Measurement Method and Analysis of Dynamic Dimensional Stability of Paper Web

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Abstract: Higher efficiency of the whole production chain, from paper making to printed product, is one of the key issues when optimising different processes. Fan-out and register errors caused by web widening and lateral movements of paper web are of serious concern for newspaper printers. The existing control methods for web widening (fan-out controls) cannot sufficiently compensate for the widening variation if different reels have unequal widening tendencies. In this study, measurement data was gathered and analysed from paper mills and from a printing press. The aim was to clarify the reasons for web widening and lateral movements of the paper web.

Fan-out and register errors have been traditionally measured with time consuming colour register measurements. In this study a set of line-scan cameras was used to measure web width and position before and after the printing units in a coldset-offset press. This arrangement allowed non-stop, on-line measurement and thus several hundreds of reels were analysed.

The method for dynamic web deformation measurement is introduced. The effect of paper properties and press conditions on paper web widening and lateral movements in the press is discussed.

1 Introduction

There is demand for higher efficiency of printing presses to minimise the manufacturing cost of the printed product. At the same time the use of colours, especially in newspapers, is increasing. To meet these trends the printer has to find ways to overcome the existing runnability and printability problems. The most common problems in newspaper presses are register errors, paper waste, web breaks and web instability.

In this paper the results of web widening and lateral movements studies in a newspaper press are presented. The studied press was a coldset-offset press

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consisting of tower type printing units. This kind of configuration has become common in newspaper presses because of simpler web leads. Also the number of cylinders and guiding rollers needed in a tower structure is smaller than in satellite configuration. It is also a known fact that tower units are more prone than satellite units to generate register errors as the web leads are longer between printing units. This web widening is better known as fan-out.

The human eye sees a colour register error of 0,1 mm (0,004 inches) as a quality failure. In machine direction the register errors can be somewhat corrected by controlling the placing of the printing plate, which can also be done automatically during a run. In lateral direction the web widening can be compensated for by making the printing images in different sizes for each colour in pre-press. Additionally, there are mechanical control means to narrow the web before crucial printing units. Nevertheless these means are powerless when the amount of web widening changes from reel to reel. Also the web's lateral movements along the press can cause severe register errors and they cannot be corrected by present technology.

The task of this work was to find important paper and press parameters affecting the web widening and lateral movements. Most of the studies carried out in literature have been performed in laboratory and pilot scale so there is an obvious need for studies carried out in production scale. In this study, over 800 reels were measured on-line in the press and the paper measurements were carried out in paper mills.

1.1 Web widening

The dimensions of paper change when its moisture content changes. This behaviour originates from the hygroinstability of fibres from which the paper is formed. When a wood fibre is wetted, it swells and this phenomenon is reflected throughout the fibre network. A wood fibre swells more in its thickness direction than in its length direction. In a commercial paper machine, the wood fibres are strongly oriented in the machine direction. This leads to the known fact that dimensional stability of paper is better in the machine direction than in the cross-machine direction. Naturally the strength of the fibre orientation also affects to the amount of the widening of the paper web when re-wetted.

Drying stresses on a conventional paper machine are not evenly distributed in the cross direction of paper web. Because of the machine structure, the edge areas of the web are more freely shrunk during drying than the middle areas of the web. This leads to poorer dimensional stability of the web edges. In addition, the stock used has an effect on the dimensional stability of the paper. According to literature, the filler in paper reduces the bonding of fibres and therefore reduces stress transfer and thus leads to better dimensional stability (Kajanto, 1998). The surface properties of paper, like roughness, affects the water transfer to the paper and consequently the dimensions of the paper. The paper properties affecting the dimensional stability of paper have been extensively studied in the literature. However, most of these studies have been made in laboratory- or pilot scale. References (Tattari, 1998), (Gomer, 1991), (Trollsås, 1998), (Kajanto, 1998) and (Uesaka, 2002) should give a good overview on the subject.

It must be stated that the dynamic conditions in a printing nip where the water is transferred to the paper structure fast and with high pressure differ greatly from the conditions of a laboratory environment. It was obvious that a large-scale production level study was needed to find out the press and paper properties affecting web widening in dynamic conditions.

Today, an increasing number of newspapers are printed in full four colours. This sets high demands for the dimensional stability of paper. In a single offset printing unit as much as 0,5 g/m^2 of water per side is transferred to the paper and it has been shown that the water amount transferred in a printing nip is independent of the amount transferred in the previous units (Trollsås, 1995).

When the paper web expands between the succeeding colour units a problem arises with the colour register. As can be seen in figure 1, if the paper expands between the succeeding units, the colours are not longer aligned correctly. This phenomenon is commonly referred to as fan-out, but the term web widening will be used in this text. This is because of the measuring method used in the study, which measures the absolute widening of the web rather than the visible fan-out in the end product. The dimensional changes of newspaper web in the machine-direction are much smaller than in the cross machine-direction (Tattari, 1998) and thus it was decided that the web widening characterises the paper behaviour adequately.

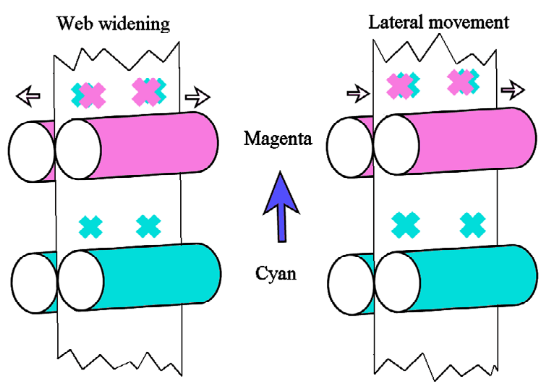

Figure 1. Colour register errors results from web widening and lateral movement of the paper web. The crosses printed in cyan and magenta should be aligned precisely on top of each other. However because of the instability of the web the alignment fails.

The perceived fan-out usually differs from the actual web widening because of the compensation methods used to counteract web widening. First of all, when discussing the compensation methods for web widening, it must be stated that the press construction has an effect on the severity of the problem. In a satellite type press, the fan-out is not usually a big problem because of the short distance between the succeeding printing units. In a satellite unit, the backing roll supports the paper web and partly reduces the widening. However, in tower-type constructions the web can have several metres long unsupported feeds between colour units where the paper web has plenty of time to deform enough to cause problems. There are means to counteract the web widening before production (Trollsås, 1993). For example, the printing plates of the first colours to be printed can be "shrunk" in the reproduction. Also the alignment of the separate plates can be laterally adjusted on the plate cylinder. Unfortunately none of these can be done during production. There are also methods and devices that can be used during production, like pre-moisturising units and different kinds of anti fan-out rollers that try to mechanically affect to the web widening. These methods however, are not very effective.

A question may arise as to why the web widening is a problem if it can be compensated. The answer to this is that paper is a very heterogeneous material and unfortunately the widening tendency of paper web changes from reel to reel and there are no very effective means available to alter the compensation during a print run.

1.2 Lateral movements

Not only the dimensional changes of paper cause colour register errors. The paper web's lateral alignment tends to alter while it travels through the printing units, figure 1 in chapter 1.1. It is possible to compensate the effects of lateral movement by shifting the cylinders in cross-direction. However, it is usually in practice difficult to see whether the error in colour register is caused by web widening or lateral movement of the web. The colour register error caused by lateral movement differs from the error caused by web widening. When the web widens, the edge areas of the web are widened more than the middle areas and so the magnitude of the register error is not evenly distributed in cross direction. In the case of lateral movement, the whole web width is affected equally. For example let's picture a worst case situation where at a reel change the previous reel has been moving 0.5mm towards the drive-side of the press between the first and the last printing unit and the colour register has been correct so far. Now a new reel kicks in and it starts to move 0.5 mm towards the front side. This results in a register error of 1mm between the first and the last colour throughout the web width. Of course there are means to compensate this but a lot of copies are wasted before the situation is corrected.

2 Methods

2.1 Measurements

Traditionally colour register errors are measured from the printed register marks. This method is accurate but time consuming. In this study, a long-term follow-up was selected for a research method. Thus a reliable means to measure web widening and lateral movements 24/7 was needed. It was decided to use four line scan cameras. One camera pair was used to measure the web width before the printing units and another pair was located after the printing units to measure the web width after printing, figure 2.

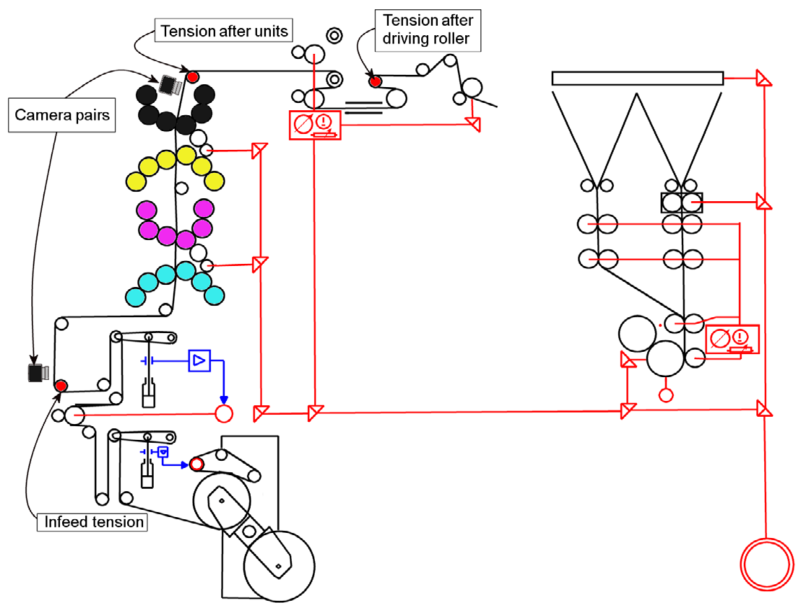

Figure 2. The instrumentation of the printing tower under study.

In addition to the camera system, the printing tower was instrumented with several weighing rollers. One at the infeed, one after the printing units and one after the driving roller, figure 2.

The most challenging part of the camera installation was the positioning and calibration. A special calibration pole, measuring exactly 1600mm wide, was constructed in order to adjust the cameras so that a paper web measuring exactly 1600mm wide positioned exactly at the centre-line of the press would give the same 12mA signal on all cameras. Because it was impossible to align the cameras with absolute accuracy, the mA readings measured with the calibration pole were used during the actual measurements to correct the signal levels. The camera pairs were bolted onto an aluminium chassis and the whole structure was firmly attached to the press frame.

The technical specifications of the cameras are as follows:

Resolution 2048 pixels
Measurement area 100 mm
Accuracy 0,05 mm
Measurement speed 1000 lines/s

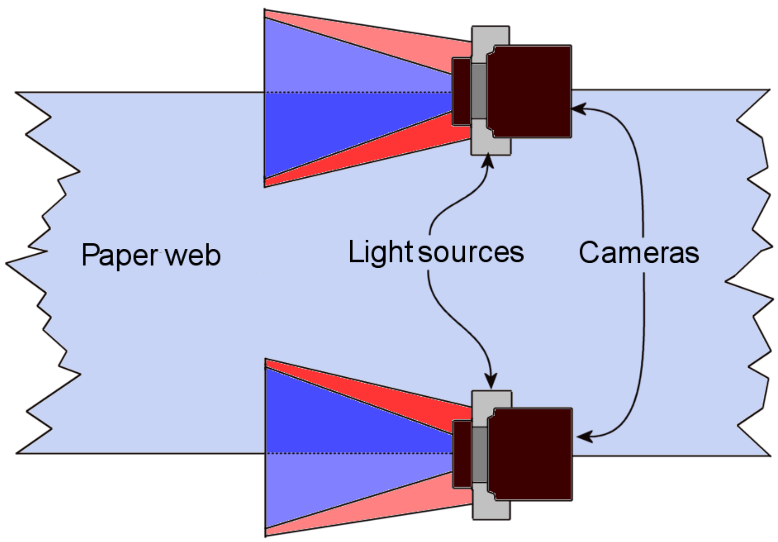

Figure 3. Web width measurement with line scan cameras.

Each of the cameras has a light source that illuminates the web edge so that a large enough contrast between the paper web and the background is created, figure 3. Each camera gives a mA signal, which is converted to millimetres as described in table 1.

Table 1. Scaling of the mA-signal of the cameras.

Amount of paper coverage	100 %	50 %	0 %
Signal mA	4	12	20
X 500 ohms = V	2	6	10
X 12,5 =	25	75	125
Web position in mm: - 75 =	-50	0	50

In practice it was found that the accuracy of the cameras was about 0.05 mm in widening, which was as expected according to technical specifications. The cameras operated very reliably during the study. A major problem was the ink mist after the last printing units where the second camera pair was located. The ink gradually covered the lenses and so after a while the system couldn't locate the web edge anymore. These upper cameras needed a careful cleanup once a day in order to operate correctly.

During the follow up a measuring frequency of 1Hz was used. When a reel took an average of 25 minutes to run 1500 measurements of web width from the two positions per reel was recorded.

The paper mills delivered measured paper properties of the machine reels from which the customer reels were cut. The paper mill data included the following measurements: moisture, grammage, thickness, tensile strength, tensile strain, tear strength, reel position and reel density. One paper mill also supplied measurements of paper roughness, ash content and Tensile Stiffness Orientation (Loewen, 2002). The values for customer reels were calculated from the mean cross-machine profiles of the machine reels with the help of reel maps from the winders. Different sets in the winder could not be separated, since only the mean profiles were stored and laboratory measurements were carried out from paper samples from the top of the machine reel.

2.2 Analysing methods

The measurements at the printing press were carried out during a time period of 6 months. In addition to the measurements at the press, the paper manufacturers delivered measurement data of the paper delivered to the printing press. This data was combined so that each reel accepted for analysis had a set of key figures describing it's paper properties and measured properties at the press.

The analysis was carried out with the developed Data miner. This analysing environment is described in more detail in the paper published at the TAGA 2003 conference (Parola, 2003).

3 Results

In order to evaluate the results presented in this chapter it is good to bear in mind that it is known that a colour register error of 0,1mm is visible to the human eye from the normal reading distance (Gomer, 1991). Of course the values presented here are larger than the actual register errors, as described earlier, but nonetheless the problem exists and varies largely.

All of the results are presented in millimetres. All of the paper reels measured during the follow-up were 1600mm wide. The web widening and lateral movement values are reel averages calculated from selected time intervals where press conditions were as stable as possible. It should also be noted that not all reels are selected to every analysis made. The material is usually grouped because there are in most cases disturbing variables present, which would otherwise distort the results. The paper grades analysed were 45g/m^2 newsprint, 48.8g/m^2 newsprint and 55g/m^2 newsprint.

3.1 Web widening

It was found that the different papers used in the printing press widened differently. The lightest paper delivered by mill B widened the most by average and the heaviest grades delivered by mill A widened the least. At this stage it should be pointed out that the absolute level of the widening is not essential because constant widening can always be compensated in pre-press. The standard deviations of the widening of each paper grade are presented in figure 4 along with the total average widenings. Unfortunately no conclusions can be made about the effect of grammage on web widening because all the papers originate from different paper mills and besides they are typically used in different print jobs.

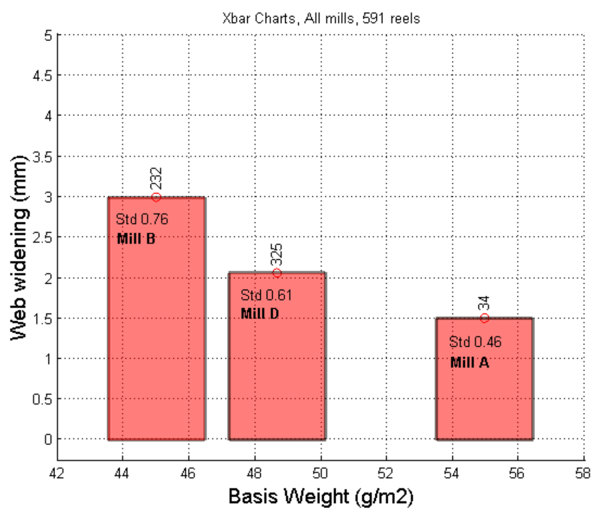

Figure 4. The average widenings and standard deviations of widening grouped by grammage. The values above the columns represent the amount of reels in the corresponding group.

During a press start-up, the automatic sequence starts to accelerate press speed and at about 5000 revolutions/minute the printing nips are closed. After that there is a short delay (a few seconds) before the ink and damping water feeding is started. During this time only the web tension and nip pressure affects the web widening. The mechanical widening that is referred to here as “dry-widening” and the total widening were measured for 251 reels, figure 5. The total widening was measured from the same reel after the process conditions were stabilised.

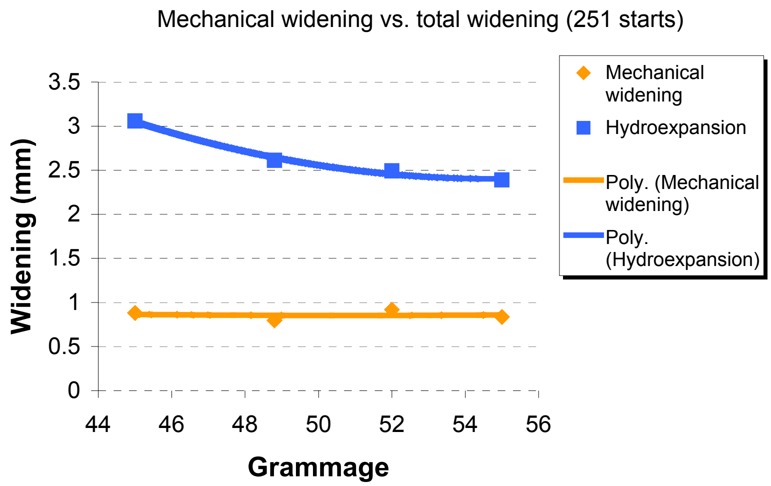

Figure 5. The average "dry widening" of the paper web compared to the average total widening of the reels of different grammages. The reels are from 251 different press start-ups.

From figure 5 it can be seen that the dry-widening is of the same amount for all paper grades. However, the average total widening of these reels is different for different papers. This suggests that the differences in paper structure affect the web widening only when moisture is absorbed to the paper. Gomer (1991) and Lindholm have had similar results in their studies.

3.1.1 Press parameters affecting web widening

Not only paper properties affect the widening of the paper web. Press parameters like web tension, press speed and damping water feed as well as ink amounts have an effect on the dimensions of the web.

The printer had noted that when the infeed tension was increased to improve runnability in overstructure, the fan-out usually worsened. This was an interesting observation because it is usually thought that the increasing web tension should lead to smaller fan-out. When paper web is stretched in machine direction it narrows in cross direction according to the materials poisson's constant (approx. 0.3 for paper). According to this study the increasing infeed tension indeed increases the web widening at a certain tension area, figure 6.

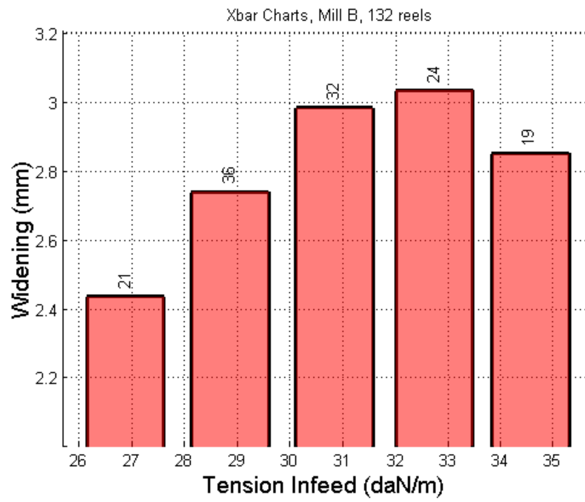

Figure 6. The effect of infeed tension on web widening. Mill B, 45g/m^2 newsprint. The values above the columns represent the amount of reels in the corresponding group.

From figure 6 it can be seen that the web tension has a great effect on web widening. The last column suggests that when the tension reaches a certain level, the web widening starts to become smaller. However, the tension level of 35daN/m is exceptionally high for this particular paper grade and so it is possible that there are other factors affecting the web widening on these reels than merely the web tension.

The reason for this positive correlation between web tension and web widening may be related to mechanosorption of paper. When paper is under tension it is believed to absorb water differently than when unstrained.

Press speed also affects web widening. Although press speed obviously cannot be used as a control variable to fight web widening, it is good to know that the press speed and web widening has a negative correlation, figure 7.

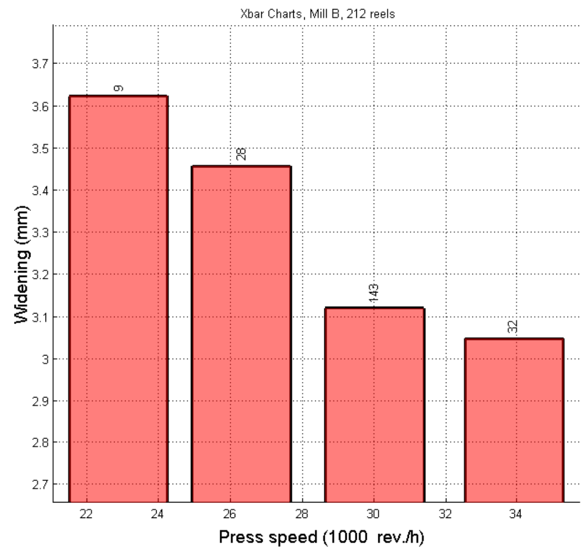

Figure 7. The effect of press speed on web widening. Mill B, 45g/m^2 newsprint.

The effect of press speed can be easily explained. When the paper web moves through the four printing units faster then the applicated water has less time to absorb into the paper between the first and the last unit and thus smaller dimensional changes are created.

The effect of damping water feed was also tested and as expected when more water was fed, the web widened more. Unfortunately no reliable means to measure the amount of water transferred to the paper web was available in the long-term study.

3.1.2 Paper properties affecting web widening

Almost all of the measured paper properties correlated with web widening on some level. The problem in the analysis was the cross correlations of different paper properties. Because of this a lot of grouping was necessary to distinguish the effects of the different properties.

The paper reel's position correlated strongly with the web widening, figure 8. The edge position reels of all paper mills widened more than the middle position reels. Of course the web position itself is not the reason for this behaviour. It is most likely that this phenomenon is caused by differences in cross-directional (CD) drying shrinkage of different reel positions (Kajanto, 1998).

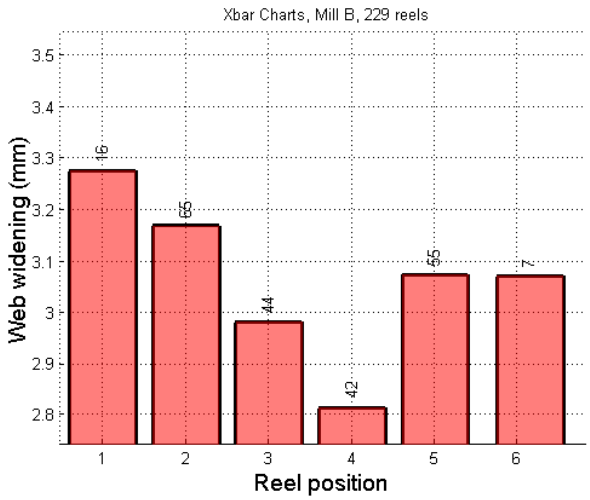

Figure 8. The effect of reel position on web widening. Position 1 is the front edge of the paper machine and position 6 and partly position 5 reels are cut from the drive side of the machine reel. Mill B, 45g/m^2 newsprint.

According to the results on the effect of reel position on web widening it would be beneficial to print the reels of different positions from different reelstands so that the sudden changes in the web widening could be eliminated. It should be noted that the front and back edge reels have different tension profiles (Parola, 2001) so the reels from opposite edges should not be mixed either.

The drying shrinkage of paper web is an interesting property, which has a distinct effect on the dimensional stability of paper (Kajanto, 1998). It is known that cross-directional (CD) drying shrinkage has a good negative correlation with CD tensile strength (Niskanen, 1998). This allows us to use cross directional tensile strength as an estimate for lateral drying shrinkage. A good negative correlation exists between CD tensile strength and web widening, figure 9. This also suggests a positive correlation between lateral drying shrinkage and web widening.

Also the cross directional tear strength correlated negatively with web widening. This probably reflects the effect of the furnish of the paper.

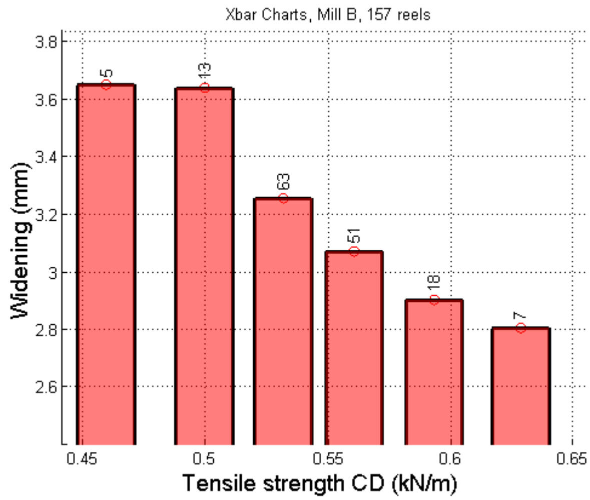

Figure 9. The effect of cross directional tensile strength (Machine reel averages) on web widening. Mill B, $45 g/m^2$ newsprint.

The moisture content of paper was found to have a negative correlation with web widening, figure 10. This is presumably due to the smaller relative moisture intake of paper containing higher initial moisture.

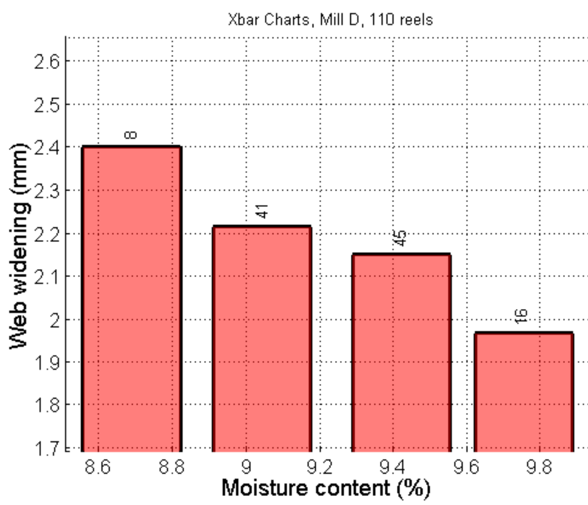

Figure 10. The effect of initial moisture content of paper on web widening. Mill D, $48.8 g/m^2$ newsprint.

It was also found that the ash content affected the web widening. An increase in ash content led to increasing web widening. Opposite results have been presented in literature but with much higher ash content levels than in this case. It is assumed in literature that increasing filler content leads to weaker fiber-fiber bonding and thus to better dimensional stability. (Kajanto, 1998), (Uesaka, 2002) The result obtained here can be explained by the pressure applied in a printing nip. Presumably the weaker structure (higher filler content) widens more under pressure. Verification of this result requires further studies.

Of paper surface properties, the roughness correlated positively with web widening (Parola, 2003). The effect of roughness on widening suggests that the surface properties of paper play a significant role in water absorption from blanket to paper. However, in order to fully understand the effect of paper surface structure on web widening, the interactions between water intake and surface structure must be studied in detail.

Furthermore, paper thickness had a positive correlation with web widening. This can relate to the calandering of paper. The surface of thicker paper may be more porous because of gentler calandering.

3.2 Lateral movements

The Tensile Stiffness Orientation angle (TSO-angle) was clearly the most significant paper property affecting the lateral movements of paper web. As can be seen from figure 11 the web tends to move to the opposite direction than that pointed by the TSO-angle.

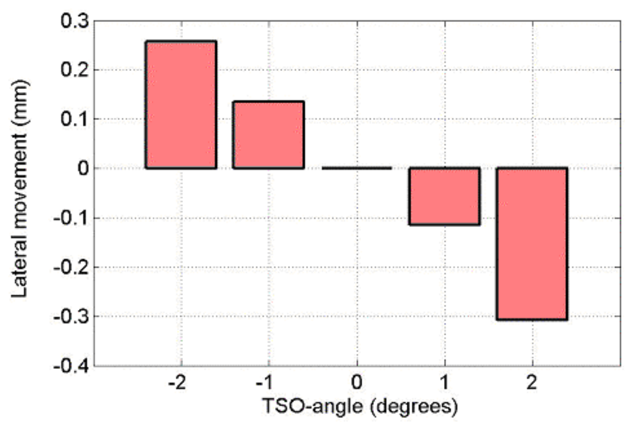

Figure 11. The effect of Tensile Stiffness orientation angle on the lateral movement of paper web. Negative values are towards the drive side and vice versa. Mill D, 106 reels. Mill D, 48.8g/m^2

The effect of TSO-angle was verified in a test run where the TSO-angles of all reels were measured, figure 12. Trollsås (1998) has reported similar results on the effect of TSO-angle and suspects that the reason for this behaviour is the distorted tension fields caused by the distorted orientation angle.

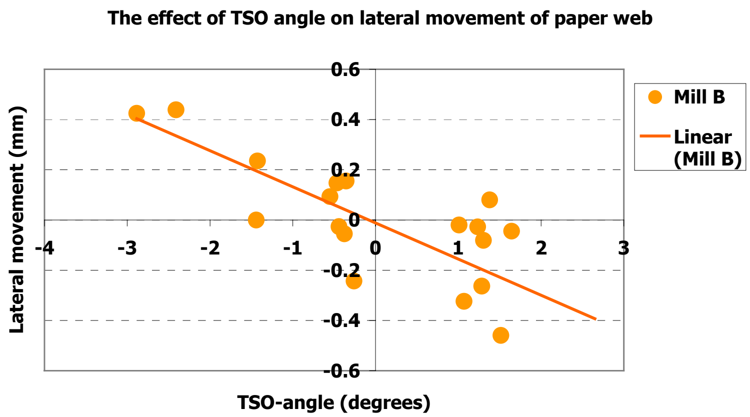

Figure 12. The effect of TSO-angle on the lateral movement of paper web. Test run, Mill B, 45g/m^2 newsprint.

4 Conclusion

The on-line measurement method for web widening and lateral movements of paper web utilising edge position cameras proved to be reliable and useful. The data mining concept where long-term paper and press measurements are analysed as a whole was found to be a powerful method to determine the interactions of the paper and the press. Although a data mining approach gives a clearer picture of the paper and press interactions it does not exclude the importance of well controlled trial runs. In fact, these two methods should be used side by side.

The most important press parameters affecting the web widening were infeed tension, water feed amount, nip pressure and press speed. The increase in infeed tension increased widening and the increase of press speed reduced the widening.

Different papers widened different amounts but no conclusions on the reason for this could be drawn. However, the dry widening of the different papers were of the same amount. This suggests that the differences in paper structure affect the web widening only when moisture is absorbed to the paper. The edge position reels widened more than the middle position reels presumably because of the differences in drying shrinkage. The cross-directional tensile strength correlated negatively with web widening which also points to differences in CD drying shrinkage. The initial moisture content of paper had a negative correlation with web widening and the ash content had a positive correlation with web widening. It was also found that increasing paper roughness led to higher widening.

The most significant paper property affecting the paper web's lateral movement was found to be the Tensile Stiffness Orientation angle. The more the angle diverged from zero, the stronger the lateral movement was.

Because of the differences in widening and lateral movements of different reel positions, it is advisable to run the reels cut from different position on different reelstands. This helps to minimise sudden changes in fan-out and lateral movement of the web and thus gain better runnability and printability in the printing press.

Literature Cited

Gomer M., Lindholm G.
1991 "Hygroexpansion of newsprint as a result of water asorption in a printing press", Proc. 43rd TAGA annual conference (Rochester, New York), pp. 268-282.

Kajanto I., Niskanen K.
1998 "Paper Physics: Dimensional stability", (Fapet Oy, Jyväskylä), 1st ed., pp. 193-221.

Linna, H., Parola, M. and Virtanen, J.
2001 "Better productivity by measuring web tension profile," Proc. 55th Appita Annual General Conf. (Hobart, Australia), pp. 323-329.

Loewen, S. and Foulger, M.
2002 "TSO and fibre orientation: an introduction," Pulp & Paper Canada, vol. 103, no. 5, pp. 42-45.

Niskanen K., Kärenlampi P.
1998 "Paper Physics: In-plane tensile properties", (Fapet Oy, Jyväskylä), 1st ed., pp. 139-191.

Parola M., Kaljunen T., Beletski N., Paukku J.
2003 "Analysing printing press runnability by data mining", Proc. 55th TAGA annual technical conference (Montreal, Canada).

Tattari H., Niskanen K.
1998 "Dynamic dimensional changes of paper in the printing nip", (KCL, Espoo, Finland) PSC Communications no: 119, 25 pp.

Trollsås P.-O.
1993 "Different ways to counteract the fan-out of newsprint in offset printing", (TFL Sweden), Technical PM 93:7, 14 pp.

1995 "Water uptake in newsprint during offset printing", Tappi Journal vol. 78, no. 1, pp. 155-160.

1998 "Pappersbanors dimensionsförändringar och sidförskjutningar i planet", (STFI, Sweden), PFT-rapport nr.42. 35pp.

Uesaka T.
2002 "Handbook of Physical Testing of Paper: Dimensional stability and environmental effects on paper properties," (Marcel Dekker, NY), 2nd ed., Vol. 1, pp. 115-171.