Hochschule Darmstadt, 1991.
10. Desch, M., Kaulitz, T., and Dörsam, E., "Industrial Use for the 'Nip Inducted Effect' to Separate Sheets," Proceedings of the IWEB 2009 (Tenth International Web Handling Conference), Oklahoma State University, June 2009.
11. Kaulitz, T., "Bilden von Schneidlagen unter Ausnutzung des nipinduzierten Effekts für die Druckweiterverarbeitung," Dissertation, 2009, Technische Universität Darmstadt.
12. Schaffrath, H.-J., "Das Kompressionsverhalten von Papier in z-Richtung, Fachzeitschrift," Das Papier, 1992.
13. Schaffrath, H.-J., "Über das Kompressions- und Reibeverhalten von Papier vor dem Hintergrund des Rollenwickelns," Dissertation / IfP, Technische Hochschule Darmstadt, 1993.
14. Golz, J., "Theoretische und experimentelle Analyse des Kraft-Verformungs-Verhaltens von Papier," Diplomarbeit, Ruhr-Universität Bochum, 2003.
15. Website: http://www.mitcalc.com/doc/boltcon/help/de/boltcontxt.htm (viewed 13.02.2009).
16. Website: http://www.baumaschine.de/Portal/Archive/2_2003/Maschinen/ polygonbandage /polygonbandage.html (Viewed 13.02.2009).

Determining the Amount of Sheets in a Stack of Paper by Using a Pressure Stamp

M. Desch & E. Dörsam,
Technische Universität
Darmstadt, GERMANY

Name & Affiliation	**Question**
Randall Hagerdon, Taconic	You show that the error decreases using more sheets in the stack. Obviously you don't want to use such a large stack size that the test is impractical. What is the repeatability of the gauge? Did you isolate what error was associated with the gauge versus what error is associated with the variability in the paper itself?
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	The test is very repeatable with the new procedure if you take the constants and additional equations into account. This is not repeatable at all when a partially loaded stack was used. When a completely loaded stack is used the repeatability increases although the test may become impractical. If you have a stack size that allows application of pressure to the complete stack the test is very repeatable. If you have a really big stack of paper, say the width associated with a printing machine, you would need a really big pressure stamp and the test would become impractical.
Name & Affiliation	**Question**
Keith Good, Oklahoma State University	I was wondering how you harvest your stacks. Are they cut from the outside of a wound roll? Do you have to worry that maybe there was some variability in the web as it was made, so that the sheets are non-uniform to begin with? Is that non-uniformity persistent in the machine direction? If so it may matter from what MD location the 100 sheets are harvested.
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	The main problem is determining which sheets will comprise the stack. We can't take it into account.
Name & Affiliation	**Question**
Günther Brandenburg, Technische Universität München	You have shown us that you compress the stack with cylindrical platens. Don't you damage the surface of the papers? Printed papers are very sensitive.
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	Our first tests were with a downscale model where a really small cylinder was used. This was completely redesigned and we tested with larger diameter cylinders so there would be no damage on the sheets in the real process.
Name & Affiliation	**Question**
Marko Jorkama, Metso Paper	Have you considered using image processing techniques in order to detect the number of sheets or is the task too demanding?

Name & Affiliation	Answer
Michael Desch, Technische Universität	Do you mean to use imaging processing to detect the number of sheets in the stack? Normally the sheets that are coming out of the printing machine which need counted are not well aligned. Some sheets may hang outside and cover some of the sheets below and then the covered sheets can't be detected and you get an incorrect value. The optical determination is not that good.
Name & Affiliation	**Question**
Aravind Seshadri, Oklahoma State University	I was wondering how you corrected your constants for environmental conditions like moisture and temperature? How do you handle that?
Name & Affiliation	**Answer**
Michael Desch, Technische Universität	The tests must be conducted at the same room or climate conditions.