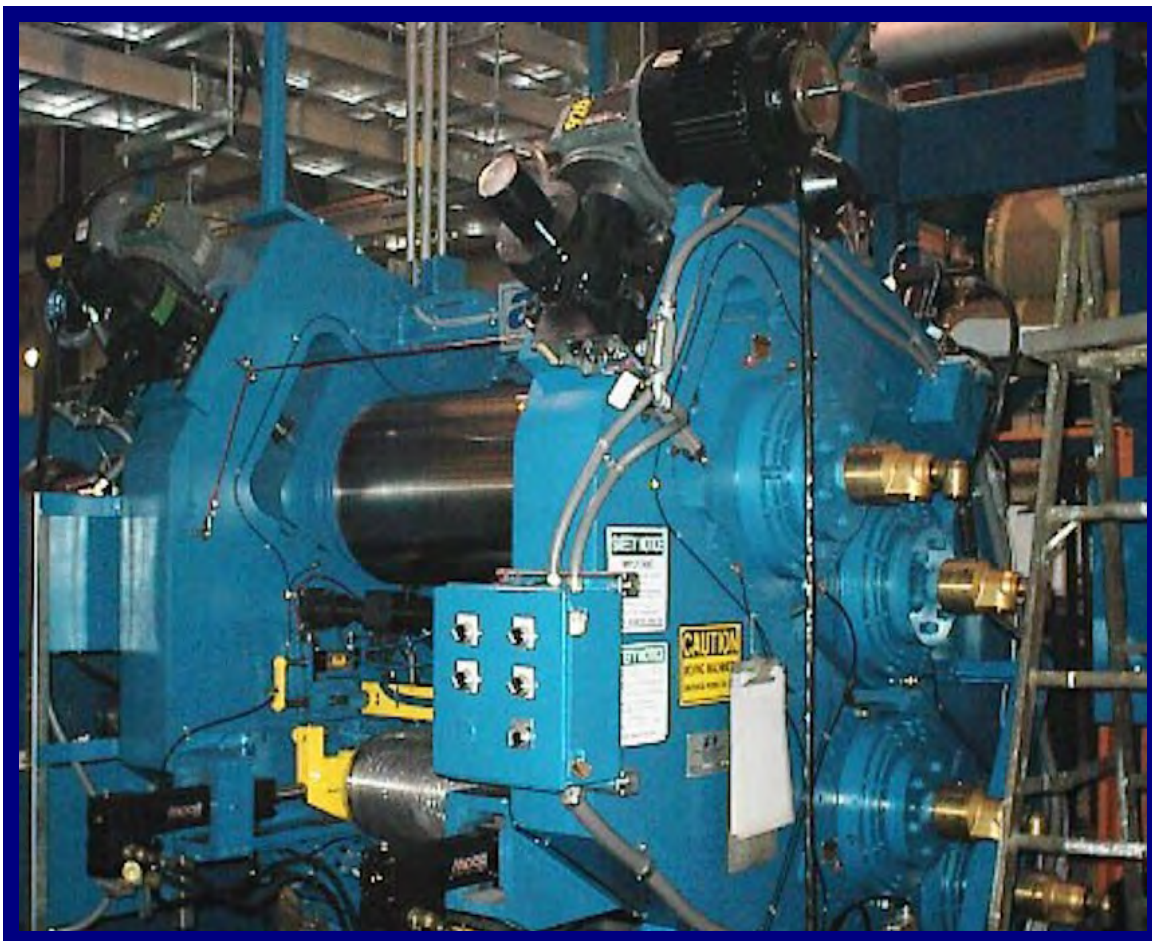


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Calender Process Control: An Opportunity for Dramatic Material Savings and Improved Quality

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Calender Process Control: An Opportunity for Dramatic Material Savings and Improved Quality

Introduction

How to achieve tighter control and reduced calendered gauge variations.

1. Start with an accurate measurement with the shortest lag time to permit fast, frequent control updates.
2. Recognize all the issues that affect the measurement, the process, and the product.
3. Follow proper operational practices and procedures to minimize process up sets. A stable process results in reduced gauge variations.
4. Maintain the calender and line equipment, and check it regularly for proper operation
5. Implement an On Going Quality Assurance Program

Measurement Techniques

Measurement techniques can be broken into two categories each with two approaches or location:

1. Category of Measurement (measurement basis)
 - Thickness
 - Square Yard Weight
2. Location of Measurement
 - On Calender
 - Post Calender

The selection of the basis of the measurement and its location will have a great deal of influence on the degree of control that can be achieved. Each has advantages and disadvantages and a number of factors must be considered before making a decision.

We will first consider the selection of thickness or square yard weight as the basis of measuring gauge. It should be noted that normally the type and location of measurement must be considered together.

Measurement Basis

Square yard weight or basis weight was the traditional measurement scheme. This approach involves the use of either nuclear transmission or backscatter gauges. Transmission gauges such as the Eurotherm gauges shown in Figures 1 & 2 below, have a source on one side of the product to be measured and a detector on the opposite side. The detector measures the amount of energy absorbed by the fabric or gum rubber between the source and detector. A scanner is typically used to traverse the source and detector across the sheet as shown but fixed point gauges could be utilized instead.

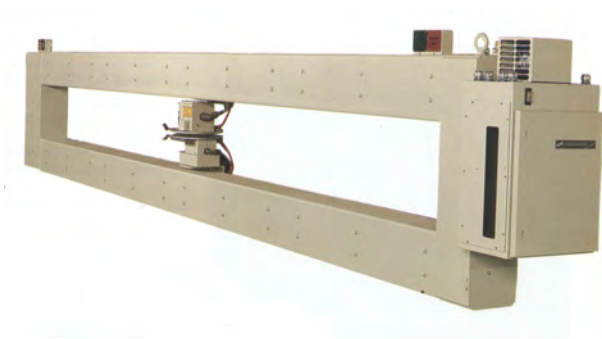


Figure 1. Eurotherm 'O' Frame with Transmission Gauge

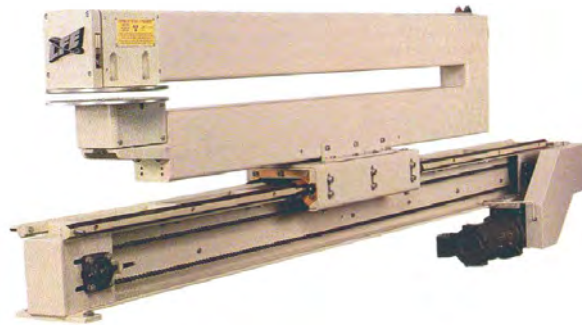


Figure 2. Eurotherm 'C' Frame with Transmission Gauge

The scanner configuration for a transmission gauge is available in both 'C' frame and 'O' frame configurations. The 'O' frame has become more common since it requires less space to the side of the product pass line and can measure wider product widths. The 'C' frame configuration generally has a lower cost and is more robust. It is most frequently utilized on lines running narrow products or in severe environments since it has half the moving parts and may be protected more easily.

Backscatter gauges measure the amount of energy scattered back by the product to be measured and thus need access to only one side of the product. With appropriate calibration they can be used to measure calendered fabric or gum with or without a roll on the opposite side. A typical fixed position Backscatter Gauge system with 3 Heads is shown in Figure 3.

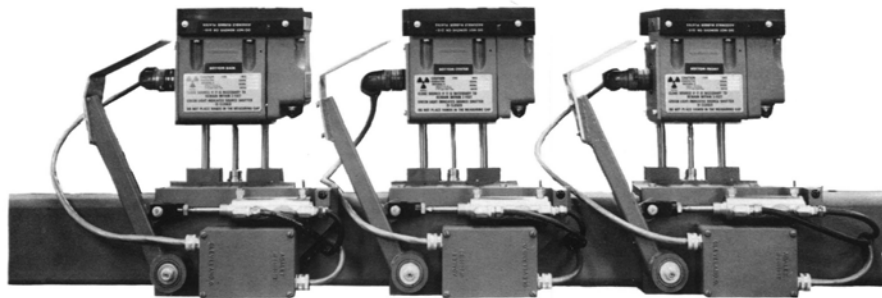


Figure 3. Eurotherm Fixed Position Backscatter Gauges

Nuclear transmission and backscatter gauges measure the mass of the target and are calibrated to report pounds per square yard or grams per square meter.

The thickness measurements may be made by several different technologies, either individually or in combination:

- Eddy current displacement
- Laser displacement
- Capacitive Displacement
- Ultrasonic Displacement

Eddy current transducers can only sense conductive materials or targets such as the surface of a steel calender or reference roll. Rubber, paper, or plastic are not conductive and therefore are not sensed by an Eddy current sensor. Eddy current sensors therefore incorporate a second reference such as a laser or contact method such as a rolling wheel on the surface of the calendered fabric or rubber gum wall to be measured. An example of a precision Eddy Current based system is the **FACTS** On-Cal 1 Sensor shown in Figures 4 & 5:



Figure 4. **FACTS** On-Cal 1 Precision Thickness Gauge



Figure 5. **FACTS** On-Cal 1 Gauge with Mount

The On-Cal 1 is calibrated for zero with no rubber under the gauge. The wheels ride on the rubber gum wall surface and lift the eddy current sensor away from the roll surface. The eddy current sensor precisely measures the distance to the calender roll surface, which corresponds to the thickness of the rubber gum wall.

Laser Displacement sensors work on the basis of triangulation to determine the distance between the source/detector to the surface of the target material to be measured as shown in Figure 6.

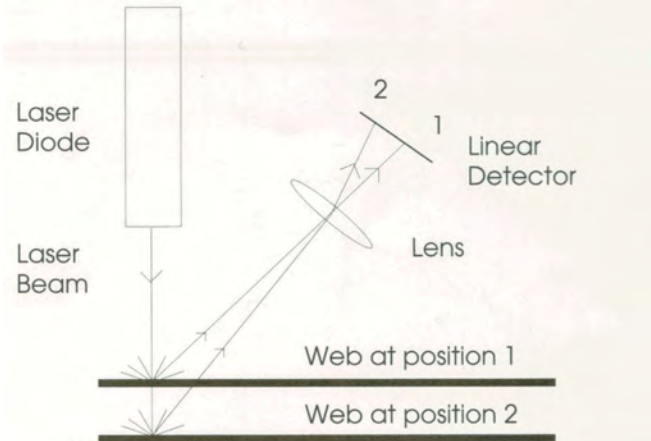


Figure 6. Principal of Laser Triangulation

Measurement of the distance to the surface of the rubber with respect to the surface of a fixed roll is the simplest approach. This approach has limited accuracy and many factors such as temperature affect the position of the Laser transducer with respect to the reference roll. Run-out of the reference roll also directly contributes to measurement error. If mounted on the calender and the calender roll serves as the reference roll, frame stretch will also introduce significant errors. For those reasons Laser Displacement sensors are normally used in conjunction with another sensor technology, such as an Eddy Current sensor, which measures the position of the sensor relative to the reference surface as shown in Figures 7 & 8 below.

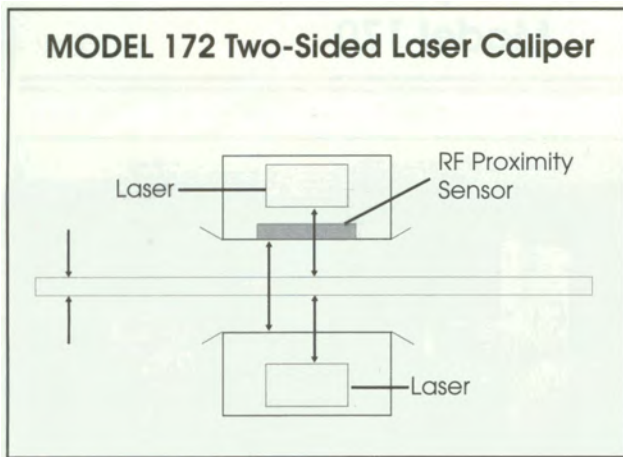


Figure 7. 2 Sided Laser Caliper

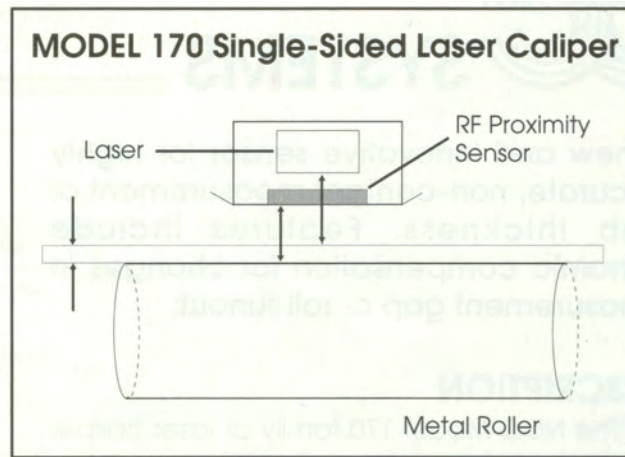
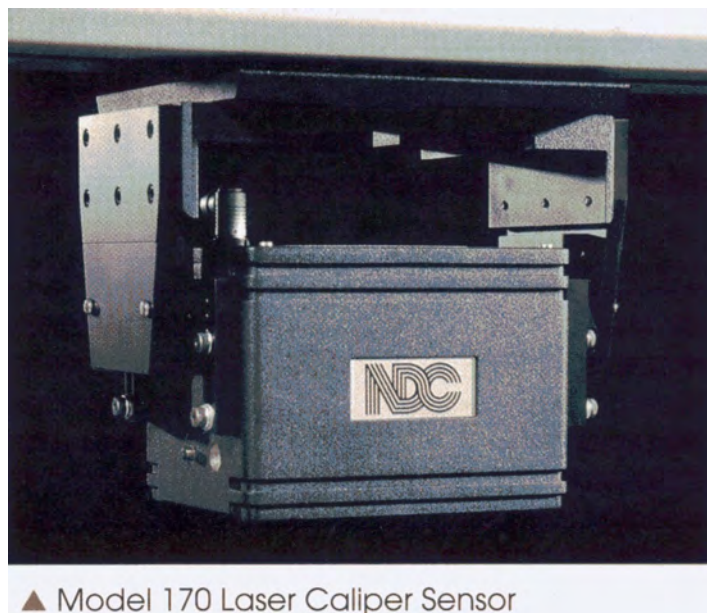


Figure 8. Laser Caliper with Reference Roll

The rubber thickness is therefore the difference of the two measurements, with the Laser measuring the distance to the top rubber surface and the eddy current sensor measuring the distance to the reference roll surface, which is the bottom surface of the calendered rubber. The combination gauge is therefore independent of roll run-out. An example of such a transducer is the NDC Laser Gauge shown in Figure 9.



▲ Model 170 Laser Caliper Sensor

Figure 9. NDC Laser Caliper

Capacitive transducers could be utilized in place of laser displacement sensors but are neither as stable nor as accurate and thus are not utilized for absolute thickness measurement in calendaring applications. However, capacitive sensors have been successfully utilized to make relative displacement measurements for applications such as run-out measurement for cured tires.

Ultrasonic transducers are not sufficiently accurate in air coupled applications and hence are not usable for calender thickness measurement. When water coupled, which is not practical in calendaring applications, 5 Mhz to 10 Mhz high frequency ultrasonic transducers are able to accurately measure the wall thickness of extruded medical tubing or the insulation thickness of electrical wire.

Air caliper thickness gauges that float on a cushion of air above the moving fabric use an eddy current style sensor to reference the opposing floating plate below the fabric to determine the fabric thickness. This style sensor is typically scanned across the moving web to measure the web thickness. This technology is not normally used in rubber applications due to the tacky nature of rubber fabric. Incidental contact with the sensor, which inevitably happens, would grab the sensor and cause damage to the whole scanning mechanism.

Thickness vs. Square Yard Weight

Thickness is commonly used as the final check of calendered gum but is not a reliable measurement of assembled fabric since it is affected by the amount of squeeze and hence varying cord penetration during the assembly operation. Additionally, manual thickness measurements using a snap gauge are subject to operator induced variability. For these reasons most tire company production specifications use square yard weight as the final basis, rather than thickness for calendered fabric. Gum walls on the calender, on the other hand, are normally checked for thickness using a manual snap gauge since it is less practical to die out precision samples for routine operator gum gauge checks.

Continuous automated gauge measurement based on the previously discussed technologies involves additional considerations. Nuclear transmission and backscatter transducers are sensitive to compound variations, particularly to variations in ingredients with higher molecular weights. Nuclear gauges must therefore be calibrated for the specific compound. This sensitivity to compound variation, their physical size, plus the slower response and obvious issues involved in having nuclear sources in close proximity to where the operator must work, have lead to the general use of thickness measurement for "on-calender" measurements.

Scanning measurements of the assembled fabric are generally made using nuclear transmission or backscatter gauges since thickness is not as meaningful a measurement for assembled fabric as previously discussed.

On-Calender vs. Post Calender Measurement

Measurement of the gauge directly on the calender has several advantages:

- Measurement is much closer to the calender nip and permits much faster response by the control system
- Measurement can differentiate between rubber layers since each layer is measured individually
- Measurement is not influenced by textile or steel cord

The disadvantages of On-Calender measurement

- More severe environment – the gauges are subject to higher temperatures, out gassing from the rubber, rubber bits and pieces can cover the gauge
- Subject to serious damage if the calender is reversed too far prior to removal of the rubber bank
- It is sometimes not possible to find suitable locations to mount gauges on the calender, particularly on multipurpose calendars that may have several gum and/or fabric pass lines, depending on the product being run.

Post calender measurement advantages

- Provides overall mass profile of the final product if used with an understanding of how cord count will influence the measurement.
- May be the only alternative if calender configuration does not permit on calender measurement

The disadvantages of post calender measurement

- Nuclear scanners can not differentiate between fabric cord and rubber. Cord count will therefore influence the measurement and when using the scanner for control will lead to filling in low cord count areas with excess rubber and causing reduced rubber gauge in high cord count areas.
- Scanning gauges must have sensors and interlocks to prevent loose rubber, fabric, or cords from snagging the head and causing damage to the scanner.
- The lag time introduced by the distance from the calender nips, time delay due to the nature of scanning from side to side, plus the slower response time of the nuclear sensors results in infrequent control updates. This is particularly noticeable during dynamic conditions when frequent control updates are needed such as during start-up and speed changes.

The 'Best of All Worlds' approach is to have both 'on-calender' and 'post calender' measurements. This gives the fast response from the 'on calender' gauges for optimized control, along with the benefits of an overall profile view from the scanner system. This is obviously also the most costly approach. When both systems can not be justified and one approach must be selected, 'on calender' gauges provide the best solution. The accuracy is equal or better and the faster response provides a significant improvement in gauge control.

Wire cord calendars present additional difficulties and opportunities in post calender profile measurement. The wire makes a single transmission or backscatter measurement relatively meaningless. To measure the balance and total gum weight it is necessary to use multiple heads on a common scanner. A detailed discussion is beyond the scope of this paper but the basic approach consists of a Gamma backscatter gauge on each side of the web to measure the gum weight on each side of the wire. This provides balance as well as an estimate of total gum weight and wire weight. The increased complexity of these scanners makes them more expensive to purchase as well as more expensive to maintain. Since newer 'on calender' gauges are more accurate than a scanner in the measurement of the gum wall, many companies are electing to eliminate the scanner systems on wire calendars.

Issues that Affect Calendered Gauge and the Ability to Control Gauge

The gauge control system is limited in its ability to control gauge by the condition of the calender and by operator technique. The following is a very brief outline of the issues that affect gauge during normal operations. An expanded discussion is available on the **FACTS, Inc.** web site www.facts-inc.com under 'White Papers'

There are two principal sources of variations in calendered gauge or thickness. These are:

- Mechanical induced variations
- Force induced variations

These two sources of variations are closely related. For purposes of this discussion, mechanical induced variations will be classified as those that are present at ambient condition with the calender not operating under load. Force induced variations will be classified as those that are induced by the way the calender is operated or by the proceeding process steps.

Mechanically Induced Variations

Mechanically induced variations relate directly to the calendars mechanical condition and are thus basically a maintenance issue. While there are many maintenance issues that affect calender performance, the following are the main items that directly affect calendered gauge:

- Calender Roll grind profile
- Calender Roll eccentricity or run-out at ambient temperature
- Bearing condition
- Roll water passage condition
- Roll end actuator condition

Calender Roll Grind Profile

The calender rolls must be ground periodically to establish the proper profile. The profile is selected so that the roll separating forces, which cause the rolls to bow apart in the center, are partially compensated for by grinding the center to a larger diameter. If the grind profile is incorrect it will be difficult or even impossible to achieve a flat calendered rubber profile.

Calender Roll Eccentricity

Calender rolls must be round and free of run-out at ambient temperature. Any run-out of the individual calender rolls will be amplified as the high spots and low spots periodically match up between the roll pairs.

Bearing Condition

Calender roll bearings may also have excessive run-out. The result is the same as, and will appear as, calender roll surface run-out. Excessive bearing clearance will result in the roll shifting during operation as roll separating forces vary.

Roll Water Passage Condition

Most modern calender rolls are the drilled type. This means that water passages are drilled across the roll face under the surface. This effectively forms a radiator-like heat exchanger around the periphery of the roll. If these passages become plugged, then non-uniform heat transfer will occur and this results in a thermal 'out-of-round' condition for the roll or rolls.

Roll End Actuator Condition

Electric screw actuators are the most common type of calender roll end positioning system. The screw and nut operate under very high loads and thus experience significant wear even with proper lubrication. As the actuators wear, back lash develops. As the back lash increases, the response to small changes or corrections deteriorates. The brakes on the screw motors must also be in good working condition.

Force Induced Variations

Force induced variations result from the way the calender is operated and from previous processing steps such as feed mill operation and from compound variations from the mixing process.

The separating forces generated during calendering are quite high; typically 160,000 lbs to 300,000 lbs at each actuator for a 66 inch active roll face producing a 60 inch wide rubber sheet. Those forces literally stretch the calender frame. Variations in these forces will therefore vary the amount of frame stretch and thus vary roll position and calendered gauge.

Force Induced Variations – The key points

- Keep the calender running – stops cause the rolls to become egg shaped and introduce significant gauge thickness variation.
- Keep the calender running during warm-up and cool-down.
- Minimize speed changes.
- Mill management - be consistent

Keep the calender running

When the calender is stopped, roll heat loss is not uniform around the roll. Heat loss along the circumference near adjacent rolls is minimal while heat loss in other areas is much higher. This leads to different temperatures and therefore different degrees of roll expansion. A few degrees on a 24" to 30" diameter will result in measurable "out-of-roundness" of each roll. This is true when the calender is empty but even more so when there is a hot bank of rubber between the rolls. The longer the calender is stopped the worse the condition.

Since the rolls run at different speeds, periodically the high spots match up resulting in thin gauge spots. When the low spots match up a thick spot results. This results in an effective doubling of any roll "out-of-round" or run-out error.

Typical short-term thermal out-of-round gauge variations are plus or minus .5 mils (.0005") to 2 mils (.002"). Thermal run-out is gradually reduced as the calender runs, but takes 15 to 25 minutes to be eliminated. To minimize "thermal run-out" the following procedures are recommended:

- Minimize calender stops
- When the calender is being stopped for more than a very brief time, remove the rubber from the banks. This is considered good practice anyway for the rubber compound.
- On gum calendars always keep the calender running when there is no rubber on it
- On textile calendars or on any calender when leader is going through the calender, dropping off tension and allowing the uncoated fabric (advance the calender 18" if necessary) or leader to go slack will permit running the calender during delays and personnel breaks. This will dramatically reduce thermal run-out.

Keep the calender running during warm-up and cool-down.

Severe thermal run-out can be introduced during warm-up of the calender if it is not kept running. Keeping the calender rolls turning during warm-up and cool down also minimizes the possibility of warping the rolls.

Speed Changes

Changes in calender speed result in gum wall thickness changes that are undesirable.

When the calender is running there are forces generated that try to separate the rolls. These separating forces are proportional to calender speed, although the relationship is not linear. The hardness of the rubber stock and bank temperature determines the magnitude of the separating forces. The thickness of the gum wall being calendered also affects the separating force, with thinner gum walls generating larger separating forces.

A speed change of 40 ypm (yards per minute) can result in a gauge change of as much as 2 mils (.002"). Different calendars have different degrees of frame stiffness, so the magnitude of the gauge change for a given speed change will vary accordingly.

Mill Management

A consistent feed to the calender will substantially reduce gauge variations. Consistent, uniform, dwell times on the break down and feed mills, as well as consistent bank size, will result in consistent stock temperatures, work history, and reduced variations in roll separating forces. The stock temperatures, bank sizes, and work history all directly influence roll-separating forces. Minimizing variations in these 3 important process parameters will minimize variations in roll separating forces, and this in turn will minimize gauge variations. Good mill and bank control practice also results in improved uniformity for other calendered gum and/or fabric properties.

Poor mill management by the calender crew also often necessitates frequent calender speed changes which produces additional gauge variations.

Good calender gauge control requires both proper maintenance of the calender and good operational practices. Educating the operational personnel in the effects related to these issues can go a long way towards achieving improved gauge control.

On Going Quality Assurance Program

The proposed program consists of two parts:

- Add an Electronic weight scale and check single sample at the end of every calendered roll
- Establish a periodic sampling program to monitor calender performance

As a check on calender performance and variations introduced by post calender operations such as tension, speed, and width control systems, it is suggested that a weight sample be taken at the end of each roll. An electronic weight scale can be tied into the gauging system to log and save the results in a database. With the proper equipment the additional work load for the operator is minimal and a history of verified calender performance is generated. Any problems with the gauging system or post calender systems will be promptly detected. This is more critical and most practical for textile and steel cord fabric calendars.

Periodically, monthly is the suggested minimum, a set of 3 or 5 samples across the sheet at the end of each of 10 rolls for each calender code should be taken and evaluated. These data points should become part of a database to track calender performance and detect any problems or trends early.

Realizing Significant Material Savings & Improved Quality

The objective of any gauge control system is to center the average gauge at the specification set point and to narrow the gauge variations or distribution about the average. The distribution of gauge, or the variation around the mean, corresponds to a normal curve. A normal curve defines the % of the readings that will fall at any given distance from the mean. Figure 9 shows the relationships defined by a Normal Curve.

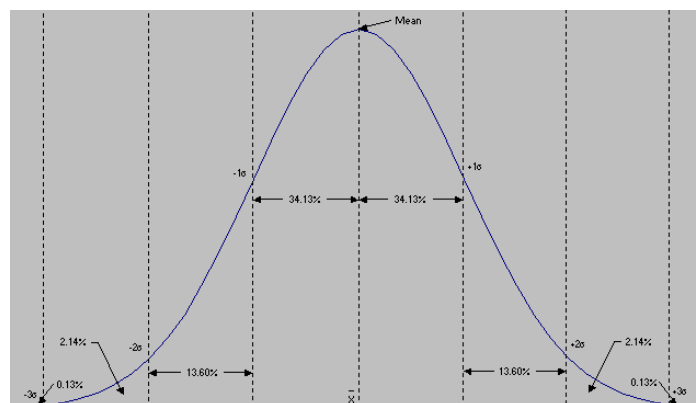


Figure 10. Normal Curve

Note that

- ±1 σ corresponds to 68.26 % of all readings
- ±2 σ corresponds to 95.44 % of all readings
- ±3 σ corresponds to 99.73 % of all readings

Figures 11 & 12 demonstrate the type of improvement provided by the gauge control system.

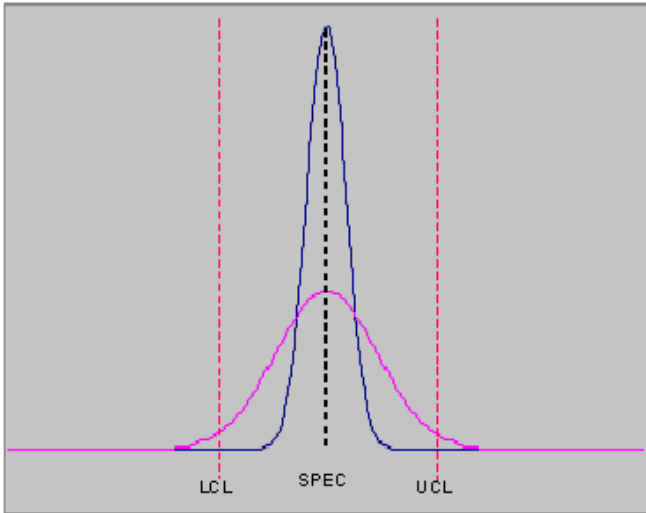


Figure 11. Gauge Distribution with & without Gauge Control

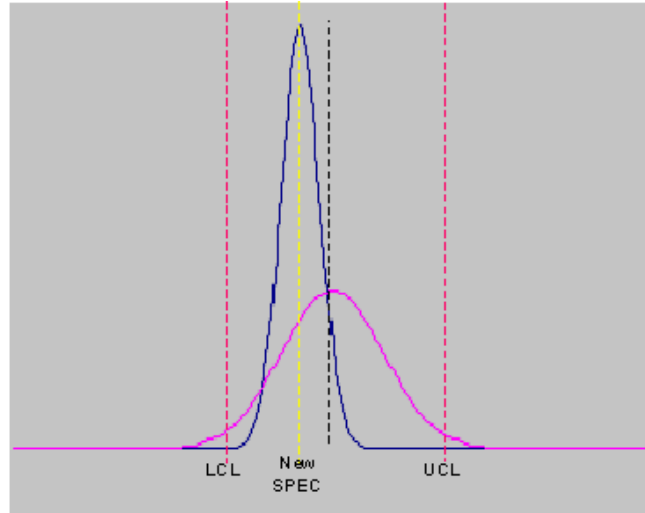


Figure 12. Gauge Distribution with Target Shifted

Where: **Red** represents the distribution without Gauge Control
Blue represents the reduced distribution with Gauge Control

This is a normal curve and represents the statistical distribution of gauge readings with and without gauge control.

The principal basis for cost reduction and savings is the ability to reduce the distribution (blue versus red in graphic) and then save material by taking a small shift of the spec, based on a continuous real time calculation. Figure 12 on the right demonstrates there is reduced risk of the product being out of specification, a narrower distribution for more consistent quality, and significant material savings.

The shifting can be either a fixed amount (static) based on the reduced gauge variation, or dynamic. Dynamically shifting the target is done under computer control and adheres to a specific set of rules. The control system constantly calculates the gauge distribution and adjusts the shift up or down depending on current results. The customer specifies the maximum shift, a lower boundary that must not be exceeded, and the degree of aggressiveness. This allows more aggressive shifting for greater savings but still maintains the reduced risk of exceeding the specification since it is based on current running conditions. This approach provides significant material savings and improved quality.

The following is a typical example

Conditions:

- 4 Roll Z Calender with well maintained older gauge control system
- Production of 63,000 yards/day at nominal 57" width, 6 days/week, 50 weeks/year
- Results from Test Sampling Program before replacing the gauge control system:
 - Total Standard Deviation or 1σ Total = .057 lbs./sq. yd.
 - σ LTMD= .042 lbs./sq. yd. Long Term Machine Direction σ
 - σ STMD = .023 lbs./sq. yd. Short Term Machine Direction σ
 - σ CD = .026 lbs./sq. yd. Total Cross Direction σ
 - Only total cross direction data was available in this study

Where

$$\sigma_{Total} = \sqrt{\sigma_{LTMD}^2 + \sigma_{STMD}^2 + \sigma_{CD}^2}$$

Note that Short Term variations can not be corrected by the gauge control system.

Results after replacing the Gauge Control System:

- Reduced Total σ CD by 20%
- Reduced LTMD σ by 30%
- Revised σ Total = 0.44 lbs./sq. yd.

Overall Reduction in σ = .013 lbs./sq. yd. (.057 - .044)

Savings:

Taking 2 sigma of the reduction as a target shift uses only 67% of the reduced variation, thus running within a tighter range than before and achieving substantial material savings. In this example $2\sigma = 2 \times .013$ lbs./sq. yd. = .026 lbs./sq. yd.

Savings = .026 lbs./sq. yd. x (57/36 x 63,000) sq. yds. per day = 2,593 lbs./day

At a rubber cost of \$.50/ pound, the savings are \$ 1,296 per day or \$ 389,000/year

Results for a calender without a fully functional control system would be even more dramatic.

Remember that the actual results are determined by the capability of the gauge control system, condition of the calender and calender line, and operational practices as previously discussed.

Conclusion

The condition of the calender often determines the limit of the improvement of the final gauge distribution but does not normally prevent a new modern gauge control system from providing a substantial reduction in gauge distribution over an existing system or for a calender with no gauge control. In many cases a new system with small gauges located on the calender is even more effective compared to older systems on a calender that is in sub par condition. The gauge control system can not eliminate short term variations that are mechanically induced but a properly designed system can still provide improved control under these conditions.

Eliminating or reducing short term mechanically induced variations with the proper maintenance will allow the system to further reduce the gauge distribution thus providing further material savings opportunities. It is therefore financially desirable to maintain the calender rolls, bearings, and actuators in good condition, but it is not a prerequisite to justify the installation of a new gauge control system. In fact, delaying the purchase of the gauge control system until the calender is refurbished or upgraded is usually a poor financial decision since substantial material savings will be lost during the delay. Given the rapid payback of a modern new system, the lost savings during such a delay would have paid for the whole system and provided improved quality at the same time.

By following the six points presented in this paper it is possible to save thousands of dollars per day while at the same time significantly improving the quality of calendered fabric and gum components.

These six points were:

1. Start with an accurate measurement
2. Recognize the limitations of the measurement systems
3. Implement an appropriate gauge control system
4. Follow proper operational procedures
5. Maintain the calender properly
6. Implement an on going quality assurance program