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ON-LINE TOPOGRAPHY ANALYSIS BY PHOTOMETRIC STEREO METHOD – NEW TOOLS FOR TISSUE, PAPER AND BOARD MAKERS

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ABSTRACT

Photometric stereo-based techniques have enabled on-line topography analysis of paper or board in astonishingly high resolution. Photometric stereo techniques are already able to measure, on-line, detailed features of the web surface moving at typical paper and tissue production speeds, that the human eye cannot resolve. In tissue grades, topography analysis of final tissue product after creping makes it possible to determine a number of useful quality parameters including tissue softness. Up until now, the objective determination of tissue softness has only been possible with few test devices in the laboratory. For paper and board grades, these modern analyzers do not just estimate PPS or other traditional measures, they provide quite another dimension for topography characterization that no air leak-based-method can offer.

This paper gives an overview of the potential of the photometric stereo principle to determine the surface topography of tissue, paper, and board. Results from trials on pilot and production machines as well as from continuous use on a production machine are presented to demonstrate how a variety of properties, some even complex or subjective by nature such as softness, can be quantified using on-line image analysis techniques.

Keywords: topography analysis, photometric stereo, surface properties, surface topography, softness measurement,

INTRODUCTION

For a few years now, many mills producing paper or board for rotogravure printing have been reported to successfully optimize their quality and production costs with the aid of photometric stereo analysis. Earlier studies have shown the key role that topography plays for major offset printed properties such as visual evenness, mottling, dot gain, delta gloss and gloss mottling. Traditionally, paper or board surface topography has been measured by indirect indicators that are easier to measure than exact topography. For example, the air leak methods produce a scalar output that is proportional to topography unevenness. Results are dependent on various configurations and settings of the measurement device as they are changed many times to meet the needs of different paper or board grades, e.g. for Parker Print Surf, different pressures and backing of the sample, soft or hard, are used. The measurement configurations and devices vary in different countries or mills with even differences between the most commonly-used choices of metric (SI), US or imperial units.

Topography or surface smoothness is also a most important property for tissue producers, playing a great part in tissue softness which is mostly based on comparisons and consumer perception. The Hand Feel score (HF) basically measures surface softness, which is related to smoothness. How soft a product feels also depends on its thickness (bulk) and its flexibility [1] or surface feel [2]. Very different than other tissue properties, softness is complex, not well defined, and largely subjective. It is complex because it is a combination of several fundamental properties such as surface topography (surface smoothness for example) and fiber morphologies. Not well defined because there is no agreement on a universally accepted definition and subjective because its measurement is based on tactile feeling of the individuals testing it. Each mill tends to use its own method. All this has led to a complex set of measurements or subjective evaluations related to topography that are not comparable at all.

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METHODS

Online surface measurement

The Valmet IQ topography measurement measures the surface quality of a moving paper sheet by using high-speed image capture and image analysis techniques. The illumination of the measured area is done with several colored LED flash lights from different directions around the camera. A high resolution camera on the same side of the web takes snapshots of the sheet as the light sources flash. Installed in a conventional on-line measuring head traversing across the whole web, it gives measurement information on-line and of the whole production, both in MD and CD. Thus, it is superior to manual sampling and laboratory measurements as it is continuously available without waiting and with significantly higher coverage.

Surface measurement analysis is done by sophisticated image analysis calculations which define a number of key surface quality parameters e.g. smoothness, roughness, variability indices, holes, peaks, power spectra, and for tissue, surface softness and crepe wave count.

Measurement Principle

The measurement utilizes the photometric stereo method where the idea is to capture multiple images from a single viewpoint with two or more light sources. The photometric stereo method provides surface gradient fields in a non-contact and fast manner using shading information. Surface topography is obtained by integrating the gradient fields.

Red, green and blue light emitting diodes are used to produce low angle illumination from three directions. A color camera distinguishes shading information produced by the illumination from each direction with a single snapshot used to capture the surface topography (Figure 1).

Three direction-illumination of the measured area is done with six individually controllable LED flash lights from different directions around the camera. Pulsed LED matrix boards generate high intensity illumination on the measured sheet. A short flash light pulse freezes the paper movement, and a high resolution CCD camera captures a snapshot. Intensity of individual colors is controlled with LED supply voltage. Practical LED flash time is 0.5 µs – 3 µs depending on machine speed and paper sheet optical properties. Image size is 1 cm x 1 cm (1000 x 1000 pixels). The default frame rate of the camera is 10 Hz. Sophisticated image analysis is applied to generate several surface quality measurement variables.

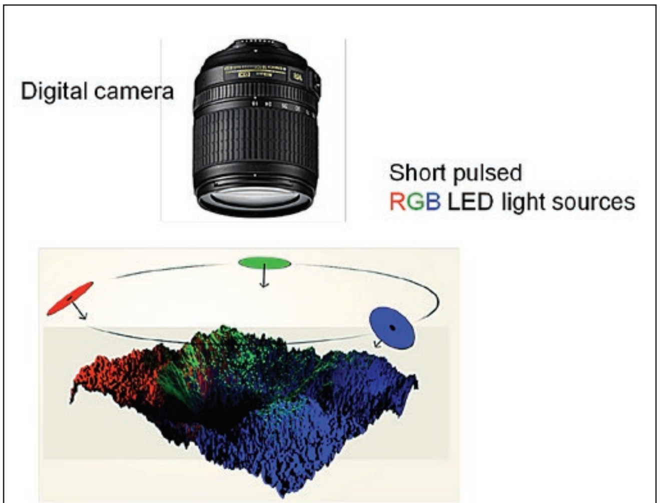

Figure 1: Measurement principle

The captured image is compensated by using a reference picture. The reference picture is calculated by averaging the images of the web captured online and represents a totally flat surface except for the distortions caused by the equipment and environmental effects. Compensation with a reference picture removes distortions from the actual measurement [3]. In addition to correlating well with Parker Print-Surf (PPS), it also gives much more valuable information than PPS or other conventional measurements. Instead of just one number, it gives a topographic spectrum, where topography is divided into wave length bands based on size of topography, and for each of these bands an intensity of variation can be calculated.

Mill experiences of printability prediction

Rotogravure printability was the first application for photometric stereo based analysis, first developed in laboratory and later as an on-line scanning sensor. The method's ability to forecast rotogravure printability and especially amount of missing or distorted dots has been published in various earlier studies and presentations [4] [5] [6] [7] [8]. It has been shown to predict poor rotogravure printed quality in many cases and in variety of paper or board grades from SC to FBB. Parameters that correlate well with the traditional PPS smoothness have been calculated from the on-line measured topography information in numerous pilot and mill scale trials.

Trials at a Finnish fine paper mill together with a local print house during normal production run have given excellent results in predicting the rotogravure printability and provided valuable insights into the mechanisms involved. In the trials, rotogravure print quality was evaluated both visually and with the help of a machine vision program. Predetermined test fields of several half-tone colors (CMYK at 25%, 15% and 5% density) were printed in a brochure, then scanned and evaluated with PTS Domas image analysis software. The fields were analyzed for missing dots and for several parameters including dot size classes and coherent dots. Roughness of the printed customer rolls were measured with the new photometric stereo on-line sensor measuring topography in both machine and cross direction and PPS smoothness in the laboratory.

No significant amount of missing dots was found on any test field other than the 5%. The number of defective dots however increased dramatically according to the on-line topography index The dot properties measured from the 15 % field had a clear correlation with both the on-line measurement and PPS. With increasing roughness, it was noticed that the dot size distribution increased as well. The visual evaluations of the printed products had good correlation with

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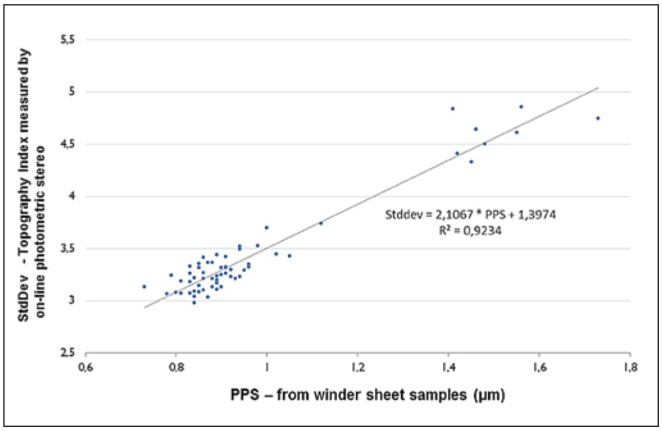

Figure 2: Relation between Surface Index and measured PPS value. Higher Topography Index means more topographic variation

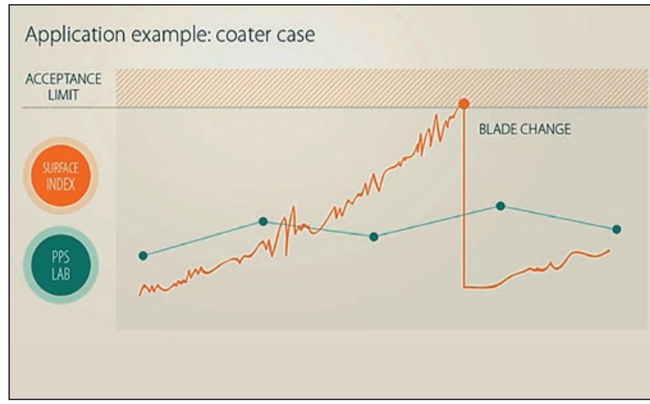

Figure 4: Trends of Surface Index from the new online sensor and the PPS measurement over the coating blade change. The Surface Index from the new online surface sensor sees the difference, but not PPS

topography measured on-line with the scanning IQ sensor and PPS-roughness for all paper grades (Figure 2).

The on-line measurement also performs well on really smooth grades (PPS < 0,9). Figure 3 from a mill producing top quality folding box board shows that surface quality decreases as the coating blade gets older, but PPS does not necessarily 'see' this clearly. The new online sensor using photometric stereo shows clearly the effect of coating blade wear on surface smoothness (Figure 4). The operators soon began to use this trend to determine when to change the coating blade.

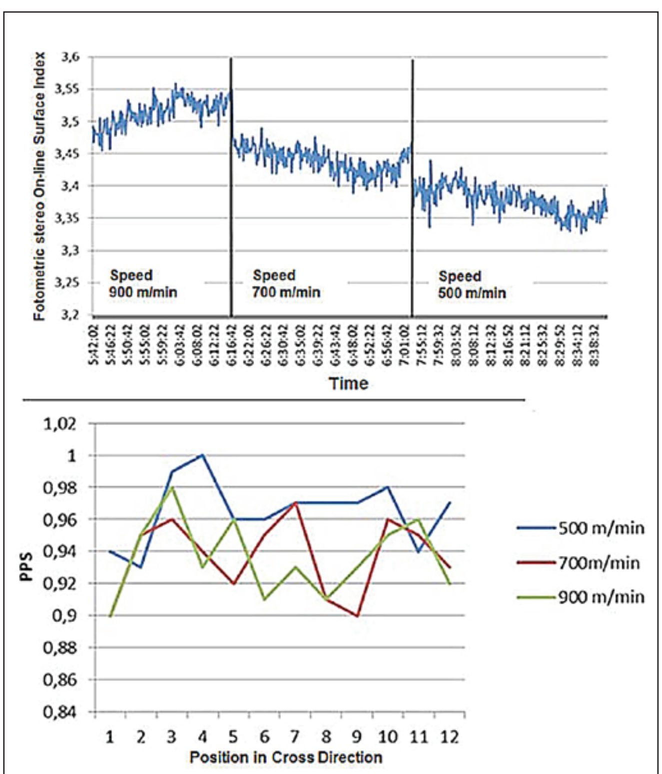

Figure 3: Machine direction trend of the online surface index measurement from photometric stereo (top), and CD profiles of PPS measurement (below). Photometric stereo sees the differences but PPS does not

Tissue softness

Surface softness is calculated from a topography picture with appropriately selected filters. The measurement is also compensated for its basis weight with the basis weight measurement from the online sensor on the scanner. Basis weight compensation improves the correlation with the laboratory measurement of softness. An example of an online surface image and the calculated topography of interest are shown in Figure 5.

Crepe wave count (1/cm) is calculated as a mean value of crepe frequency distribution (spectrum) from the topography picture. Additionally, caliper is calculated from frequency distribution spectrum with crepe wave counts. Similar methods were used earlier for crepe count calculations in offline applications [9].

Figure 6 shows the online pictures of medium/high-softness bath

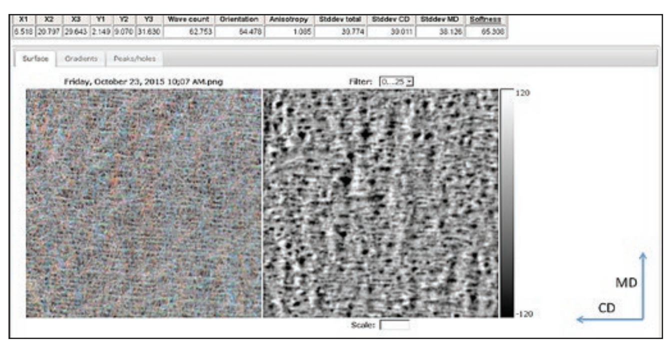

Figure 5: On-line image (left) and the calculated topography of the interest (right).

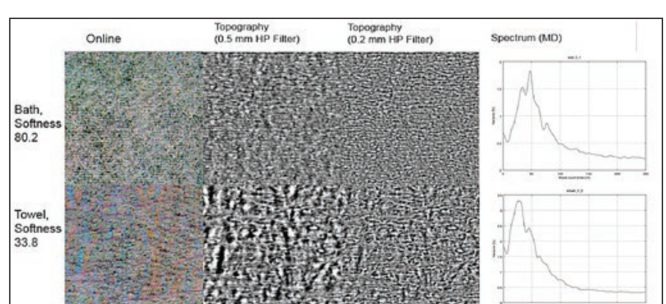

Figure 6: online image and calculated topography picture

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tissue and low-softness towel grade on the left. The corresponding topography pictures that are calculated with a 0.5-mm HP filter are shown in the middle and with a 0.2-mm filter on the right. With different filtering values, large scale and small scale variations can be separated from each other so the analysis can focus on the relevant frequencies.

Tissue mill experience

The softness sensor based on photometric stereo analysis was first tried on our pilot machine before embarking onto long-term tests on a production machine. After successful runs on the pilot machine with good correlation to the laboratory device, the softness sensor was installed on the scanning platform of a tissue machine along with the existing basis weight and moisture sensors on the same scanner. The sensor was positioned on the bottom side of the scanner to measure the surface properties of the Yankee side of the tissue web. The sensor behavior was monitored on a continuous basis and its output was correlated to the discrete measurements of the laboratory softness tester. A wide range of tissue softness (30-80 HF) was covered during the tests as shown in Figure 7.

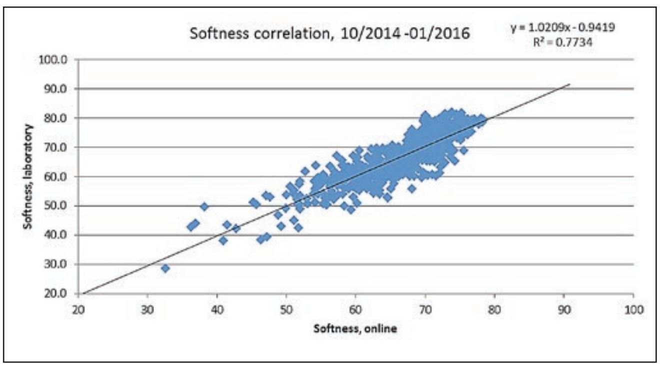

Figure 7: Long term Softness correlation results

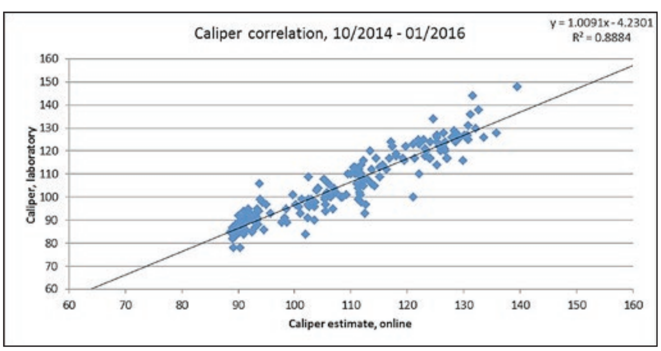

Figure 8: Long term Caliper correlation results

Sheet caliper is also estimated from the same online topography images. Caliper estimates are correlated with a stack of 10-sample sheets measured in the laboratory.

As can also be deduced from Figures 7 and 8, this production machine makes multiple bath and towel grades, some grades using up-to 90% recycled furnish. The corresponding softness and wave count trends from a single grade run over 12 hours are shown in Figure 9. Laboratory softness values are shown as discrete blue squares which, as can be seen, the continuous black line of the online measurement follows quite well. Another interesting and important observation that can be made from Figure 9 is how well the effect of crepe blade wear can be seen both from online and laboratory softness measurements as well as the wave count trend. As soon as the blade is changed at 7:40 and 15:52, the softness of the tissue web is restored to its high value (corresponding to the transients at the indicated times). With the blade wearing over time, the softness value ramps slowly down until the next blade change.

Similar results are recorded on another tissue machine producing only bath grades (with small basis weight variations) from virgin fiber. As shown in Figure 10, the same observations are made on this machine leading to the same conclusions: In addition to excellent conformance to laboratory for softness, this sensor is an excellent predictor of optimum crepe blade change time, resulting in further savings. Note that the transients in Figure 9 and 10 correspond to the crepe blade change times.

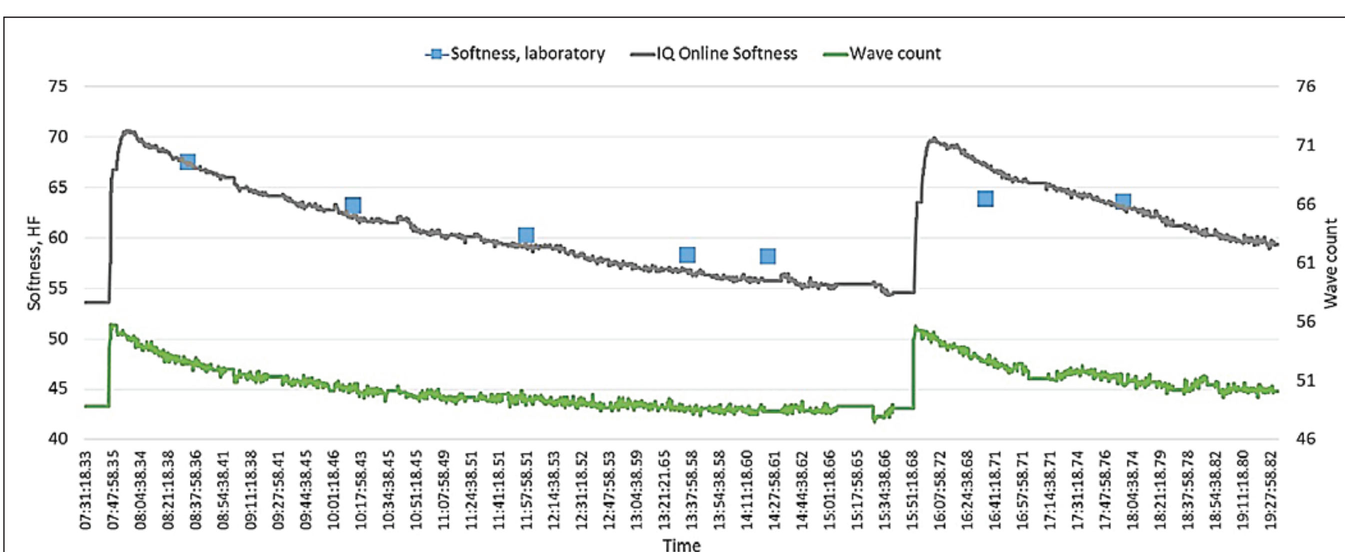

Figure 9: Softness and wave count trends on a tissue and towel machine

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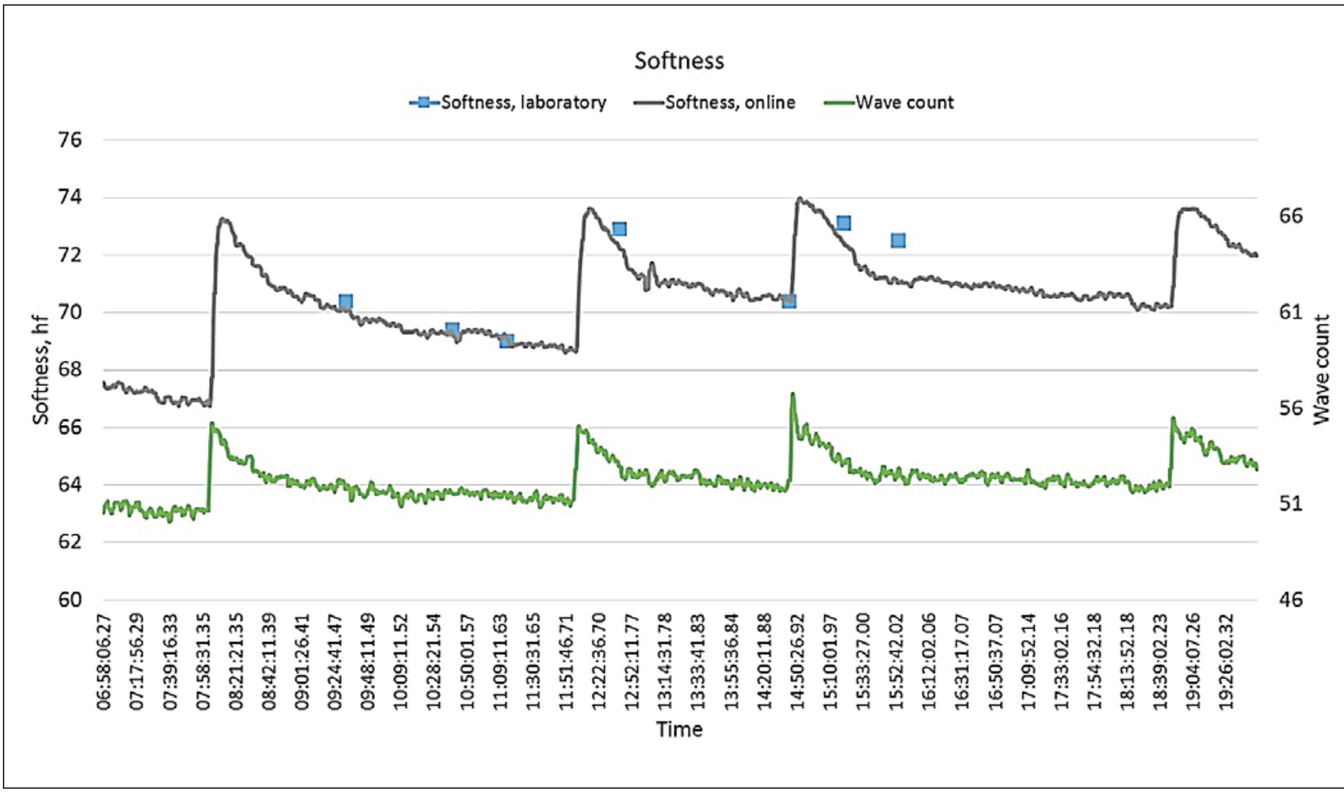

Figure 10: Softness and wave count trends on a machine producing bath tissue grades

RESULTS AND DISCUSSION

Tissue manufacturing is typically an optimization between good softness and tensile strength. In converting machines, tissue stretch capacity also plays an important role. The biggest process factors that affect tissue softness are furnish selection, coating chemicals, creping blade angle and blade wear. Furnish selection is typically grade dependent, i.e. during a grade change, creping properties and operation as well as creping blade wear are the dominant factors affecting softness. Creping blade wear is also a dominant factor during the grade run.

The presence of a softness sensor on the first production machine has already led mill personnel to optimize quality and production based on the measurements provided by this sensor. Tissue makers have used it to operate in the desired softness range as well as optimize the grade changes to quickly reach the acceptable level of softness. They know when the right level is reached. They no longer make unnecessary changes, or wait for the laboratory results and prolong grade change operations.

Availability of the softness and wave count trends provide another significant benefit to tissue makers: crepe blade change that is typically made on an hourly basis is now done based on the trend from the online measurement: if the softness value from on-line measurement goes below the specified target value, a blade change action is triggered. In customer trials, absolute time limit for hourly based change has now been increased in most important grades from 8 to 12 h and with other grades to 16 h.

With good correlations to laboratory softness, many of factors influencing tissue softness and related practices can now be studied with instant and reliable feedback from the online sensor measuring the surface topography, softness, wave count and other surface properties. The following have been the subject for much discussion:

- Softness versus tensile strength versus stretch
- Follow-up and control
- Coating chemical changes
- Wet-end chemical changes
- Blade angle changes
- Crepe ratio changes
- Softness correlation with other online measured quality variables (moisture, basis weight)
- Softness with other process changes,
    - ❑ Refining
    - ❑ Fiber morphology changes

Clearly, there are many unknown factors, a lack of understanding of why a sheet is soft or the relationship with other properties, the influences from key operational parameters, and much speculation regarding softness, which is the primary quality parameter for tissue consumers. With the addition of an important measurement that was missing from the online measurement portfolio, it is hoped that these factors can now be better understood and ultimately controlled.

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CONCLUSIONS

Image-based topography measurement principles have already been used to measure paper parameters related to paper surface quality and printability, online; e.g. smoothness, roughness, surface standard deviations, etc. The same measurement principle is now used to also measure tissue properties like tissue softness, with selected image filters and image calculation algorithms.

The correlation obtained to laboratory devices are shown to be excellent. It was also shown that creping blade change times can be optimized based on the softness or wave count measurements obtained from this sensor. The addition of this tool to the tissue automation concept is likely to increase our understanding of softness. The measurement is already used to manage tissue operations including grade changes to achieve optimum softness. Development of better softness models with instant feedback from the sensor and control applications relying on the relevant models are likely to improve the profitability of tissue lines.

For printing papers, the accurate machine direction and high-resolution cross direction topography profiles provide a solid foundation for producing high quality paper and board, with real time information of sheet surface properties making it possible to optimize printability already at the paper machine. The spectrum of different scales measured, from the micrometers of fiber diameter scale to centimeters of cockling and drying shrinkage patterns, have different levels of importance for different printing or converting methods and certain scales interlink more than the others for certain quality criteria.

Another strength of on-line photometric stereo analysis is its ability to recognize cross or machine directional topographic patterns over a wide wave length region, on-line and across the whole web. This can give quite new insights into paper or board fine structure, and how topography with different wave lengths is deeply interlinked with other process and web characteristics such as fiber composition, machine concepts, unit processes and numerous process parameters involved. ■

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