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VARIABLE SPEED SCANNING – A FUNDAMENTALLY BETTER WAY TO SCAN

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ABSTRACT

It has long been known that the CD profiles from conventional scanning sensors contain a mixture of MD and CD variations. This is often referred to as MDaliasing. The reasons for these phenomena are reviewed.

Simulation studies have shown that scanning a moving web with a more random velocity pattern can reject much of this MD aliasing effect. In particular, fast MD variability can be kept from affecting the CD profile where it would result in erroneous control actions. Recently, one vendor has introduced a scanner that uses variable speeds for scanning. CD velocity is changed depending on direction and the operational situation. The results of a real mill experiment scanning forward and back and at the edges at different rates are presented. Variable speed scanning provides more realistic MD measurements and CD profiles than conventional single speed scanning. As part of this development, a number of tools have been built into the quality control system (QCS) to aid mill personnel in detecting and troubleshooting process variability problems. Real mill cases are presented where these tools found process issues.

Keywords: Analysis, profile, trouble shooting, variability, variable speed scanning

INTRODUCTION

The cross direction (CD) profiles from conventional scanning sensors contain a mixture of MD and CD variations. The process of machine direction (MD) variability finding its way into the profiles is often referred to as MDaliasing. It creates fictitious variability in profiles that does not exist. If one is lucky, profiles are contaminated with seemingly random noise. In the worst case, CD controls chase fictitious peaks that may migrate across the web. In the first case, a moderate amount of profile time filtering may be sufficient for acceptable control, although this approach slows down the controller response to real upsets. In the worst case, no amount of filtering will remove the problem.

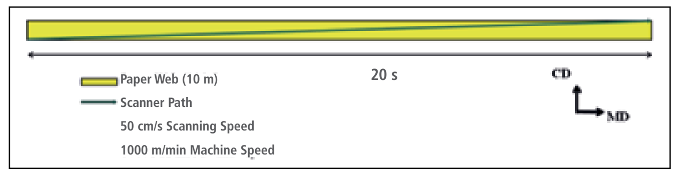

Figure 1. Scanning contaminates "CD profiles" with much MD variability

Figure 1 shows the diagonal path traced by a modern scanner drawn to scale. For such a machine 333 meters of paper pass the scanner during one 10 meters traverse across the sheet. Although we call the signal produced a CD profile, it could as well be called an MD trend! For a faster machine, the situation gets worse. Scanning faster only improves the situation slightly.

This MD aliasing phenomenon has been the "dirty little secret" of the gauging world. It is real, but not talked about much in the industry, with the notable exception of the Control Systems conferences. One reason for this reticence is that, unlike conventional aliasing in time domain loops, there has not been much that could be done about MD aliasing of two dimensional measurements until now. The reason that it is possible to ignore this unfortunate truth is that true CD disturbances are usually much slower than profile traverse times, so the time filtering normally required has been an acceptable compromise.

MD aliasing

MD aliasing can be demonstrated easily using simulated data. **Figure 2** shows a trivial worst case when there is a

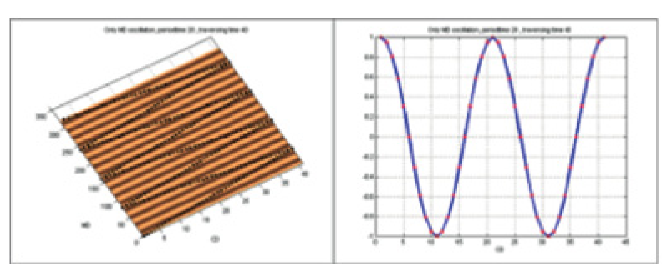

Figure 2. MD aliasing worst case (MD cycle synchs with scanning period)

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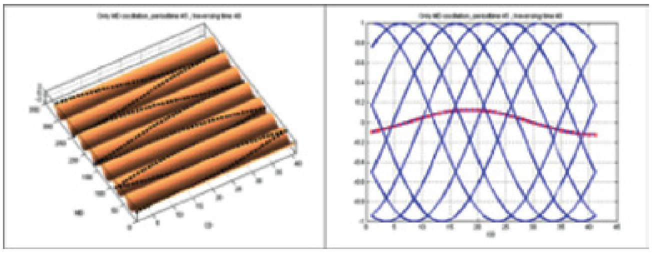

Figure 3. MD aliasing when MD cycle nears scanning period

perfectly flat profile and MD variation with a period of half the scanner traverse time. Scanned data shows a totally false profile shape. No amount of time filtering or averaging will yield the true flat CD profile. However, hourly standardize or other offsheet period would break the phase relationship and result in a new false profile shape.

A more common case would be when the MD cycle is near but not equal to the scanning period (**Figure 3**). In this case time filtering multiple scans helps, but does not reveal the true flat profile. This would lead to erroneous control actions.

Changing scanning velocity will not help in any fundamental way. Aliasing is worst when an MD cycle is at or near some multiple or submultiple of the scanner traverse period as discussed below and in[5]. The effect of changing the scanning speeds merely to change the MD periods will alias the profile badly. It does not eliminate the aliasing effect.

Real world cases also contain actual CD variation and noise making the picture presented to the operator and the control system extremely complex and confusing. When quality control system screens show profiles bouncing around or flipping or streaks migrating across the sheet, the first thing to check should be what MD variation is occurring[1]. Typically CD control gets the blame and checking MD is only done after a fruitless session of retuning the CD controller.

The dream of non-scanning measurements for all important paper properties will not be fulfilled soon. In the meantime, the most useful thing to do is to improve methods of estimating true MD and CD information from scanning data. Also badly needed are simple methods to detect and alarm the presence of MD cycles that would alias into the CD.

Review of MD/CD separation methods

The simplest technique that is used by most CD controllers is to time filter or average the profile to be controlled. As shown above, this crude technique will not work for worst case MD aliased profiles. If such aliasing is significant, an excessive amount of filtering or averaging may be required that would severely degrade the performance of the CD controller.

- Variability of paper can be classified in the following ways[5]:
- MD (actual + random MD noise)
- CD (actual + random CD noise)
- Patterned variations that are neither MD or CD
- Truly random residual variation

The last two are commonly lumped together and called either Short Term or Residual. There are a number of methods proposed to calculating the size of each component[2, 3, 4]. The first two are Tappi standards, and the third is a suggested improvement. However, there are problems with all these methods particularly when patterned variations that are neither MD nor CD are present. The proper way to estimate the MD or CD noise component statistics is to use a truly random 2D residual variation. This correction to previous methods is discussed in[5].

Ylisaari *et al*. looked at manipulating scanning speed for optimal control and diagnostics[6]. Building on this work, [5]included simulation studies that show that scanning a moving web with a more random velocity pattern can reject much of this MD aliasing effect. In particular, fast MD variability can be kept from affecting the CD profile where it would result in erroneous control actions. One of their simulation studies is reproduced below in **Figure 4**. The data was flat CD profile with random noise combined with MD variations. For the constant-speed scanning case, the scanning time period is 30 seconds. For the variable-speed scanning case, the scanning time is randomly selected from the shortest 15 seconds per scan to the longest 60 seconds per scan.

Figure 4 shows the relationship between the simulated MD variation (σ=1.42) of wavelengths from 1 second to 150 seconds and the estimated CD variation (using deviation value) under the two different scanning methods. Constant speed scanning (green trace) is severely aliased at critical multiple and submultiple periods. The random scanning mode (red trace) is able to reject this phenomenon.

This points the way to something fundamentally new, a better way to scan. Improved separation of the MD and CD components in scanned data in real time will invariably improve MD and CD control performance and provide better diagnostic information for operations.

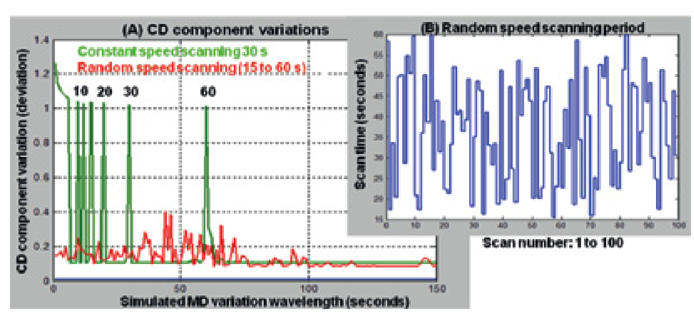

Figure 4 - Estimated CD variation of two scanning patterns under different MD variation frequencies

Mill scale experiment using variable speed scanning

Recently, one vendor has introduced a scanner that uses variable speeds for scanning[7]. CD velocity is changed depending on direction and the operational situation. Multiple speeds can be used to increase the randomness of the scanning pattern. This provides more realistic MD measurements and CD profiles than conventional single speed scanning.

To compare variable speed and constant speed scanning, some

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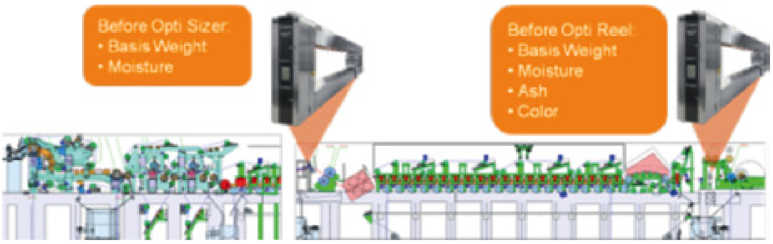

Figure 5. Propapier PM2 QCS layout

trials were conducted at Propapier's PM2 in Eisenhüttenstadt, Germany[1]. PM2 is a two layer liner machine with scanners at the size press and the reel, as shown in **Figure 5**. For the tests, the reel scanner was set up at a constant speed of 40 cm/s. The size press scanner used variable speeds of 33 cm/s forward and 50 cm/s reverse. This gave both scanners a traverse time of ~35 cm/s. Then, near the end of a reel, a square wave disturbance was introduced by repeatedly stepping the top layer stock flow up and down with the period of just over a minute. One would expect a disturbance of this frequency to be badly aliased. **Figure 6** shows trend of the trial. The bottom

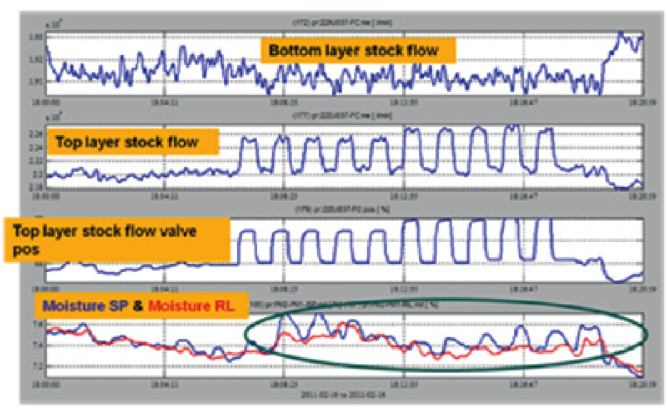

Figure 6. Variable speed size press scanner sees disturbance more clearly than constant speed reel scanner

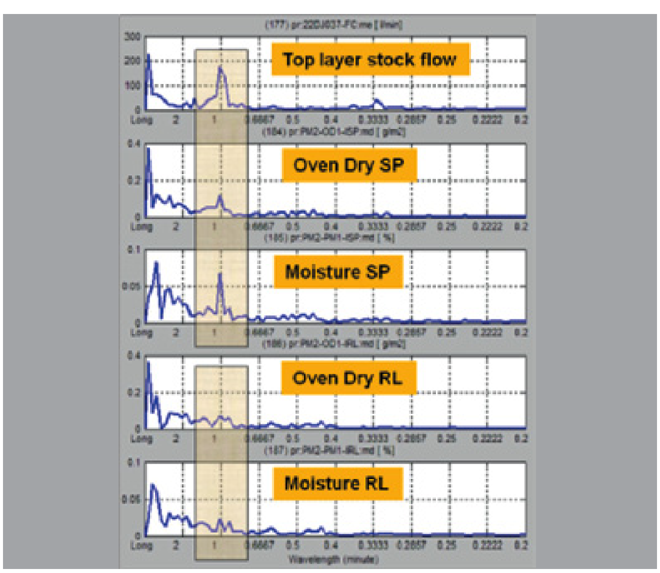

Figure 7. Spectra Also show variable speed size press scanner detects disturbance when constant speed reel scanner does not

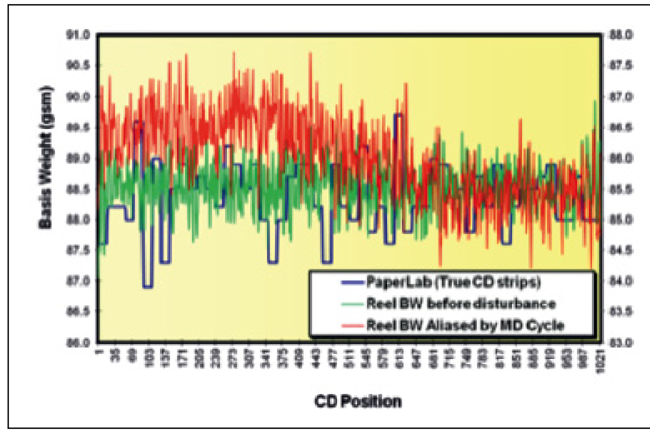

Figure 8. Reel scanner (constant speed) showed false profile shape during test

traces show the effect on moisture as measured by the two scanners. Note that an MD estimate that is computed faster than the scan average is plotted. The variable speed size press scanner (blue trace) clearly sees the disturbance. The constant speed reel scanner does not (red trace). This conclusion is confirmed when MD spectra are calculated in **Figure 7.**

To check the profile performance of the reel scanner during the disturbance, the profile before and during the test are plotted in **Figure 8**. Also plotted (lower resolution) was an offline weight profile from a true CD strip measured using the mill's PaperLab. The sample was from the reel turn up before the disturbance test was finished. Both the profile before the disturbance and the CD strip sample are flat. The reel scanner using constant speed scanning shows a distinct tilt during the test. CD control would have made quite wrong control actions if this data had been used.

As a second comparison of the profiling performance between the two scanning methods, conventional MD/CD statistics were calculated for sets of profiles before and during the disturbance. The results are summarized in **Table 1**.

Comparing the periods before and during the disturbance, it looks like the machine quieted down somewhat. With a disturbance period of slightly more than 60 s and a traverse time of 35 s, one would not expect the disturbance to be significantly detectable in the MD sigma figures of Table 1. During the period of the induced disturbance, the

Table 1. Basis weight variability before and during the disturbance (ANOVA of scanning data not true MD and CD variability)

2σ (g/m²)	Size Press Scanner			Reel Scanner		
	Before	During	% change	Before	During	% change
Total	2.028	2.105	+3.8	1.728	1.855	+4.3
CD	1.025	1.057	+3.1	0.707	0.958	+35.5
MD	0.740	0.605	-18.2	0.809	0.505	-37.6
Residual	1.598	1.723	+7.8	1.433	1.511	+5.4

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constant speed reel scanner CD 2σ increased significantly while the variable speed size press scanner did not. As predicted in[5], the variable speed scanning appears to have moved primarily into the residual term. The constant speed scanning overestimates CD variability and underestimated MD 2σ.

Variable speed scanning can be thought of as a way to increase the robustness of CD controls. By improving MD aliasing performance, the CD controller would avoid making erroneous control actions while chasing variability that is, in fact, not really there.

Mill experiences with variable speed scanners

In the development of the new scanner, Metso recognized that while variable speed scanning promised significantly improved immunity in the area of MD aliasing, this was not enough to meet papermakers' needs. It was also important to build tools into the quality control system to aid mill personnel in detecting and troubleshooting process variability problems.

One of the features of the new scanner was the ability to program it to automatically go to a fixed position for a short period of time when certain conditions were met, and record a set of true MD data. **Figure 9** shows a Propapier operator display with the analysis of one such fixed point dataset. There is a strong peak in moisture at 0.9 Hz which corresponds to the length of the second press felt. The history page showed this peak was consistently present. Previously, automatic detection of machine component variations was only possible with dedicated condition monitoring systems.

The current generation of sensors is capable of much faster measurements than older gauges. Some sensors (IR moisture and cellulose) can supply measurements as fast as 1 kHz, thus extending the limit of what frequencies can be detected considerably. Other measurements are limited by the speed of their detection technology to 25 Hz or less.

It is also important to provide tools that can detect, from scanning data, when fast MD cycles are present that might compromise CD controls. One technique that has been used is to compare the power spectrum of the average of a group of profiles with the average of the spectra of each of the individual profiles. If there is MD aliased

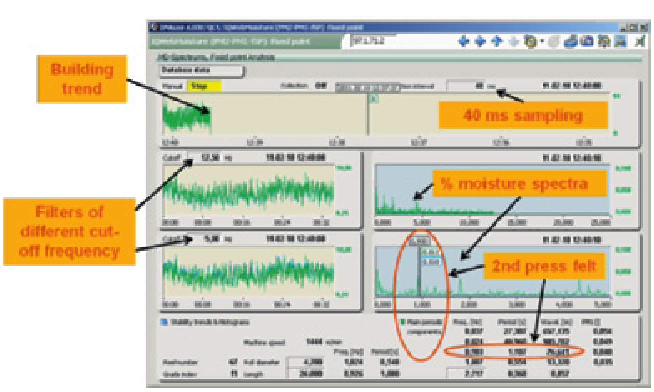

Figure 9. Automatic fixed point analysis reveals the 2nd press felt is imprinting itself on the sheet

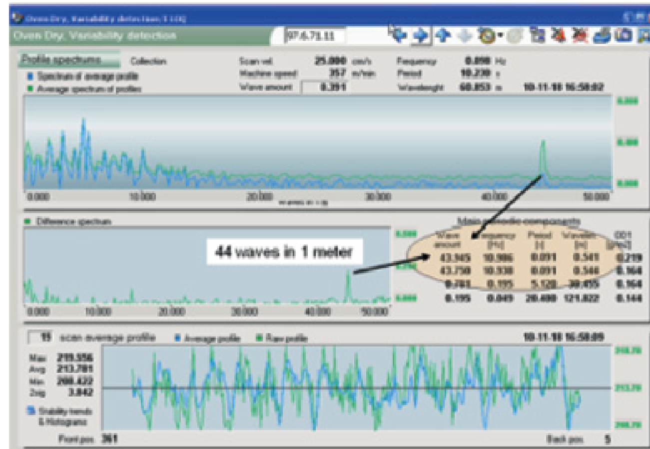

Figure 10. Spectral difference reveals a fast MD cycle from scanning data

variability in the profiles, there is a high probability it will be attenuated in the average profile compared to the individual profiles. Peaks that are prominent in the average of the single scan spectra, but not in the spectrum of the average profile, reveal the existence of relatively fast MD cycles. Such a screen has been programmed as part of the customer tools for the new scanner. **Figure 10** shows a case from a Finnish board machine revealing a fast MD cycle (11 Hz) hidden in the scanning data. This technique does not require variable speed scanning, but it is limited to detecting MD frequencies fast enough to repeat several times during one sensor traverse of the web, but slower than twice the time taken to traverse two profile cells.

For variable speed scanning, there is another technique that can be used. The apparent wavelength at which an MD cycle shows up on a profile depends on the scanning velocity. For true CD streaks, this is not the case. Thus, if a variable speed scanner uses different forward and back velocities, comparing spectra of forward and reverse traverses, will reveal the existence of MD variations by spectral peaks that appear in different locations and CD streaks that do not. **Figure 11** shows a screen from Finnish fluting machine where the scanner was configured to scan forward at 35 and reverse at 25 cm/s. One case can clearly be seen where at 2.674 Hz when scanned at 35 cm/s

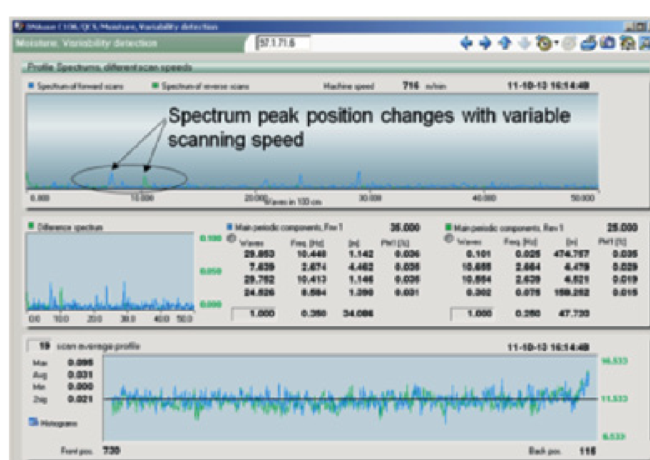

Figure 11. Variable speed scanning detects 2.6 Hz (4.5 m) variation

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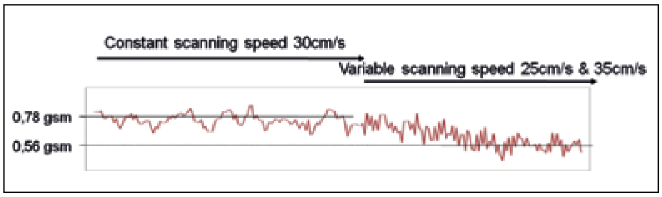

Figure 12. Variable speed scanning improved CD weight control performance for this machine

and 2.664 and 2.639 when scanned at 25 cm/s. The frequencies are given as waves/100cm, Hz and meters of paper to simplify the user's task to correlate variation with machine elements.

For this machine, the scanning and fixed point tools found MD cycles at 30 Hz, 25Hz, 7,5Hz and 2,6Hz in dry weight and moisture. These problems had been adversely affecting control. Initially, scanner was set up for constant speed scanning at 30 cm/s. When variable speed scanning was configured, the dry weight CD 2σ dropped by more than 30% as shown in **Figure 12**.

Dramatic improvements like this cannot be expected in most cases. For this machine, the CD 2σ clearly contained MD aliased variability and when this was reduced with variable speed scanning, CD 2σ improved. It is not known how much of this improvement is merely decreased aliased variability and how much is from the CD weight control no longer chasing phantom MD aliased streaks.

The benefit of variable speed scanning comes from the following:

- Less MD aliased apparent CD variability should produce a moderate reduction in CD 2σ.
- In some cases, the control will no longer chase phantom streaks and the CD 2σ reduction will be more substantial.
- Control performance should not degrade as badly when MD variation near a critical frequency appears, since variable speed scanning will reject more of this MD variation from the profile.

The techniques and tools outlined above are useful for a range of frequencies. However, there is no one view that looks at all the variability in the paper machine's production [9,10]. The fixed point and scanning tools target fairly fast MD variability. The scan average and faster MD estimates offer excellent tools for characterizing slower variability. The papermaker needs a "dashboard" or overview of the state of his machine from a variability point of view. **Figure 13** shows such a screen.

The purpose of this screen is to point out where variability is above normal and should be investigated using the more specific tools. Simple presentation is crucial. It should be as simple as a traffic light. Variability is divided into ranges by period and simple dials are used to indicate low, medium or high (relative to normal). The page shows longer-term weight and moisture variability in the left set of dials. This is based on scan averages or other MD estimates. The right set of dials targets higher speed data and is based on results from the automatic fixed-point analyses. The most common periodic frequencies are shown on the right side. In the example of Figure 13, the medium speed fixed-point variability (20-5 m of board) shows high variability.

Figure 13. Papermaker's variability "dashboard" from a Finnish board machine

CONCLUSIONS

The improved MD aliasing performance of variable speed as opposed to traditional constant speed scanning has been verified with mill scale experiments. Two scanners, one constant speed and the other variable speed, were subjected to a periodic MD disturbance whose period was chosen to MD alias a conventional scanner. The variable speed scanner showed little MD aliased variability in the CD profile. The MD estimate of the variable speed scanner was able to measure the imposed periodic disturbance.

Variable speed scanning provides several benefits.

Less MD aliasing will produce a better estimate of the actual CD variability. This will lead to a moderate reduction in CD 2σ as it is usually calculated today.

- To the extent that MD aliasing is causing a CD control to chase phantom streaks, reducing this aliasing will lead to a real control performance improvement.
- Control performance will not degrade as badly when MD variation near a critical frequency appears, since variable speed scanning will reject more of this MD variation from the profile.

One case was shown in which enabling variable speed scanning resulted in a substantial reduction in CD 2σ. In other cases, the main benefit will be to make CD control more "robust" when faced with MD variability that would otherwise alias the profile.

Variable speed scanning also permits clearly identifying fairly rapid MD cycles in scanning data by detecting the shift in profile peaks comparing CD spectra at different scanning speeds. Peaks will shift for MD variability and remain constant if the variability is true CD.

The papermaker also needs tools to look at variability faster and slower than that causing MD aliasing of profiles. Variable speed scanning is just one member of a suite of tools available with a new scanner. Automatic fixed-point analyses can be configured to target high speed variability and verify that a variability pattern is indeed MD in nature. Scan average and MD estimate data are

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used to characterize slower periodic variability. The whole picture is presented to the user using a simplified variability "dashboard".

With these advances, the industry is seeing the next stage in the evolution of the QCS. As well as improving CD control performance with better MD/CD separation, the new tools are moving the QCS from being just a measurement and control platform to becoming the papermaker's companion in optimizing the operation of the process. ■

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