

Rubber calendering:

reducing manufacturing costs and improving quality

Improvements in calendering machines, materials and process control are benefitting the industry. Process control is bringing economic and quality benefits

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Beta gauges have been used in measurement and control for over 50 years, followed by gamma, X-ray, and lasers. First employed in the rubber calender industry back in the early 1970s, basic three-zone controls were used to flatten the sheet. Microprocessors came along and permitted faster signal processing, and PLCs were used as the interface to machine controllers. In the 1990s, the power, flexibility, speed and performance of the PC was unleashed, while communication links to off-line computers allowed more data management. The question today is, where is this technology taking us?

The objective of a rubber calender measurement and control system is to produce a flat sheet with a low spread. Spread is the standard deviation (sigma or σ) of the measurements usually expressed in terms of 2σ or 3σ . The spread of the calendered sheet is a function of variations of the product that develop from disturbances by the machine and by the process. These disturbances may be long-term (controllable by the system) or short-term (uncontrollable by the system).

A good measurement and control system will identify and interpret sources of product variations in order to maximize quality and minimize costs. In addition, the improved process visibility of a good system will assist the operator in taking control of the process.

Product variation is a function of four components. The first components are

cross direction (CD), which is an across-the-sheet profile, and machine direction (MD), which is downstream or calender to the windup direction. The third component is short-term (ST) – or uncontrollable variations – which are beyond the control of the measurement and control system. ST variations include roll run-out, bearings, temperature gradients, and roll-grind profiles.

Finally, long-term (LT) or controllable variations are within the capabilities of the measurement and control system. These variations include compound changes, gradual temperature changes due to warm up procedures, dynamics of the calender, cord changes, environmental changes, and speed changes.

Statistically this variation can be shown as:

$$3\sigma \text{ Total} = \sqrt{3\sigma^2 \text{MD}_{\text{ST}} + 3\sigma^2 \text{MD}_{\text{LT}} + 3\sigma^2 \text{CD}_{\text{ST}} + 3\sigma^2 \text{CD}_{\text{LT}}}$$

Total variation includes MD and CD components. MD refers to variation downstream, from the calender to the windup, measured in average values for a number of scans. CD refers to side-to-side variations, usually divided into two or three controllable zones.

A measurement and control system has the capability to control MD and CD variations. MD variations can be controlled by automatically adjusting the gaps of the calender; CD variations by automatically adjusting the gaps in concert with cross-axis or roll bending.

$$3\sigma \text{ Total} = \sqrt{3\sigma^2 \text{MD} + 3\sigma^2 \text{CD}}$$

MD and CD variations have controllable and uncontrollable components. Control capability is limited by the measurement system's ability to detect variations, and by the actuation device's (hydraulic cylinder or electric screwmotor) ability to act on the variation.

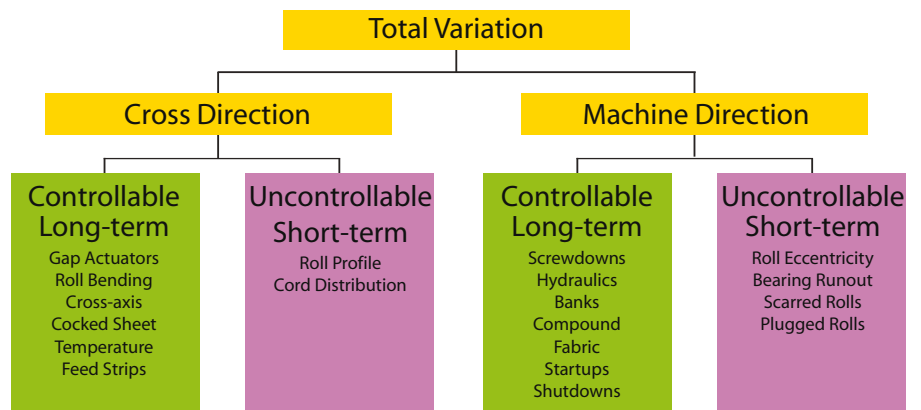


Figure 1: Several variations can develop from disturbances by the machine and process, both long- and short-term

Short-term variations (seconds) are caused by variations in the machine (speed, roll run-out, bearings and roll crown). Long-term variations (minutes to hours) are caused by process changes.

Short-term variations are characteristics of a line, defined by the ability of the measurement system to characterize process changes. Short-term can be five seconds with an effective measurement system, or two minutes with an unresponsive measurement system.

Long-term variations can result from random or repeating causes, including changes of the calender gap, compound and cord, stock temperature, speed changes, a loss of feed to the forming nip, or changes to a control component such as a sensor or actuator. Some variations can be eliminated, and most can be corrected through selection of sensors, controls, and machine maintenance and process operating procedures.

An effective measurement and control system allows its users to minimize the effects of process variations. The types of calenders, sensors and controls that lead to cost savings and quality improvement are shown in Figures 2 and 3.

Measurement of the process provides opportunity for improvement. Use of appropriate and repeatable sensors provides a statistical representation of the sheet. Accurate representation of the sheet also provides visibility for the operator to make good decisions for on-line quality control. In other words, operators can become quality managers. There are several major components of measurement and control.

Sensors include Beta (weight), Gamma (weight), X-ray (weight), laser (thickness), and CCD camera (width). Measurements include basis weight (grams per square meter, gsm), thickness (mm), wire cord count and position, width (meters), and speed (mpm). Processors include digital signal processors, central processors for measurements, controls, displays and communications, and process input and output processors.

Typical controls are three-zone profile controls, windup weight control, and automatic target optimization control.

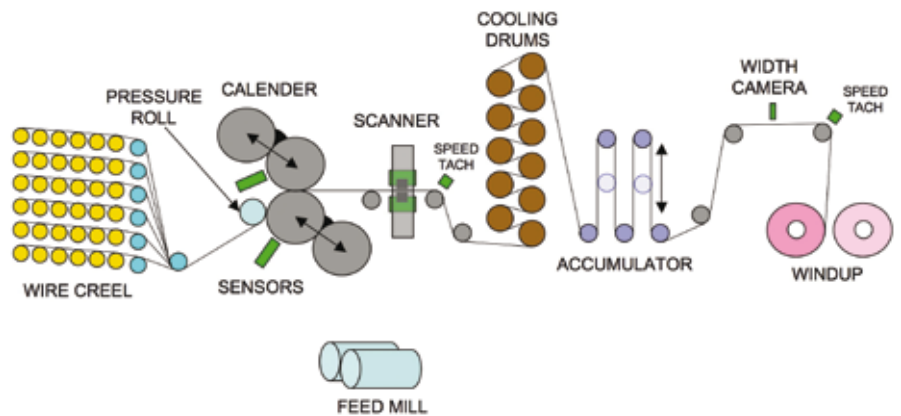


Figure 2: This wire (steel or metallic) calender setup can result in the effects of process variations being minimized

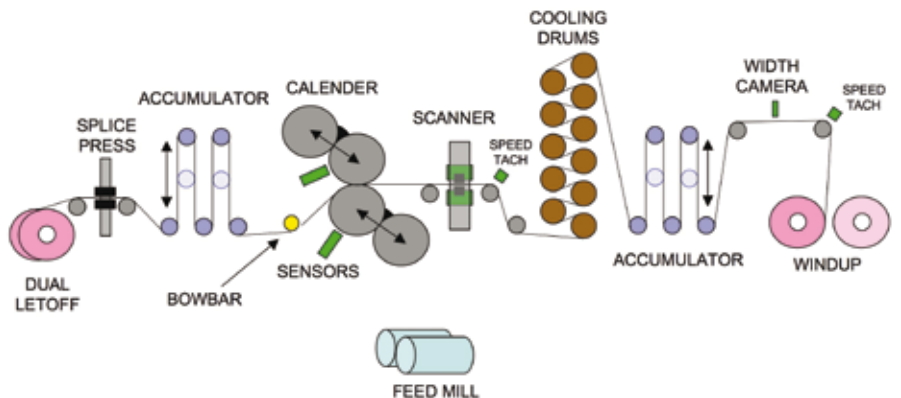


Figure 3: This textile (fabric) calender setup can also result in the effects of process variations being minimized

“An effective measurement and control system provides the opportunity to minimize effects of process variations”

Finally, displays and reports can be summaries of key process variables, high-resolution profiles, and management information summaries.

Wire (steel, metallic) and textile (fabric) calenders are best controlled by basis weight (grams per square meter) sensors because even though finished tire specifications are in dimensional units (mm), calendered sheets include trapped air or porosity. Porosity is variable but expelled at the curing press. Weight sensors measure only the rubber mass and not the porosity, whereas thickness sensors measure mass and porosity. Therefore, the best indicator of finished tire uniformity and mass distribution at the calender is a sensor that measures basis weight (gsm).

Either thickness or weight sensors can be used to measure gum or inner-liner calender sheets, but operators prefer thickness gauges because their specifications are in dimensional units (mm).

When measuring textile fabric products, the top/bottom ply balance is derived from on-the-calender weight measurements; therefore control is relative to the ratio of the specification weights minus the weight of the textile cord. The balance could change, however, after the material passes through the two or three squeeze rolls.

When measuring wire material, the top/bottom ply balance measurement is essential. Using backscatter sensors after the calender, one top and one bottom, control can be applied to correct the balance where it is important, after the material passes through the two or three squeeze rolls.

Three equal zones are measured every scan – left, center and right. With gap control, the left and right zones are modified by the water- and drive-side gap actuators – either electric screwmotor or hydraulic actuators. With crown control, the crown (center) is changed by either cross-axis or roll-bending

actuators. With sheet average control, the objective is to keep the average sheet on target, even after changes to either gap, cross-axis or roll-bending actuators.

Automatic target optimization (ATO) control compares the measured sheet to the specification target, and shifts the sheet average such that no material falls below the lower specification limit. The objective is to save raw materials.

Sheet dimensions can change between the calender and the windup, mainly due to sheet tension and shrinkage from cooling. Windup weight control is the ratio of sheet weight, speed and width at the scanner to the speed and width at the windup. Windup weight control is applied to the calender actuators to achieve correct sheet weight at the windup.

Having executed good measurement and control, results must be presented. To do this effectively, the information displayed should indicate accurate process values and material conformity to specification, operator display screens must be in clear and easy to understand terms, and standard communication links should allow users throughout the factory to see the process and trends in real time. Information gathering is easy. Getting it to the right people at the right time is paramount.

An effective measurement and control system can reduce total product variations by up to 50 percent. With reliable operation and proper training, a system can typically reduce raw material consumption and save up to US\$500,000 per year on a calender line that produces 25,000 meters per day.

“There is a good opportunity to reduce operating costs and improve quality by using on-line measurement and control”

There are tangible and intangible areas of improvement. Using an effective measurement and control system will reduce spreads, which in turn will allow for two major economic improvements: running the process on-specification, and reducing the target.

Some areas of economic improvement include raw material savings by running to specification. Calender operators have a tendency to run heavy and above specification, in order to avoid running light material below spec. If an operator has confidence in a measurement and

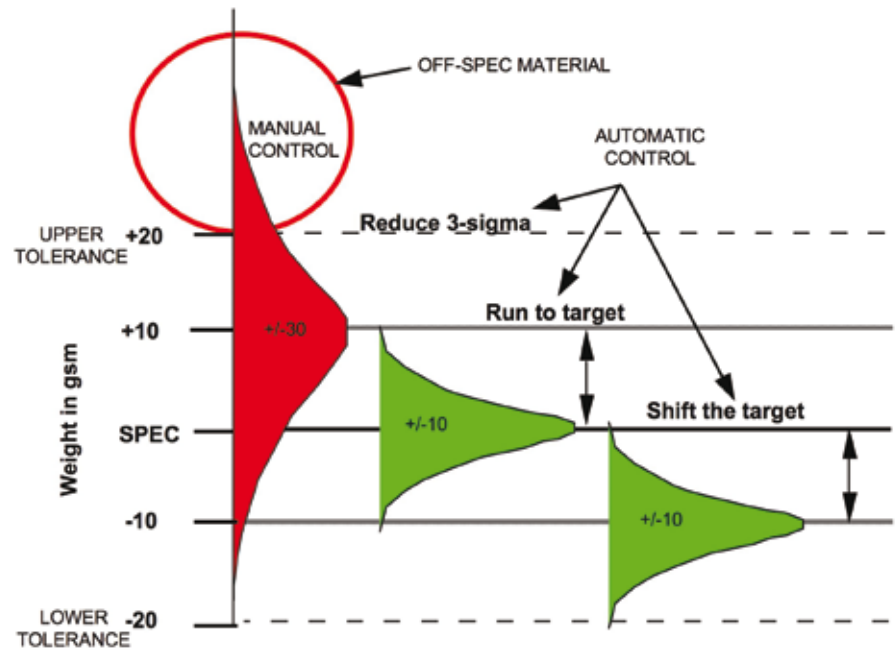


Figure 4: The target can be shifted to a new spec. In this diagram it is shown before and after automatic control

control system, he will be able to run on-spec, thus avoiding heavy material. The operator will have confidence in the system if it responds to process upsets while maintaining low spreads and no deviation from target.

After gaining confidence that the system can hold the average to spec without violating the lower tolerance, the next opportunity is to shift the target to a new spec, either manually or automatically, without violating lower tolerance. Figure 4 shows an example, before and after automatic control:

When a calender first starts, the machine is cold, the stock from the warm-up feed mills may not have reached optimum temperature, and the bearing

lubricant is cold. The process does not react predictably until equilibrium is reached, which usually takes 15 to 20 minutes. During this start-up period, it is difficult to produce material that is on-spec. However, with the proper selection of sensors on the calender rolls, start-up scrap can be minimized. The same problems occur when the calender is slowed or stopped.

Calender operating costs may be reduced if the operator is permitted the opportunity to produce it right the first time. In addition, the plant floor

space required to store off-spec material is reduced.

Reductions are also possible in calender operating time, bringing a reduction in utilities (electric, water, air), variable labor, and machine wear.

Intangible improvements are more difficult to quantify. Possibilities include reduction in frequency of calender slowdowns due to operator confidence in the measurement and control system, and cost avoidance of material returned from downstream processes.

Thus there is a very good opportunity to reduce operating costs and improve quality standards throughout the entire rubber calendaring process by means of on-line measurement and control.

The keys to success and results are accurate and reliable measurement of the calendered sheet, identification and interpretation of sources of sheet variations, an effective control solution, a reduction in variations, shifting the target to lower raw material consumption, and getting the right information to the right people at the right time.

Typically the return on investment of an effective measurement and control system is about one year, and in some cases sooner.

As tire manufacturing becomes more global, there is greater need to look for ways to reduce costs and improve quality to become more competitive. Evaluating the opportunities using a reliable on-line measurement and control system in the rubber calendaring process represents a good opportunity. **tire**