APPLICATION NOTE AP-123-01

DETERMINING KNURL THRESHOLD LOCATION FOR FLOAT GLASS

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***Abstract* — we describe a non-contact measurement approach that uses a scanning beam of light to find the knurl on float glass. Measurement data is used to objectively determine where optical distortion is minimized and reduce waste associated with cutting, when compared to current subjective method.**

***Index Terms* — float glass, knurl, non-contact metrology, pane thickness.**

I. Introduction

All panes of manufactured flat glass, such as those installed in homes or skyscrapers, come from the same process known as float glass fabrication. This process takes its name from the fabrication step where molten glass floats on top of a molten tin bath inside a furnace. This process forms an even thickness layer of glass. Once it cools down, it results in an endless flat web of glass which is continuously pulled out of the furnace. The glass sheet is then cut into pieces that are appropriate for handling and for shipping[i].

A typical tin bath holds a 127-inch wide sheet of glass. Several pairs of textured wheels push the molten floating glass sheet from the furnace, as seen in Figure 1. The handling of the glass by the textured wheels results in the deformed (knurled) surface along the edge of the glass sheet. The deformations are not limited to where the wheels contact the glass sheet but extend further away from the edge due to the pulling forces. This knurled edge must be then cut away and scrapped. Due to high volume manufacturing of glass, a small reduction in the width of the cut-away edge results in the dramatic reduction of waste material and associated cost.

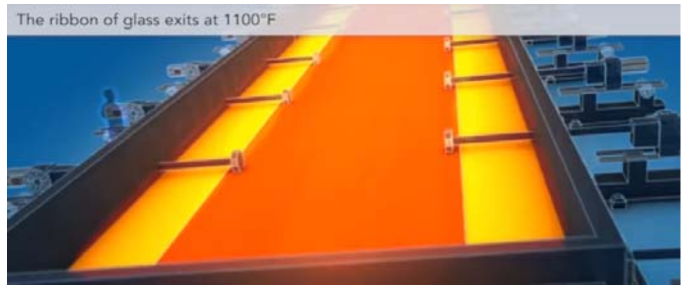

Figure 1: Float glass (dark orange) on tin bath (yellow) knurl wheels extend out over molten tin to edge of glass

Figure 2: Zebra board reflection of the knurled surface

Operators typically visually inspect the glass, using a Zebra board (Figure 2). A Zebra board consists of interchanging black and white stripes. A large sample of glass is cut from the sheet and is carried to a special room configured for the zebra measurement. By looking at the reflection of the stripes, the operator can find the location on the surface of the glass sheet where the straight lines of the Zebra board start to deform due to the edge knurl. The operators then mark the point on the glass where the distortions are no longer visible (Figure 3). The edge is then cut based on the mark.

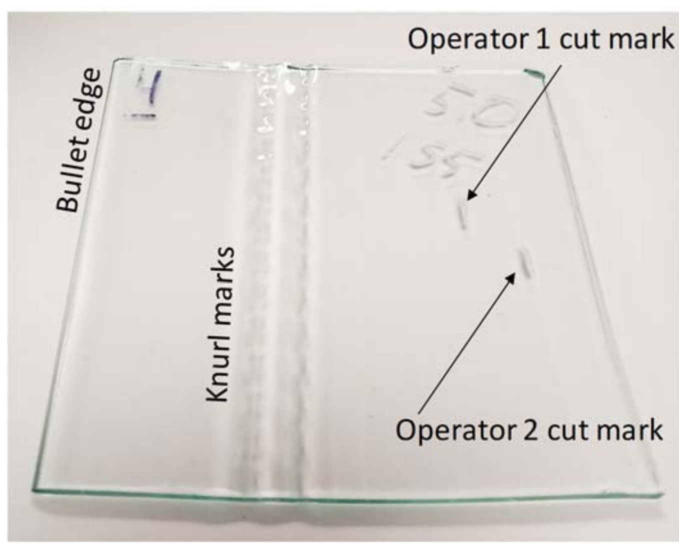

Figure 3: Sample scrap edge glass

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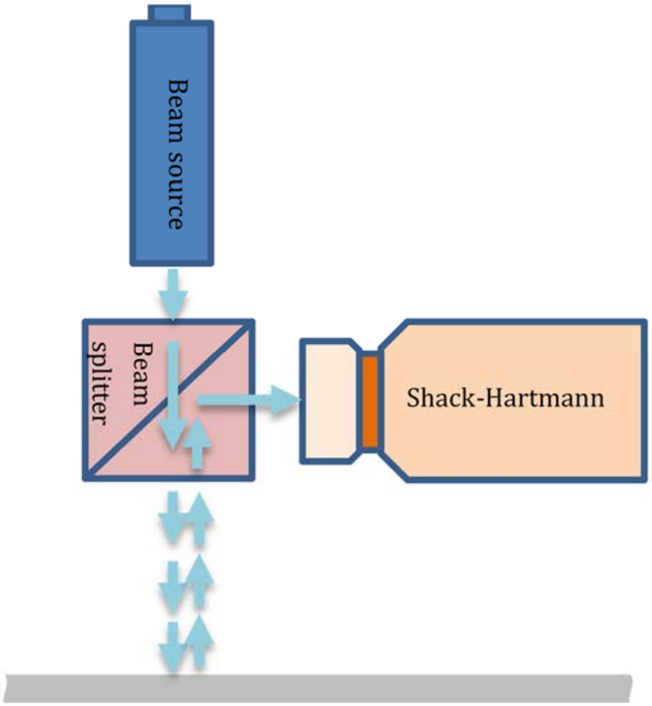

Figure 4: Wavefront sensor layout.[ii]

This method of finding the knurl edge is highly operator-dependent and variable. Figure 3 illustrates almost 2 cm difference in the location of the cut location identified by two different operators. Such error either results in metric tons of wasted glass material, or alternatively leads to low quality distorted glass panes shipped to the customer. In either case, there is an economic impact.

We propose a quantitative optics-based deterministic method for finding the optimal cut location, independent of the operator.

II. Measurement Setup and Approach[ii]

The proposed method is based on Shack-Hartman wavefront sensing (SHWS) technology. Figure 4 shows the schematic of the measurement configuration. A collimated (i.e. the wavefront) beam of light is directed onto the surface of the glass sheet. The light, reflected by the glass sheet, is then directed into the SHWS sensor via a beam-splitter.

When the reflecting surface of the glass is perfectly flat, the reflected beam then retains the flat wavefront properties of the incoming beam. However, a knurled surface modifies the wavefront of the reflected beam. This distorted wavefront is then measured by the SHWS sensor, which can be used to identify the type as well as the magnitude of the distortion.

To quantify beam distortion, we use the root-mean-square (RMS) parameter. In short, the RMS is calculated using the Zernike terms – the parameters of the mathematical framework used to describe the wavefront. When only higher Zernike terms are used, the RMS can be called as higher-order (HO) RMS. We have measured both the RMS and HO RMS but found that the RMS is the more optimal parameter for this application.

We have utilized a manual translation stage to move the measurement beam along the glass surface, in the direction perpendicular to the edge, in order to measure different locations of the glass surface. On the actual manufacturing line, the measurement setup can be mounted onto a motorized translation stage that continuously moves across the glass sheet, from the smooth "bullet" edge formed during the melting process, past the knurled wheel marks, and out to the cut edge.

The measurement data from different location is then analyzed, and the decision is made based on the threshold for the magnitude of the beam distortion.

III. Results and Discussion

We received 7 samples cut to approximately 5" squares to represent a small portion of the glass sheet. Each of the samples was marked by an operator showing where the knurl begins based on his/her observations from the Zebra board.

Figures 5 show the measured RMS and HO RMS as a function of distance from the operator mark in Sample 3. The negative part of the horizontal axis on the graph is

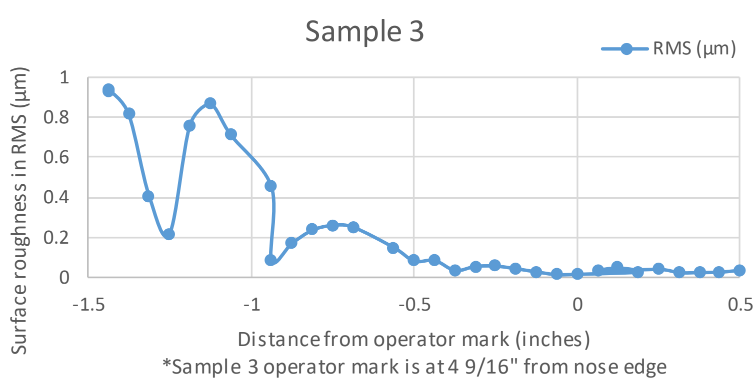

Figure 5: Sample 3 RMS wavefront

Sample	Thickness (mm)	Cut-off mark shift (mm)
1	2.3	-2.5
2	3	-3
3	4	-10
4	5	0
5	6	-7
6	7	-20
7	8	-5

Table 1: The shift in the cut-off location defined by the SHWS measurement criterion, as compared to the mark by a technician using Zebra board.

pointing towards the edge of the sample.

In the flat portion of the glass, which corresponds to the positive portion of the horizontal axis of the graph, the RMS is close to zero, consistent with the flat wavefront. As we move the measurement beam towards the knurled edge (towards the left portion of the graph), the RMS rises. The "bouncing" behavior of the RMS is expected and is not important for this application.

By evaluating the RMS before the first bounce (for coordinates larger than -0.7 in the graph), one can set a criterion for marking the knurl. For example, the location of the knurl cutoff can be defined where the RMS is below 0.1 micron.

We have applied this criterion for all 7 measured samples. Table 1 shows that the knurl cut-off mark can be shifted to the edge of the glass samples by up to 20mm, as compared to the operator-defined mark.

When the Shack-Hartmann sensor is integrated onto the production line (Figure 6), the measurements can be used by the glass cutting tools in real time, creating an optimal approach for reducing waste[iii] and eliminating the need to cut samples for off-line testing.

For additional information:

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[i] Float Glass Industries. How float glass is made. https://www.youtube.com/watch?v=JMGkbrETU8M
[ii] Patent pending
[iii] The average reduction from Table 1 is 6.7 mm for each side of the glass sheet, which corresponds to 0.42% increase in good glass production for 127inch wide glass sheet. For a plant producing 650 tons of glass per line per day, it corresponds to material savings of 2.7 tons per day (or $410 per day at $150 per ton). The annual savings is therefore approximately $150,000.