Real-time quality analysis of newsprint paper machines

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ABSTRACT: A real-time paper quality analysis system has been developed and tested under mill conditions. The analysis system has been used to detect sensor miscalibrations and random test errors as well as determine the sources of paper quality disturbances.

KEYWORDS: Analysis of variance, data, newsprint, newsprint machines, paper tests, quality control, variability.

In the characterization of newsprint, over 20 different tests may be used to determine paper quality. While these tests are performed on each reel of paper produced, a large portion of these data are not examined or analyzed in real time. As a result, when quality disturbances occur, the majority of the data are analyzed well after the fact, when large amounts of off-quality paper have already been produced.

Real-time analysis of a large number of paper quality tests is complicated for several reasons:

1. Paper quality tests contain a large amount of random testing variation. As a result, it is difficult to react appropriately to a single test which is outside its specification limits.
2. Paper testing equipment requires continuous maintenance and calibration. Paper quality changes observed by operating personnel are often attributed to miscalibrations rather than true process shifts. Since the calibrations are often performed by groups other than the operating personnel (such as the technical staff), there are often long time delays before the "miscalibration" is validated or disproved.
3. Paper quality tests are highly interrelated. Thus, changes in certain paper quality tests are often reflected in a number of other tests. Trying to interpret shifts in paper quality when a large number of paper quality tests are changing is difficult to do in real time.

A number of analysis techniques, such as principal component analysis and factor analysis, have been applied to paper quality data in an attempt to deal with these problems. More recently, factor network analysis has been applied to the characterization of newsprint quality. The theory and mathematics of factor network analysis have been discussed in earlier articles *(1, 2)*. The basic technique as applied to newsprint quality can be broken into two stages:

1. In the first stage, conventional factor analysis is used to determine how many significant independent properties are considered in the paper quality tests. Earlier work has shown that the 15–25 paper quality tests can be reduced to 5–7 independent "common factors." These common factors represent the underlying properties which determine paper quality.
2. Using specialized analysis techniques, the analyst uses process experience to manipulate these common factors into recognizable patterns. For example, an experienced papermaker knows that when the sheet becomes highly oriented, the CD tear will increase while the MD tear will decrease. In addition, MD tensile and elongation will increase while the CD properties decrease. If the analyst inputs this pattern into the analysis system, the analysis will search for this pattern in the paper quality database.

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I. Newsprint quality tests

Basis weight	CD tear
Caliper	MD tear
Density	CD tensile
Porosity	MD tensile
Water drop	CD TEA
Coefficient of friction	MD TEA
Top roughness	CD elongation
Bottom roughness	MD elongation
Opacity	Brightness

II. Seven common factors which determine newsprint quality

Newsprint properties affected	*Common factors*
Fiber number	Basis weight Caliper Opacity
Fiber bonding	Porosity Water drop Tensile TEA
Fiber length	Tear Porosity
Fiber pressing	Caliper Roughness
Fiber orientation	MD vs. CD properties
Unbonded surface	Opacity Roughness
Light absorption	Brightness L*

3. Once the pattern is detected and verified, the analysis system creates an equation for the pattern. The common factors such as "fiber orientation" are calculated as linear functions of the paper quality tests.

The mathematical model which results from the analysis is called a factor network. Patterns such as fiber orientation, fiber bonding, etc., are changed from qualitative impressions to a quantitative variable which can be plotted and tracked over time. In addition, factor networks not only calculate these common factors but also use the common factors to predict the raw data. This allows random test variations to be filtered out or miscalibrations to be detected.

Mill experiences

Data were gathered from the Ponderay Newsprint Co. mill located in Usk, WA. The data, covering a six-month period, included the tests listed in **Table I.** The moisture of the paper was originally included in the analysis, but since the moisture is carefully controlled on this paper machine, the majority of the variations were random test variations rather than true process changes.

Factor network analysis was performed using the FactNet analysis system *(3)*. This analysis system allows a large number of variables to be analyzed interactively. The analysis system can also be tied directly into on-line information systems to allow the factor network results to be presented in real time to both the operating personnel and the technical staff.

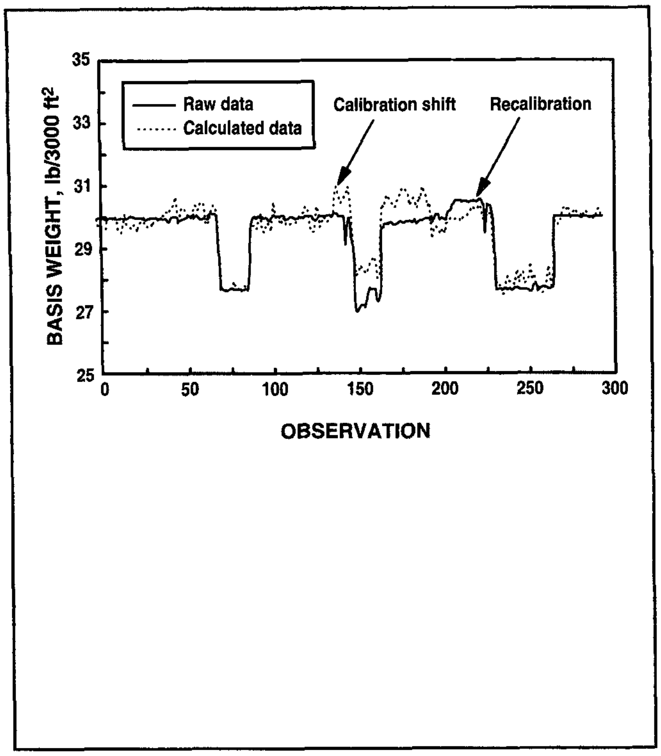
Factor network analysis of the paper quality tests indicated the existence of seven common factors. These common factors and the patterns associated with them are shown in **Table II.**

Detection of shifts in sensor calibrations

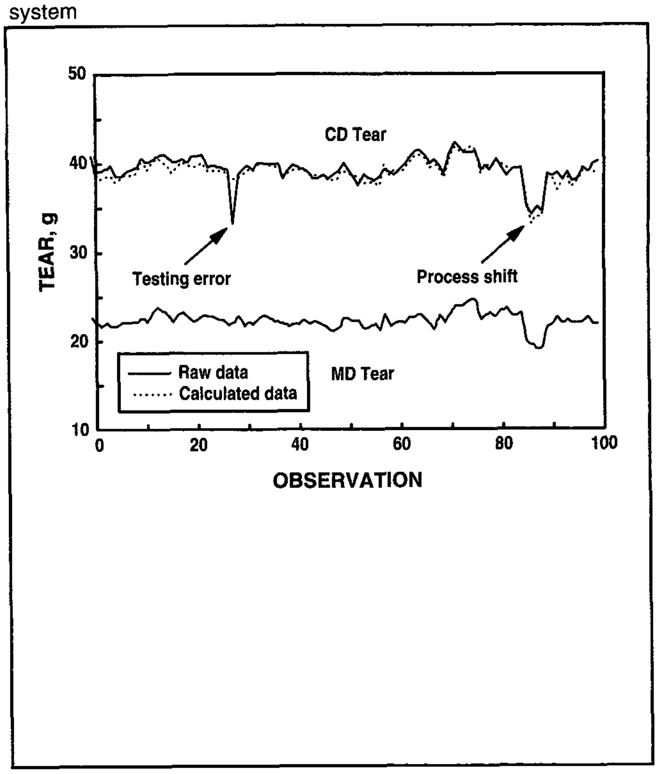
After a paper machine maintenance shutdown, a shift in the calibration of the on-line basis weight sensor occurred. Upon starting up, the on-line analysis system immediately detected the error, as shown in **Fig. 1.** The analysis system determined this by examining other paper properties which were highly related to basis weight (such as caliper and opacity). The analysis system determined that the basis weight measured by the on-line sensor was inconsistent with these other tests.

The miscalibration was checked using manual testing, and the shift in calibration was confirmed. As it was not possible to repair the unit immediately, the paper machine was operated using an offset in the basis weight. After the basis weight sensor was repaired, the sensor was then recalibrated.

1. Detection of a shift in the basis weight calculation



2. Changes in CD tear as measured and predicted by the analysis system



3. Changes in MD and CD tensile energy absorption

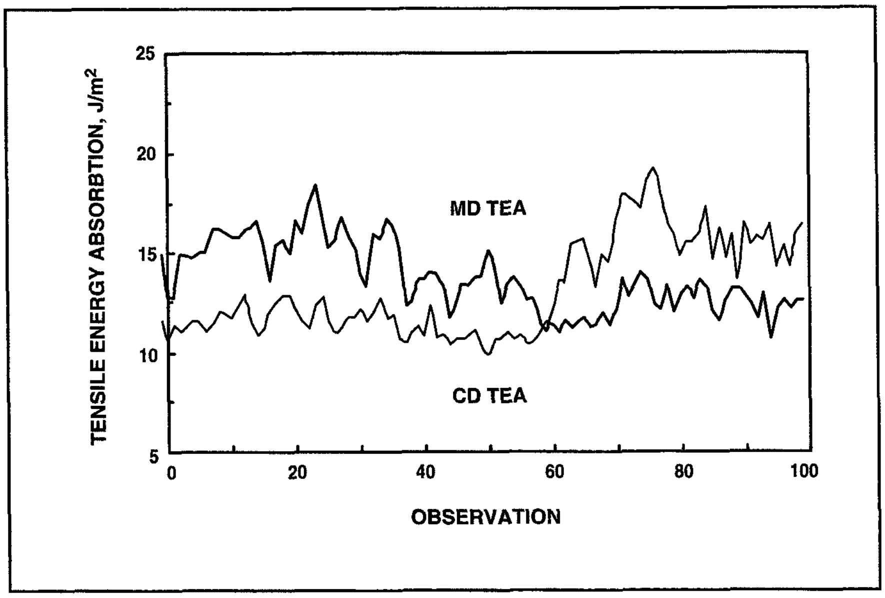


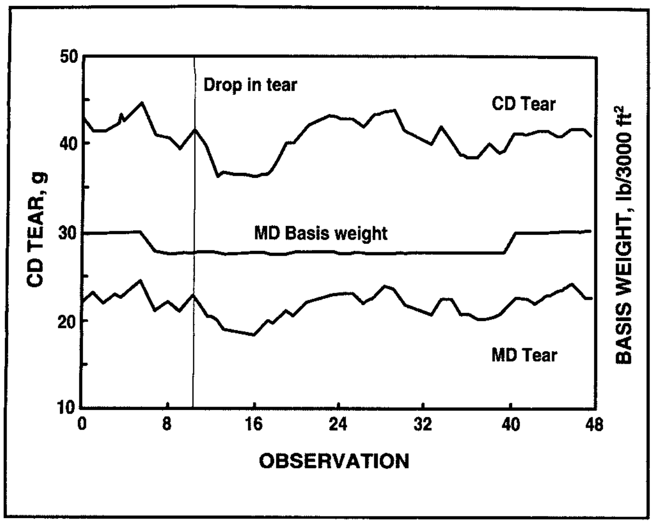
Figure 2 shows that MD tear did not change during the first "disturbance." This disturbance could have been caused by a change in fiber orientation, which changes the relationship between the CD and MD properties. However, the factor network would have detected this by examining changes in the MD and CD elongation, tensile and tensile energy absorption (TEA). As can be seen in **Fig. 3**, while MD and CD TEA varied over this time period, there were no shifts in the relationship between the two variables which would indicate a change in fiber orientation. Examination of elongation and tensile leads to a similar conclusion.

As no changes in fiber orientation were detected by the analysis system, the factor network determined that the first "disturbance" was actually a random test variation. Figure 2 indicates that the second disturbance was validated by the factor network. The implications of this type of analysis are obvious. CD tear

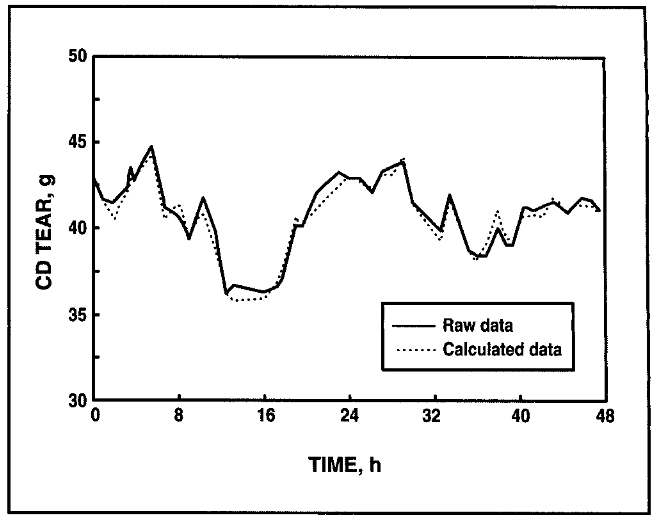
Filtering out random test variations

During a one-week period, the CD tear experienced two downward drops. As **Fig. 2** indicates, the factor network predicts that the first downward drop in CD tear is a random test error while the second drop is a true process change. The factor network determines this by examining other variables such as MD tear, which correlates highly to CD tear.

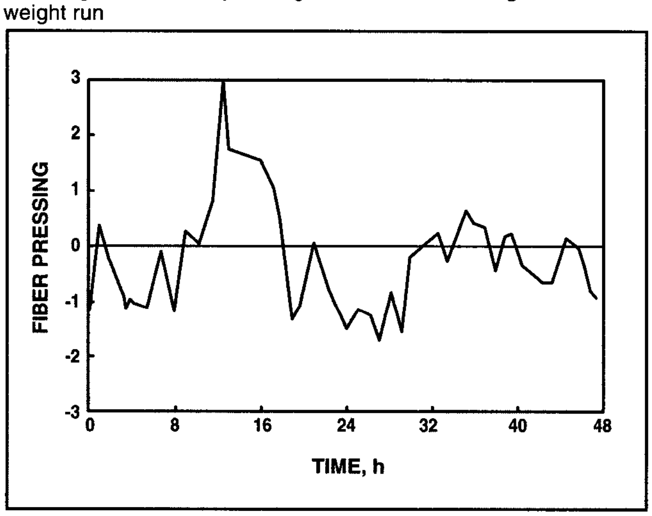
4. Drop in CD and MD tear during a low basis weight newsprint run



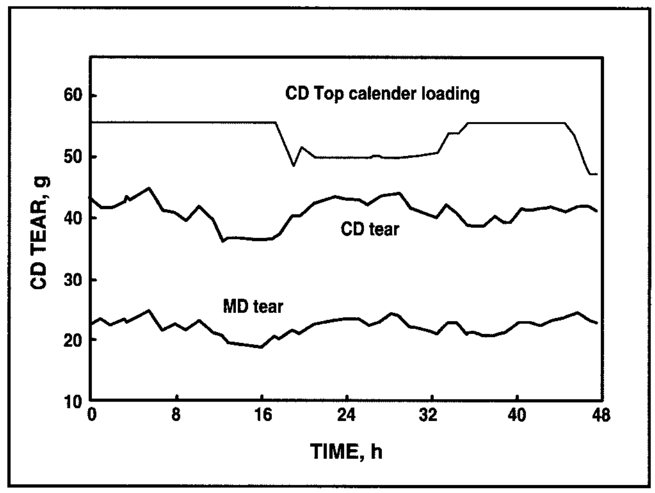
5. Confirmation of the CD tear measurement using the analysis system



6. Changes in the fiber pressing common factor during the low basis weight run



7. Changes in the calender stack results in increased CD and MD tear



is a primary quality variable, being controlled by the addition of kraft pulp. By increasing the reliability of the CD tear measurement, the operators can react more quickly to true process disturbances while ignoring random test variations, resulting in a more uniform paper quality and reduced kraft usage.

Identifying process disturbances

During the production of a low basis weight newsprint sheet, severe drops in the MD and CD tear were observed, as shown in **Fig. 4.** Initially, a miscalibration in the measurement device was suspected, but as can be seen in **Fig. 5,** the factor network indicated that the drop was a true process shift. Manual calibration checks also confirmed that the drop in tear was not a miscalibration.

As discussed in the earlier section, the tear is controlled using kraft pulp addition. The operators responded to the drop in CD and MD tear by increasing the kraft usage from 10% to 16% without any discernible effect on tear strength.

Factor network analysis not only detects miscalibration and random test errors, but also builds a mathematical representation of the underlying properties which determine paper quality. These underlying properties are summarized in Table II. During the disturbance in tear strength, there was also a shift in the "fiber pressing" common factor. The fiber pressing phenomenon is characterized by low caliper and low roughness. In addition, when the fiber pressing phenomenon is extremely high, low tear strength will result.

A time trend plot for fiber pressing is shown in **Fig. 6.** By definition, common factors have an average of zero and range of approximately –3 to +3. As can be seen, the fiber pressing common factor is at its upper limit, indicating the fiber is being pressed too severely in the press section or the calender stack. The operators were informed of this possibility and responded by dropping the calender loadings by 5%. CD and MD tear responded by increasing dramatically, as shown in **Fig. 7.** As a result, the kraft addition was reduced by 10 percentage units for the remainder of the low basis weight run.

Expanding the factor network

The examples presented in the previous sections have used only the paper quality data to diagnose several different types of quality disturbances. As more information from the process becomes available to the factor network, this information can be used to more accurately isolate the cause of paper quality variation. This technique has been used to analyze the effects of pulp mill operation on newsprint quality *(4)*.

Factor network analysis is also being applied to a number of other applications in the mill, including on-line prediction of freeness fiber length and shives after the main line refiners and determining the causes for paper curl and roll density.

Summary

Analyzing paper quality data in real time is difficult because of the large number of interrelated paper quality tests. However, this mill study has shown that factor network analysis can be used to reduce testing uncertainty as well as increase the interpretability of the data. This means the operating personnel can more efficiently control product quality in real time rather than performing "post mortem" analysis of off-quality paper. The results are reduced product variability for the customer as well as an increased understanding of the process for the mill.

Literature cited

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