Roller Wave Distortion – Definition, Causes and a Novel Approach to Accurate, On-line Measurement

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3 = Heat treatment 4 = On-line inspection

Abstract

Roller wave distortion in heat-treated glass results in customer complaints and lost product. Roll distortion is defined in peak-to-valley measurement terms and related to optical distortion as seen by the customer. A technique is described to accurately measure roll distortion using on-line optical methods. Feedback to furnace operators has resulted in dramatic improvements in product quality.

Introduction

The market for heat-treated glass is growing. In North America, the demand for heat-treated products grew 5% in 2000. New applications for heat strengthened and tempered glass offer growth opportunities for glass fabricators. Post-temperable low-E coatings allow fabricators to respond rapidly to customer requirements. Demand is growing for laminated glass applications requiring heat-strengthened lites for one or more elements. Hurricane glass is one of the fastest growing products in North America. Acoustical glazing demand is rising in Europe and Asia, and the demand for security glass is growing worldwide.

Customers of heat-treated glass require "distortion-free" products, particularly for insulated and laminated windows. The US, ASTM C 1048 is undergoing revision to quantify roll-wave distortion in heat-treated glass. UK industry standards are moving in a similar direction. As the glass industry pursues advanced applications, quality requirements rise. Historically, the demand for improved quality has driven industry toward improvements in performance. Improved quality benefits our customers and ultimately increases profitability.

High-quality, low-distortion, heat-treated glass can be consistently manufactured using on-line measurement of roll distortion.

The Main text

A new technology has been developed to measure roll wave distortion on-line as glass conveys out of a tempering furnace. The new system measures every lite exiting the furnace while the glass moves at normal conveyor velocity. The system mounts over existing conveyors. Roll distortion is displayed to operators as peak-to-valley measurements. The measurements are stored in a quality control database for later review and analysis. These systems are being installed today and are rapidly changing the quality paradigm for heat-treated glass.

As the demand for heat-treated products grows, a complementary trend is toward more stringent flatness requirements. Architects and end users frequently demand products free of visual distortion. Laminated products require a prescribed flatness for manufacturing. 3 mm and 4 mm glass is often desired but not available for these markets due to difficulty in controlling distortion. New applications are requesting 3mm and 4mm glass to be heat-treated and distortion-free.

These market dynamics offer both opportunity and challenge. Thin, flat product applications are generally early in their life cycle. They typically bring higher margins. The challenge is to produce thinner, heat-treated glass with low distortion on existing furnaces. This new on-line roll wave distortion measurement technology empowers the fabricator to meet and exceed the new market expectations.

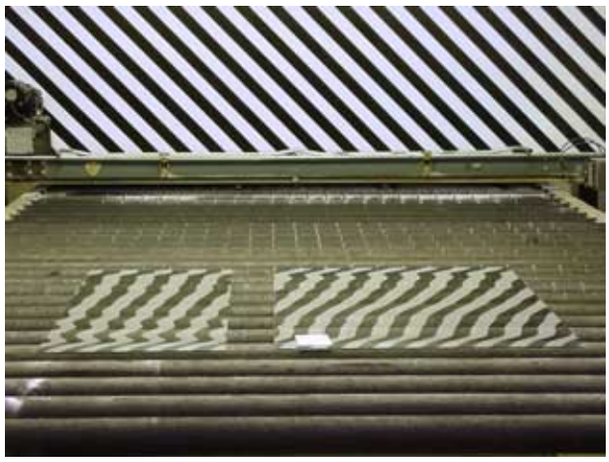

Figure 1: A View of Glass Sheets in Front of a Zebra Board

What Is Roll Distortion?

Roll distortion is the periodic wave imparted to glass during heat-treatment. It is measured by the industry in peak-to-valley distance. The customer perceives role distortion as optical distortion in reflection or transmission in the finished window. Roll distortion is the transition of flat glass into a lens. The severity of the lens radius defines the lens power of the curved glass and therefore the optical distortion in the resultant glass.

In theory, heat treatment requires uniform heating of the glass to 621 +/- 3 deg C, while holding the glass in a flat state. Heat and quench uniformity are difficult to maintain with varying conditions. The glass softens to a taffy-like consistency as it approaches the critical temperature. Although the furnace is designed to control thermodynamic conditions, variations are difficult to eliminate. Any roll eccentricity imparts deformation to the glass. The leading and trailing edges of each lite form a cantilever as the glass leaves a roll. The glass sags under this load. Overheating causes sag between the rollers. Uneven heating and inconsistent loading exacerbate the problems due to hot spots in the furnace. In a perfect world, precisely enough heat is added to relieve stress without making the glass too soft. In reality, critical variables such as glass type, glass thickness, coatings, furnace temperature, atmospheric temperature, ambient humidity and personnel constantly vary.

To the trained eye of the customer, roll distortion in heat-treated glass is observed as a distorted reflected image in the final IG installation or as a distorted transmitted image in a laminate. The most expensive point to find the distorted window is upon installation! This ‘fun house’ distorted image is no ‘fun” when the glass has reached its full value and the customer demands replacement.

In laminated products roll distortions cause

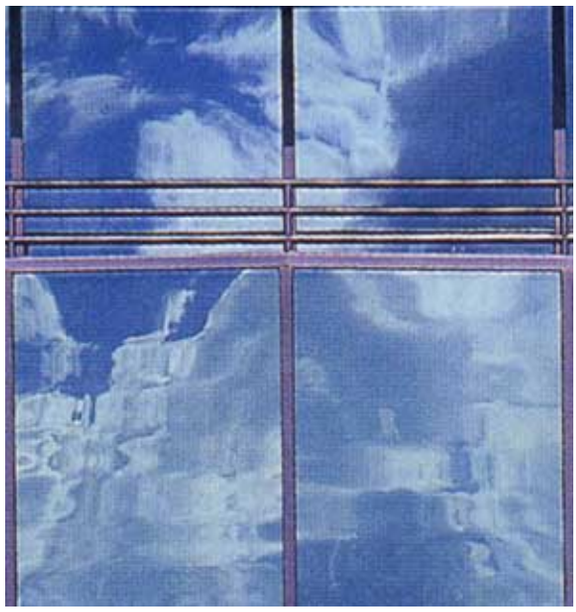

Figure 2: Architectural example of Optical Roll Distortion in Heat-Treated IG

fabrication difficulties. Distortion in one or both lites to be laminated leave voids which are filled with flowing interlayer. The result is a lens affect and visible distortion most evident in transmission. The problem often discourages the use of 3mm glass for lamination.

Figure 3: Architectural example of Optical Roll Distortion in Laminated Window

The ‘Old’ Way to Measure Roll Distortion

Although awareness of roll distortion has increased and demand for improved quality grows, the measurement technique for glass flatness is the same today as thirty years ago. Flatness is still monitored on-line using a ‘zebra’ board. Roll distortion is seen as waviness in the reflected image of the zebra stripes. While a skilled furnace operator may effectively expose process problems with the zebra board, the

method has weaknesses. Observations are subjective and inconsistent, measurements are not quantifiable and no permanent, traceable record is created. Architects are specifying “no distortion” in windows due the lack of quantifiable standards. Subjective measurements invite problem when the product reaches the customer.

The standard off-line method uses a flat-bottom ‘GAR’ gauge. This tool is a flat steel bar, 300 mm (12-inches) long with a dial indicator gauge mounted in the center of the bar. With this method, a sheet of glass is brought to a flat surface, preferably a granite table, and the operator drags the gauge over the surface of the glass while recording the results. The dial indicator in units of 0.025 mm (0.001 inches) measures roll distortions as the gauge moves over peaks and valleys on the glass. The disadvantages of this method include;

- The requirement for a separate, off line, step in the process.
- Handling and measurement may scratch the glass in a destructive manner.
- The operator must be trained and meticulous. The human interface element is inconsistent even with good training.
- An unacceptably small sample of production is measured. The frequency of sampling is far less then the frequency of variation in process conditions and product. The furnace conditions change much more rapidly than one can make off-line gauge measurements.

A New Way to Measure Roll Distortion

The LiteSentry_ Roll Distortion Measurement System dramatically improves glass flatness measurement techniques. With this new device, all glass is measured on-line without operator intervention and all data is recorded. The system implements machine vision technology along with a novel optics design (patent pending) to solve problems that frustrated past solution attempts.

The system offers many benefits, including-

True on-line measurement. The leading edge, central area and trailing edge of each sheet exiting the tempering furnace are measured. Roller wave peak-to-valley values are displayed for each part of each sheet.

Operation occurs at normal exit conveyor velocity. Throughput is not compromised for measurement. In fact, throughput increases as operators are better able to tune the furnace for optimal cycle time while maintaining roll distortion within specification.

Figure 4: LiteSentry™ Roll Distortion Measurement System

Measurement readings for all pieces are immediately displayed on a large monitor as the glass conveys to the unload station. The operators immediately observe and properly disposition out-of-specification lites, prior to additional value added processes.

Real-time feedback allows the furnace operator setup and maintain the furnace. Multiple sheet loads show the side-to-side and front to back roller wave variation - invaluable information for adjusting furnace parameters! Using the feedback to rapidly tune the furnace for a new thickness minimizes product changeover time.

A graph depicts the average and maximum roller wave distortion for the edge and center sheet sections. Each shift can observe their progress.

Any individual sheet may be examined in profile by clicking on the sheet image with the mouse. Upon clicking, a window pops up showing the glass surface profile from leading to trailing edge.

Roll distortion data is saved in a MS Access

Figure 5: CCD cameras - repeatable, reliable, accurate, and don’t need breaks

(.mdb) format file. This data can be retrieved via Ethernet or a ZIP 250MB disc installed with the system. Reports are easily created to track glass production quality over any time period.

The system is designed for the rugged, hot environment of a tempering line. All computer components are sealed in an air-conditioned electrical enclosure. The system is comprised of a light box with unique projected image, two high-speed digital CCD cameras, and a real-time computational computer receiving camera input, an operator interface computer, and support and mounting system. The number of cameras required is a function of the width of the tempering furnace. For example, a 2,100 M (84-inch) conveyor requires two cameras. In this configuration, roll distortion is accurately and repeatably measured with a resolution of 0.01 mm (0.0005 inch).

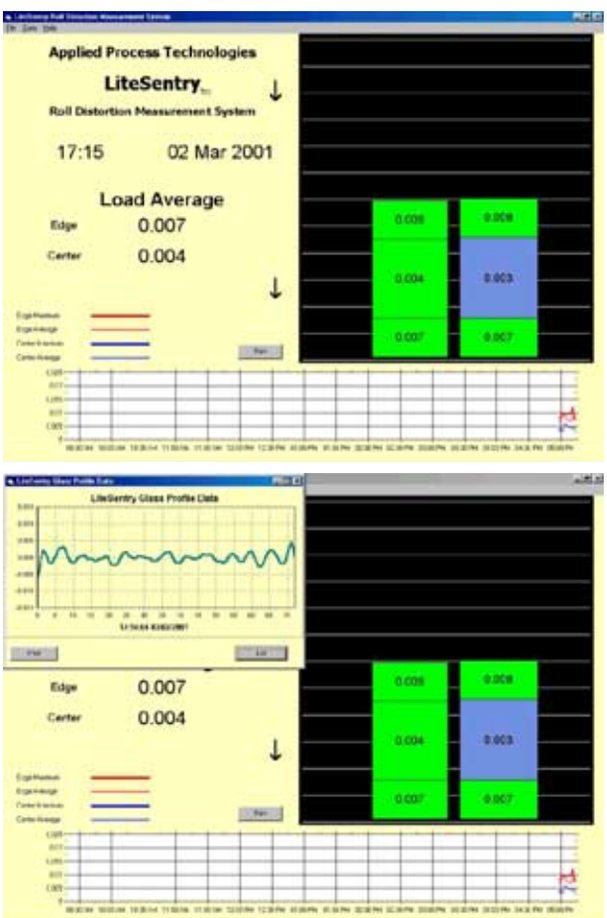

Figure 6a & 6b: Operator Display without and with sheet profile

The operator interface displays each lite divided into three sections - the leading edge (25% of length), central area and trailing edge (25% of length). For each area, roller wave peak-to-valley measurement data is displayed. Graphically, each section is filled with an appropriate threshold color. For instance, if a leading edge has edge kink distortion of 0.30 mm (0.012 inch), and the threshold between colors yellow and red is 0.25 mm (0.010 inch), then that section would appear as red on the screen. Four colors are used with threshold levels set by the management.

Individual lites are examined in detail by clicking on a lite to view a side profile of the full length of the lite. When clicked, a scaled pop-up window is displayed showing roll distortion in enlarged scale over the length of the sheet. This powerful feature allows the furnace operator to inspect individual sheets. For instance, if a sheet portion is red indicating excessive roller wave, clicking on that sheet will show the sheet profile, revealing exactly why it exceeded specification.

The side profile of the glass displays 'signatures' that reveal various problems in the furnace. For example, the spacing of peaks and valleys may correlate to furnace roll circumference or quench roll centerline spacing. Depending on the observed signature, appropriate action may be taken to correct the problem.

Users of the system have consistently experienced 50 to 75 percent decrease in roll wave values within months of start-up. Most importantly, they have maintained the improvements over time!

New Opportunities

New technology opens up new markets. This has never been truer than today. We are amazed at technical advancements and then go about our busy lives. Often years later, we realize the advancement has changed the way we live. The early realization of opportunity often takes a pioneer in the field. The LiteSentry roll distortion measurement system offers glass fabricators such an opportunity. While the tool will benefit any tempering operation, it offers the user the opportunity to enter into new markets, such as,

ISO 9000 certified products with recorded roll distortion data for all glass

Thin, heat treated, laminated glass for a lighter, less expensive, more transmissive product

Thinner heat treated glass for markets such as LCD displays, projection TV's, and mirrors

Conclusion

The need for higher quality, distortion-free, heat-treated glass is creating both challenges and opportunities for the glass industry. While furnace technologies are advancing to meet more stringent requirements, improved measurement of roll distortion is required for process control of the furnace. A new machine-vision technology has been developed and is now available to accurately measure roll distortion. The LiteSentry™ Roll Wave

Distortion Measurement system measures the peak-to-valley optical distortion on-line as glass exits the furnace. This system provides the tool necessary to improve and maintain the quality of heat-treated glass, thereby opening new markets for tempered and laminated glass.

Acknowledgements

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