Support Designs for Reducing the Sag of Horizontally Supported Sheets

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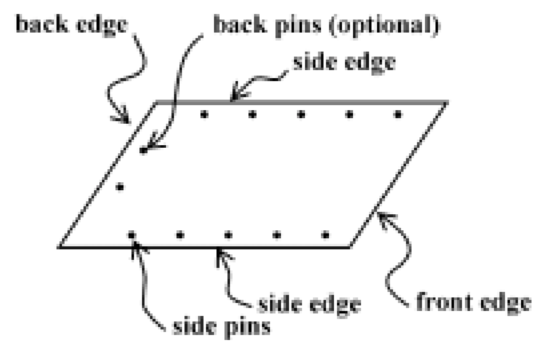
Abstract

At some stages in the manufacture of liquid crystal display panels, thin glass sheets are stacked horizontally in cassettes. The sheets sag due to gravity; with the ever-increasing sheet size and decreasing sheet thickness, the amount of sag has been increasing. Excessive sag is undesirable, since it limits the number of sheets that can be stacked in a cassette of given height. In this note, I describe some support designs that lead to reduced sag.

Introduction

A common way of storing glass sheets during liquid crystal display manufacture is to stack them horizontally in cassettes. The sheets are typically supported on pins located near the edges of the sheet, as shown in Figure 1. One edge of the sheet, the ‘ front’ edge, must be free, to allow the sheet handling robot access.

Figure 1. **Typical sheet support configuration.**



The glass sheets deflect due to gravity, and occupy a vertical range that is significantly larger than the sheet thickness. This vertical range is important, since it limits the number of sheets that can be stacked in a cassette of given height.

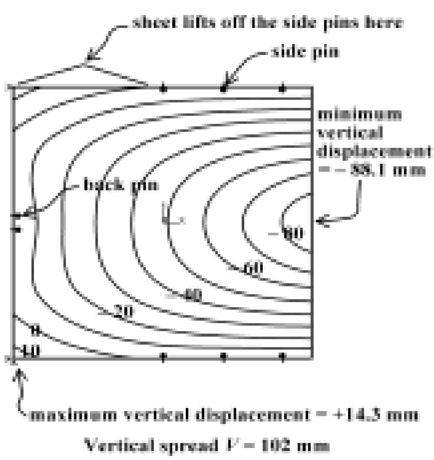
In this note, the *vertical spread*, *V*, is defined as the difference between the maximum and the minimum vertical displacements of the mid-plane of the sheet. The sign convention is that upward displacements are positive, and downward displacements negative. The actual vertical range occupied by the glass sheet would be $V + \tau$, where τ is the thickness of the sheet.

The Problem

The vertical spread V is proportional to the fourth power of the sheet size[1]. Hence, seemingly modest increases in sheet size can cause significant increases in vertical spread. The vertical spread is also inversely proportional to the square of the sheet thickness. Thus, in the near future, as sheet size increases and thickness decreases, the vertical spread is expected to increase to unacceptable levels.

For example, a Corning 1737 glass sheet of size 1000 mm x 1000 mm x 0.7 mm, which is roughly the size expected in the near future, has a vertical spread of about 108 mm when it is supported at the two side edges. Such a high vertical spread is not acceptable. Supporting the back edge may help in some cases, but not in our 1000 mm x 1000 mm x 0.7 mm example, as shown in Figure 2:

Figure 2. **Sheet with side and back supports: contour plot of vertical displacement (in mm). Sheet is 1000 mm x 1000 mm x 0.7 mm, of Corning glass 1737.**



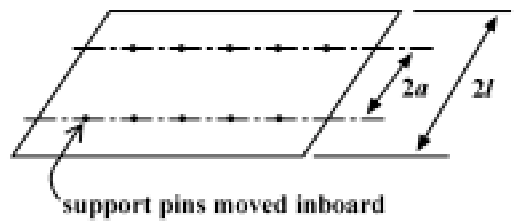
when the back edge is supported, the downward vertical displacement reduces in magnitude, but the two back corners of the sheet lift upward, so the vertical spread remains roughly the same. The two pins supporting the back edge in Figure 2 are spaced 50 mm apart. Increasing the spacing, or using more pins, does not help either; the vertical spread remains about the same.

Thus, excessive vertical spread of sheets will pose a problem if current support designs are used for larger sheets planned for the future.

A Solution

Clearly, to maintain a reasonable sheet stacking density for the planned larger sheet sizes, we must find ways to reduce the vertical spread. One possible way is to suspend the sheets vertically; that is not considered here. Another way is to support the sheets horizontally, but to locate the support points inboard of the edges of the sheet, as shown in Figure 3.

Figure 3. **Two-row support**.



For **two rows** of support points, the optimal separation between the rows that gives the least vertical spread has[2]

$$\alpha = 0.5537\, l,$$

[2]For details, see Meda [1].

where *1* is half the width of the sheet, and a is half the separation between the support rows, as shown in Figure 3. The vertical spread under optimal two-row support is

$$V = 0.518\, \frac{g\rho(1-\nu^2)}{E}\, \frac{l^4}{t^2} \;,$$

where τ is the thickness of the sheet, E the Young's modulus, *v* the Poisson's ratio, p the density, and *g* the acceleration due to gravity. For 1000 mm x 1000 mm x 0.7 mm sheets of Corning 1737 glass, which has $E = 70$ GPa, $v = 0.22$, and $p = 2.54$ gm/cc, the vertical spread under optimal two-row support is a mere 2.2 mm, which is well within acceptable limits.

For yet larger and thinner sheets, the vertical spread may be too high even with optimal two-row support. For example, a 2000 mm x 2000 mm x 0.5 mm sheet of Corning 1737 glass under optimal two-row support will have a vertical spread of about 71 mm, which is too high. For such large and thin sheets, we can consider three-row and four-row support, as shown in Figure 4. For three-row support, the optimal placement has

$$a = 0.7153\, l \,,$$

and the corresponding vertical spread is

$$V = 0.00859\, \frac{g\rho(1-\nu^2)}{E}\, \frac{l^4}{t^2} \;,$$

[1]If the sheet deflects into a non-developable surface, bringing membrane stresses into play, V increases slower than the fourth power of the sheet size. Nonetheless, V increases rapidly with the sheet size.

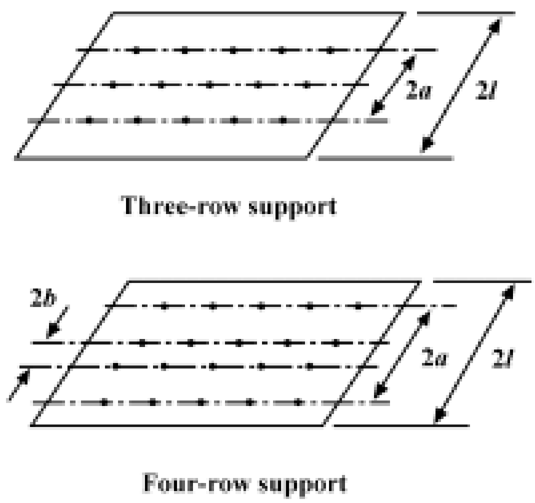
For **four-row** support, the optimal placement has

$$a = 0.7909\, l\,, \quad b = 0.2658\, l\,,$$

and the vertical spread is

$$V = 0.00250\ \frac{g\rho(1-\nu^2)}{E}\,\frac{l^4}{t^2}$$

Figure 4. **Three-row and four-row support.**



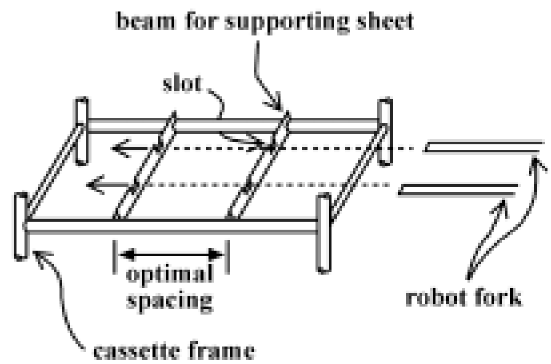
From the preceding formulas, for a 2000 mm x 2000 mm x 0.5 mm sheet of Corning 1737 glass, the vertical spread is about 12 mm under optimal three-row support, and about 3.5 mm under optimal four-row support. Both those values of vertical spread are within acceptable limits.

Thus, if we are prepared to support glass sheets inboard of the edges, we will be able to maintain an acceptable sheet stacking density even for the larger and thinner sheets planned for the future.

Some Practical Considerations

In current cassette designs, support pins are attached to the ends of short cantilevers that extend from the cassette frame. Extending the cantilevers far enough to provide optimal support may not be practical - the lengthened cantilever may need to have a very large section. An alternative is to use optimally spaced support beams that span the entire width of the cassette, as shown in Figure 5. Slots can be provided in the support beams to allow the sheet handling robot fork to slide under the sheet.

Figure 5. **Full-width support beams.**



Under optimal support, the supports touch the glass in the usable area, far inboard of the edges. So carefully designed padding should be provided to prevent scuffing of the glass. In this regard, the full-width support beams of Figure 5 are better than pins mounted at the ends of cantilevers: for the full-width support beams, the glass-to-support contact area can be made much larger than for cantilevered support pins. The larger contact area leads to lower contact pressure, and hence reduces the tendency to scuff.

Vertical spread can be reduced even more by exploiting stiffening effects caused by large deflections. For example, the full-width beams of Figure 5 can be made with a slight upward bow. However, such tricks may not be necessary for the sheet sizes expected to be used in the near future.

References

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