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Paper Machine Auditing

When there are operational issues with a machine, several variables must be examined or audited, including the clothing. That is why several paper machine clothing manufacturers offer services to their customers to support the operation and performance of their fabrics. Evaluation of the performance of the machine clothing requires a thorough understanding of the entire machine and support equipment. Audits can be performed throughout the machine, or in one specific section. The main purposes of the audit are to gather and analyze operational data that: 1) can be used to benchmark operations, 2) will help troubleshoot operational problems, and 3) will uncover opportunities to improve or optimize machine performance. Machine audits are also often referred to as Process Optimization Studies. A typical study will take a few days to complete and consists of several stages as explained in this chapter. It is important to understand that only a snapshot of the machine and conditions are collected during a study or audit. It should be emphasized that audits are machine (and sometimes grade) specific and will therefore vary from site to site. Examples from actual studies are used throughout this chapter to demonstrate the type of information that can be gathered. A more in-depth study may be called for when a piece of equipment or a specific section of the machine is identified as a poor performer.

Analysis of Process Information (PI) data are very helpful in looking at how the machine or particular piece of equipment performs throughout the life of a particular fabric, with varying speeds or with changes in grade. Long-term trends often show gradual shifts in performance that might not otherwise be noted in a snapshot view.

This chapter focuses on optimization of the current operating conditions and equipment. More detailed process “bottleneck” studies, evaluation of mechanical limitations, risk analysis for major capital expenditures, etc., would require more specific expertise and would be classified as specialized audits. Also, chronic problems and/or larger improvement opportunities might require a dedicated audit and analysis of their own.

5.1 Variability Study Information

5.1.1 Background and Objectives

Variations in basis weight, either in machine direction (MD) or cross direction (CD), are detrimental to product quality and often result in increased operating costs. Quality parameters such as strength, caliper/density, permeability, and printability can be adversely affected by non-uniform weight distribution. Excessive variability can also significantly reduce paper machine runnability and converting efficiency, which results in lower tonnage and increased cost/ton. In severe cases, where average weight must be increased to meet minimum specifications or to achieve consistent machine runnability, direct costs such as fiber and chemicals are increased.

The objectives of a MD Basis Weight Variability Study are to: 1) characterize the variations (frequency content and amplitude), 2) identify the sources, and 3) provide specific recommendations for corrective action. The ultimate goal is to provide information that can be used to make machine and/or process adjustments that will result in a more uniform product.

Basis weight variation can be periodic or random, high frequency or long-term. Variations can be caused by total head swings or pulsation in the headbox and approach flow system, furnish variability (principally consistency), variation in retention, and/or machine speed fluctuations. A comprehensive study must consider all these variables. A study team combining experienced personnel with specialized instrumentation and the right analytical software can provide a thorough variability analysis.

5.1.2 Test Procedures

Specialized instrumentation, in combination with computer-based signal analysis and other software, are used to record and analyze pulsation, vibration, and process data. Following is a partial list of instrumentation that is often utilized in variability studies:

1. Wika pressure and vacuum transducers
2. Kajaani LC100 consistency meter
3. PFI Intrans sheet variability meter
4. "Dryline" optical sensor
5. Wilcoxon vibration sensors
6. Infrared and laser photo-tachometers
7. National Instruments SCXI signal conditioning system

Up to 32 channels of data can be recorded simultaneously for each test. The channels are normally a mix of pressure, vibration, consistency, process signals, and triggers from rotating machine elements. The actual number of channels will be determined by the complexity of the approach flow system and the problem at hand.

In most cases, it is desirable to record the raw unfiltered signal from the on-machine basis weight sensor while it is measuring at a fixed position (or positions) across the sheet. These signals are useful in quantifying long-term variations, and can be used to measure high frequency variability to a certain extent. The newer basis weight sensors provide signals with frequency responses up to 200 Hz or so. The signals from older gauges typically have an upper limit of 40-50 Hz. An opto-isolator circuit is used at the point of connection to the basis weight signal (as well as other process signals) to prevent inadvertent loading of the signal and potential process upsets that would result.

Two-point calibration of the basis weight signal is normally conducted prior to the actual data acquisition. Standard Mylar® samples provided by the sensor manufacturer are inserted into the measurement gap when the scanner is off-sheet. These samples should be slightly higher and lower in weight than the basis weight of the paper/board being produced to bracket the measurement calibration. This procedure is required so that the data can be presented in physical units, such as gsm or lb/3000 ft^2.

The PFI Intrans is an optical device that emits a focused infrared beam and measures its transmission through the sheet. This signal is sensitive to variations in weight, density, and moisture. The upper frequency limit for this device is higher than 1 kHz. The unit is mounted in a C-frame and can measure variability within 45-60 cm of the sheet edge. This signal cannot be calibrated, i.e. the output is not expressed in physical process units. However, its high frequency response provides a means to identify variable frequencies that cannot be measured on the machine by other means.

On Fourdrinier machines, the "dryline" sensor is used to provide an indication of sheet variability by observation of light reflection off of the stock on the fabric. A high-intensity spotlight is reflected at a low angle across the machine at or near the dryline. The intensity of reflected light is measured from the opposite side of the Fourdrinier table. The frequency content of the measured signal normally correlates very well with that of basis weight variability, to an upper frequency limit of approximately 50 Hz. As with the PFI unit, the signal is not calibrated, thus amplitude is expressed in volts. It is useful when troubleshooting lower frequency variations when the basis weight sensor is not accessible or when putting the sensor in a fixed-point mode on the sheet is disruptive to the process.

The dryline sensor has also been used successfully to provide an indication of sheet weight, draw fluctuations, and sheet cockles. In all cases, the signal from this device is compared and correlated to upstream variables such as pressure, consistency, and vibration to establish a cause-and-effect.

Pressure sensors are installed at multiple tap points throughout the stock approach system. These sensors are capable of measuring high frequency pulsation, as well as long-term total head variation. The use of a multi-channel system is necessary to determine the propagation path of a pressure variation through the system. This will be discussed further in the "Analysis Techniques" section which follows.

Vibration, particularly headbox vibration, can be a source of high frequency basis weight variability. The vibration of stationary table elements and rolls in the forming section can also cause significant and sometimes severe weight variations. Headbox vibration is routinely measured. Other machine elements can be checked if a frequency is found in basis weight, dryline, or PFI signals that cannot be accounted for by pulsation or headbox vibration.

Vacuum sensors are used to check stability of the vacuum in drainage elements, as well as in the couch roll. The measurement of couch roll vacuum will respond to long-term weight variations and is sometimes used in lieu of single-point measurements from an on-machine basis weight sensor when troubleshooting a variation that spans a very long period of time.

The Kajaani consistency meter is used to correlate consistency variations in the approach flow to variations in the basis weight and/or couch vacuum. The calibration process for this meter is rather involved, so this test is normally not performed unless there is a need to know the magnitude of consistency variation. From a troubleshooting standpoint, the only thing of importance is whether or not there is signal correlation, i.e., cause-and-effect.

5.1.3 Analysis Techniques

Basis weight variability can generally be characterized as either high frequency, or long term. It is generally accepted that a variation occurring at a frequency of 1 Hz (one cycle/second) or greater is classified as high frequency, while a variation occurring over a period of one second or more (frequency less than 1 Hz) is long term. Variability can further be characterized as periodic or random. Analysis techniques differ according to the classification of variability encountered.

In most cases, all channels are conditioned as appropriate with anti-aliasing filters and then sampled for a 12-minute time period at a rate of 1,024 samples/sec. These sampled data can then be analyzed for high frequency variation, and can also be digitally filtered and then resampled for long-term analyses. This method allows both types of analyses to be conducted on one set of measurement data.

In the case of very high frequency variability, a higher sampling rate can be used and usually for a shorter time. When very long-term problems are encountered, a lower sampling rate is used over a longer time period.

High Frequency Variability Analysis

The most common analysis technique that is used to investigate high frequency variability is Fast Fourier Transform (FFT). This is a mathematical method which breaks down a sampled signal and displays the data as a spectrum (i.e., a plot of frequency versus amplitude). Frequencies found in the process signals (e.g., basis weight, PFI, dryline) are compared with the frequencies found in pressure and vibration signals to pinpoint where the variation in sheet quality is originating from. Normally, FFT is performed for sequential portions of each data set and the results are summation averaged to "even out" the basic noise. Averaging makes periodic variations from rotating sources more distinct in the FFT results.

Synchronous Time Averaging (STA) is a method to separate the contributions from various rotating sources out of the total variability in a signal. An FFT is then computed for the resulting STA time waveform. The total power in the STA spectrum can then be compared to that of the "raw" spectrum, and the contribution of the rotating source can be determined and expressed as a percent of total variability. For example, the results of an analysis might determine that the fan pump contribution to pulsation at the headbox is 15%, while the pressure screen accounts for 38%.

Waterfall analysis is useful when the frequencies or amplitude in the high frequency spectrum are not constant. An example is when there are multiple rotating components operating at the same nominal rotational speed.