A New Approach to Measuring Distortion in Tempered Glass

Gerald L. Hendrickson. P.E. (ME)
Aspen Research Corporation

Poster 11

Keywords

1 = Distortion 2 = Rollerwave 3 = Opticaltest 4 = Reflectedimage

Abstract

Rollerwave distortion is commonly measured by either of two methods. One is deviation of the glass surface from a flat plane by use of a flat bottom rollerwave measuring device or a three point contact gauge. The other is by subjective viewing of the reflection of a zebra board. Optically, the distortion surface can be described in terms of millidiopters. Correlation of measured values to human perception has had varied results. Human perception of distortion is not easily described by the shape of a surface. Examination of the physiological basis for human perception leads to the idea that more appropriate measurement techniques are needed.

Distortion is often perceived when the image of an object fails to agree with the true shape of the object. Movement of an image in an unpredictable direction or velocity produces the mental perception of distortion in the reflective surface of the glass and may be an even greater source of discomfort than shape variation. New measurement techniques may include reflected image velocity as well as image shape. Several possible techniques for distortion measurement will be presented.

Introduction - Perception of Distortion

Distortion effects in tempered glass have been a persistent problem. Annealed glass leaves the float line with a flatness that has been well accepted. When a sheet of float glass is heated to the softening point in a tempering furnace, the glass flexes (sags) and loses its initial flatness. Cooled, the glass retains this no-longer-flat surface. The shape of this distorted surface is more apparent when viewing an image reflected from the surface then when viewing a transmitted image. Zebra boards are commonly used to view a reflected image and the viewing is a subjective judgement on the part of the viewer. The instrument called a three point contact (GAR) gauge is used to obtain an objective numerical value that can be used to check the quality of the glass surface. The length of the GAR gauge is related to the roll spacing in a typical furnace since the distortion seems to be related to sag of the glass between the furnace rollers. The gauge measures the deviation from flat as the gauge is moved along the sheet. The distortion has usually been termed "Roller Wave Distortion".

The distortion prevalent in tempered glass is often seen as a sequence of concave and convex variations from a flat surface. Optically, these variations appear lens like and optical properties can be calculated from the shape of the distortion elements. Lens power can be expressed in diopters or millidiopters.

The author knows of no specific values in millidiopters that have been specified as an acceptable quality standard for tempered glass. The distortion problem has traditional been treated as a mechanical problem with measurements and specifications given in mechanical terms and with an uncertain relationship to human response.

The main text

Measurements and calculations

To upgrade the mechanical measurement of the distorted glass surface, an attempt was made to measure a profile the entire length of a sheet of tempered glass by moving a depth indicator along a beam mounted above the glass. This produced a sine wave like output which was then converted to diopters by assuming that small segments of the wave represented spherical lens elements. Three points in a line were treated as a circular segment and the radius of curvature calculated. Values from -300 to +300 millidiopters were found. A radius of curvature of 1000 inches is equivalent to lens power of 78.74 millidiopters. (The difference between spherical and parabolic lens shape is on the order of a few hundred thousandths of an inch.) [9]

The data

Prior to building a fixture to measure the flatness of a large sheet of tempered glass, the author was given a set of data measured on a Coordinate Measuring Machine (CMM) from a set of eight tempered glass lites. The CMM data was the only data available on these lites, although it was thought that the lites represented units with objectionable distortion. The CMM data consists of a set of x, y, and z values for each point in a one inch by one inch pattern over the length and width of each lite. Orientation of the length and width of each lite in terms of the tempering furnace direction is unknown. Calculations of the apparent lens shape for each location of the grid was calculated using a 3x3 and a 5x5 array of points. Calculations were made for the width, length, and each diagonal in each of the 3x3 and 5x5 arrays. A ninth set of data points was prepared for an IG lite with excessive deflection from argon loss. This set of data was analyzed in the same manor,. .

Results

The analysis of this data clearly shows that optical distortion occurs both in the width as well as in the length direction. Values exceeded -200 to +200 millidiopters on many of the lites. Values on the excessive deflection unit varied from -244 to +244 millidiopters. A CDROM [10] containing the raw data, the analysis programs and the resulting data outputs files is available upon request from the author.

Random pockets of concave and convex distortion were found in both the length and width of the eight lites. The excessive deflection lite had high values of distortion in the cross sheet direction and low distortion parallel to the edges of the sheet. When viewing the excessive deflection lite, the viewer noticed that the sheet appeared to be curved, and did not appear to have unexpected variations.

Back to basics

The basic premise of distortion was then revisited. Distortion is perceived when the observed object or image does not agree with the expected shape of the object. The following discussion will be limited to reflected images.

Static distortion is observed when the object, the reflection surface, and the observer are stationary. Shape distortion of a vertical flagpole, a horizontal railing, or roof lines are all examples of static distortion. Dynamic distortion occurs when the object, the reflection surface, or the observer is moving. With

Poster 11

movement, the exact geometric shape of the object is not always precisely discernable, and other factors of the image take precedence.

A number of references to human visual perception were found that were instructive to as to the details on how humans perceive objects and motion in the world around them. In comparison to static distortion, the dynamic effect and the appearance of movement seem to have an even greater effect on how human react to distortion. Ref: [1] to [8].

Human development of the visual cortex was determined by survival needs. Small changes in horizontal direction and horizontal movement predominated as an indication of danger. When people move about, horizontal image movement is smooth and is coordinated with their speed of movement. Danger often had higher associated movement rates. When viewing horizontal movement of a reflected image, a slowing of the apparent rate is typically perceived as a sign that the object is curved, A good example would be the reflection from the curved surfaces of automobiles. When the reflected image moves faster than expected, the higher rate may subconsciously be perceived as danger and result in an increased awareness of the image.

Another analysis calculation was performed to show the direction of the axis of each circular segment. These axis were projected to a distance where a viewer might observe a reflected image. When the calculated projection points are plotted in the plane of a viewer, the vector movement of an image shows both the direction and the velocity of the image. Convex and concave areas in the reflection plane produce significant changes in velocity at the viewers plane. The magnitude of this image velocity may be the key to valid distortion measurement testing. A further effect is the nature of the gathering ability of a concave surface. Light gathering effect increases awareness of the image and brings it to the attention of the viewer.

Conclusions

Past methods of measuring depth of the variations from flatness of a tempered glass sheet, are good mechanical methods. Static mechanical methods and dimensional values, however, do not fully take into account how humans react to distortion in the flatness of glass. Human perception of distortion varies among individuals. Interaction of people with glass used in architectural applications involves movement as well as static viewing of reflections. Test methods that make use of human perception in both the dynamic and the static modes will produce more realistic results.

Specialists in human visual perception, physiology, and psychology should be consulted for input as to the factors important for human comfort and discomfort when viewing images of tempered glass distortion. The appearance of a reflected image, how the image moves, and the shape of the image are all important. An object viewed by reflectance may appear to be stationary, moving away, moving closer, rising, falling, or some combination. Distortion that causes comfort rather than discomfort should be the goal of glass tempering when flat glass can not be produced.

Standards, when fully developed, may well have elements with different sections dealing with: static images, dynamic distortion with direction/ velocity vectors, and apparent motion direction.

Development of improved glass distortion tests seems very achievable. Several methods are immediately thought of. All of the following proposals involve dynamic test methods.

One: A rotating mirror or prism produces a series of spots that move across a sheet of glass. Reflections of the spots on a screen are viewed by a camera which locates the position of a spot in respect to where the spot would be located with a flat sheet of glass. This image position would be synchronized with the moving projection to provide the equivalent of a grid of points across the surface. Deviation of the point locations would indicate the shape of the glass surface.

Two: Reflection of a fixed array of pinpoint lights would be observed as the glass moved under the array. Flat glass would produce a fixed image, while distorted glass would produce reflected images which would move according to the shape of the glass. Relative size or brightness of each reflected light will also indicate the relative convexity or concavity of the surface.

Three: Movement of a cell containing a light source and sensor grid in a scanning path above a fixed piece of glass would produce a non-moving image with flat glass and a moving image with distorted glass. Mapping of the glass surface would result when the position of the reflected image on the sensor grid is recorded in relation to the position of the cell above the glass.

With these three methods, the significant data will be the apparent velocity and directivity of the reflected image. To repeat, a lite of flat glass will produce a reflected image with smooth apparent movement.

A further thought on tempered glass distortion deals with the source of the distortion. The literature contains data on the evenness of heating in the furnace, the contact of the supporting rollers, and the reflectivity of the glass surface. Other items that may well be examined are:

Localized chemistry variation in the glass sheet which changes the viscosity to temperature relationship.
Localized heating differences caused by the furnace shape acting like a reflecting mirror and focusing varying amounts of heat on different areas of the glass.
Uneven roll contact of the exit and cooling rolls causing more rapid cooling in certain areas of the sheet.
Pressure fluctuations caused by subsonic resonance or pulsation in the air cooling channels. At a speed of 0.8 meters per second, a resonance frequency of 5.24 hertz would result in surface dimples at 6 inch intervals that could be confused with furnace roll spacing.

References

[1] Spatial Perception in Virtual Environments: Evaluating and Architectural Application, David Henry, 1992, Thesis, University of Washington.
[2] The Joy of Visual Perception, a web book, Peter K. Kaiser, York University, http://www.yorku.ca/eye
[3] Model of visual motion sensing, D. Heeger and E. P. Simoncelli, In SPATIAL VISION IN HUMANS AND ROBOTS, L. Harris and M. Jenkins, eds., Cambridge University Press, p. 367-392, 1993.
[4] Human Depth Perception, Institute for Information processing and Computer supported new Media, Inffeldgasse 16c, A-8010 Graz, Austria - EUROPE, http://www2.iicm.edu/0x811bc833_0x000dacca
[5] Perceptual Image Distortion, P. Teo and D. Heeger, First IEEE International Conference on Image Processing, vol2, PP 982-986, November 1994.
[6] Motion parallax, stereoscopy, and the perception of depth: Practical and theoretical issues, Jocelyn Faubert, École d'optométrie, Université de Montréal, 3744 Jean-Brillant, Montreal, Canada H3T 1P1 http://mapageweb.umontreal.ca/faubert/jocelyn/papers/FaubertSPIE.pdf
[7] Perspective Information and the Perception of Location and Shape, Jack M. Loomis, Department of Psychology, University of California, Santa Barbara, CA 93106, http://www.psychology.adelaide.edu.au/psychophysics/Library/FD99/Contribute/Loomis.pdf
[8] The Purple Perils: A selection of James J. Gibson's unpublished essays on the psychology of perception, J. J. Gibson, http://www.ksu.edu/psych/farris/gibson/
[9] Amateur Telescope Making, A. G. Ingalls, Scientific American, Inc., Book One, 1953, Book Two, 1954.
[10] A CDROM is available from the author containing the following files:
Raw CMM data files
Copy of the programs used to calculate distortion analysis
Copies of all of the extracted analysis results.
A readme.txt file with the latest information
Contact the author at: Gerald Hendrickson, PE, Aspen Research Corp,1700 Buerkle Road, White Bear Lake, MN 55110 , USA
651 264 6000, 651 264 6270 fax, ghendric@aspenresearch.com