MEASUREMENT AND QUANTIFICATION OF BAGGY WEBS

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ABSTRACT

Webs that have crossweb variation in machine direction length are commonly called "Baggy Webs". All real webs have some degree of bagginess. When the bagginess exceeds some quantity, web handling problems such as wrinkling and lateral motion begin to appear.

There have been many articles, technical papers and patents on the subject of web bag measurement. This paper will summarize the measurement methods in the open literature. New mathematical techniques will be presented to quantify baggy webs. A new concept of "Web Bag Strain" will be presented for the quantification of baggy webs

WHAT IS A BAGGY WEB?

A web having a crossweb variation in machine direction length, commonly called "Baggy Web" is shown in Figure 1. Another term "Planarity" is also commonly used in the literature to describe a web that will not lay straight and flat in a plane when smoothed onto a flat surface.

D. R. Roisum [1] describes the "Strip Method" of quantifying web bag. This method cuts square ends on a section of web a few meters long. Next the web is cut into strips lengthwise and the lengths of the strips compared. It can clearly be seen that the strips cut from the center of the web shown in Figure 1 would be longer than the strips cut from either edge. Webs are thin and buckle under very small compressive stress. The extra length is stored in the longer path length of the buckled web.

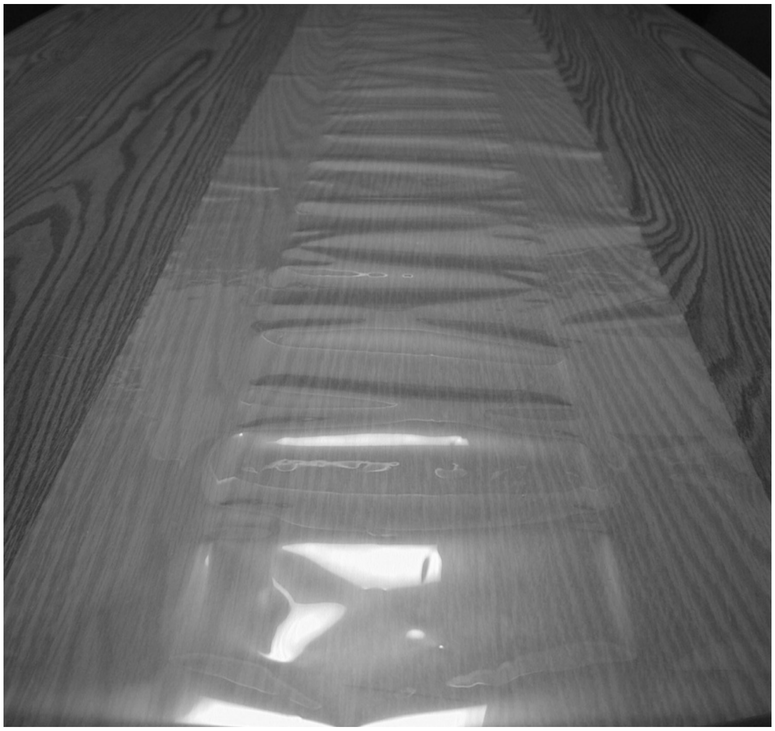

Figure 1 – A Baggy Web

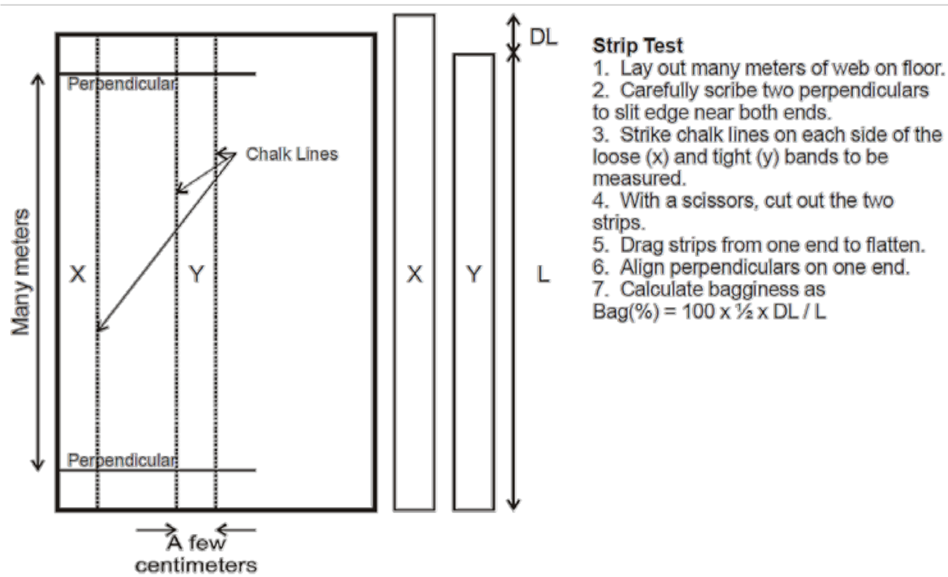

Figure 2 – Strip Test Measurement Method [1]

TYPES OF BAGGY WEB

Figure 1 is a good example of what would be commonly called “baggy center” web. Figure 3 would be commonly referred to as “baggy edge” web or “lasagna” because of the similarity to the pasta. Figure 4 is commonly called a “Baggy Patch”, a football size defect sometimes seen is oriented films such as PET and BOPP. Figure 5 is a web that will lie flat, but not straight when smoothed onto a flat surface. This defect is commonly called “camber”.

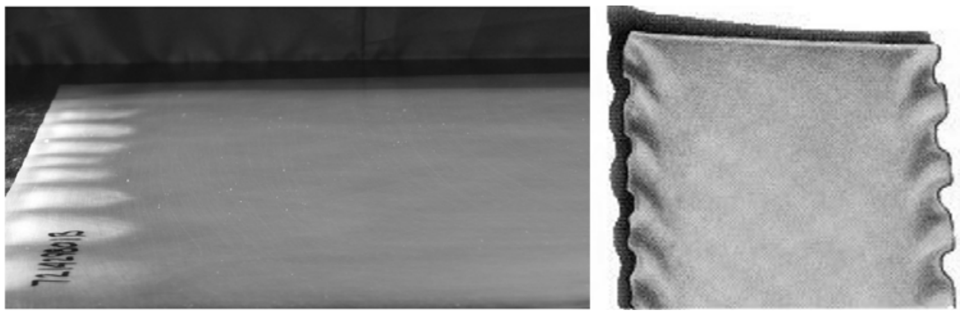

Figure 3 – Baggy Edge or Lasagna

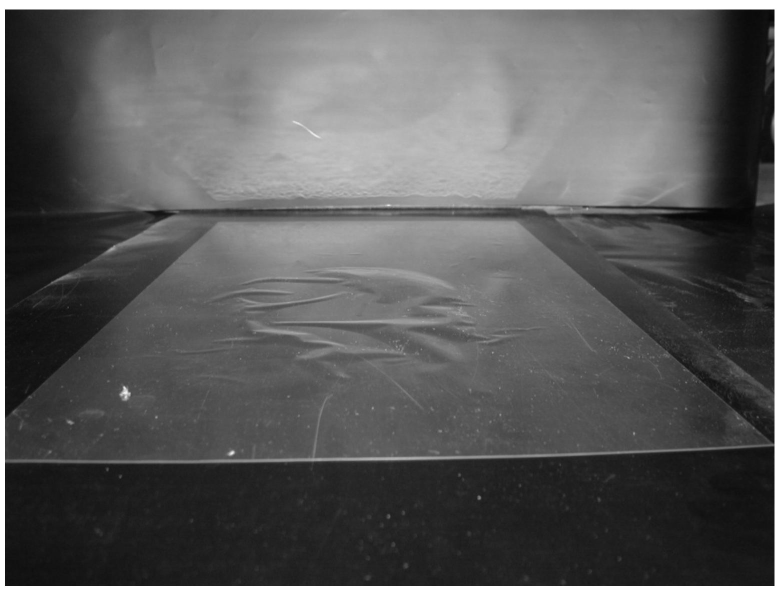

Figure 4 – Baggy Patch

Figure 5 – Cambered Web

A SURVEY OF PLANARITY MEASUREMENT METHODS FOUND IN THE LITERATURE

Strip Test

The Strip Test [1] shown in Figure 2 and discussed above, is a simple and inexpensive offline web planarity test measurement method. The test is time consuming, sometimes on your knees for extended periods of time and has relatively low resolution. The data is in useful units (Bag(%) or mm/m) and can be plotted verses crossweb position. The author uses a slightly modified version by not cutting the strips completely at one end, securing the uncut end and sweeping the strips to the cut end. In this manor the strips stay in order and the differential length can easily be measured at the far end.

Profile Height Test

The Profile Height Test, shown in Figure 6, is an offline web planarity test measurement method. It is relatively fast but sensitive to operator skill. The single point quantity measured, maximum profile height, is insufficient without wave period data to quantify web planarity (see "Web Bag Strain Due To Sine Wave Buckling") below. Cambered webs would have no profile height, but are decidedly baggy when run through web lines. Data from this test cannot be plotted as a function of crossweb position. US patent 4,500,607 is expired and legally dead. Although this type test is used in industry, it has little if any value.

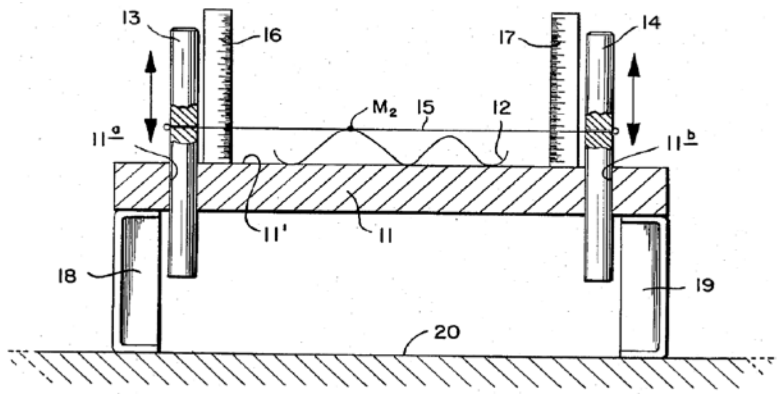

Figure 6 – Profile Height Test (US 4,500,607)

Catenary Sag Test

The Catenary Sag Test, shown in Figure 7, is an offline web planarity test measurement method. It is relatively fast but sensitive to operator skill. The quantity measured, maximum catenary sag, is a quantity that could be used to quantify web planarity. Data from this test is not, but could be, gathered and plotted as a function of crossweb position. US patent 6,363,621 (International Paper) is legally dead.

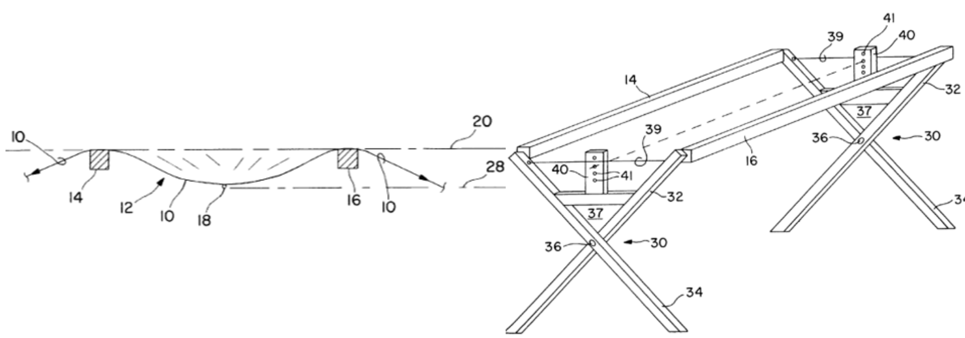

Figure 7 – Catenary Sag Test (US 6,363,621)

Line Laser Test

The Line Laser Test, shown in Figure 8, is an online web planarity test measurement method. It is relatively simple and inexpensive test. This is a visual test and data is not, but could be collected. If data were collected it could be plotted as a function of crossweb position. US patent 5,778,724 (3M) is legally dead.

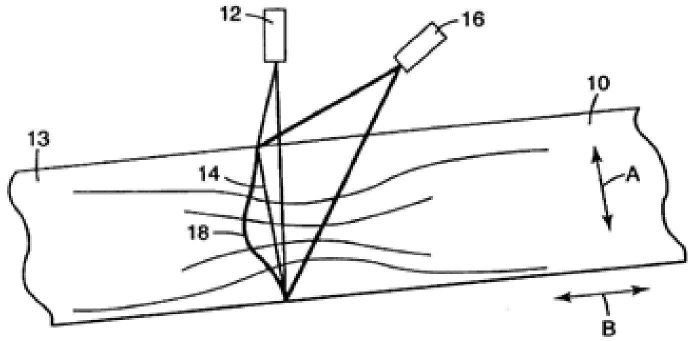

Figure 8 – Line Laser Profile (US 5,778,724)

Segmented Tension Roller

The Segmented Tension Roller, shown in Figure 9, is an online web planarity test measurement method. Unlike the online test methods listed above, which rely on slack sections of the web to get a measurement, this method needs taught web to give a signal. Slack web will give a zero tension signal independent of the degree of slackness. Consequently this method would be best placed in a high tension section of the webline, whereas the previous online systems would best be place in a low tension section of the webline. Assuming the webline tension is high enough to remove all slackness in the web, this method would have high resolution and tension could be plotted as a function of crossweb position. US patent 6,192,765 (SMS Group) is legally dead.

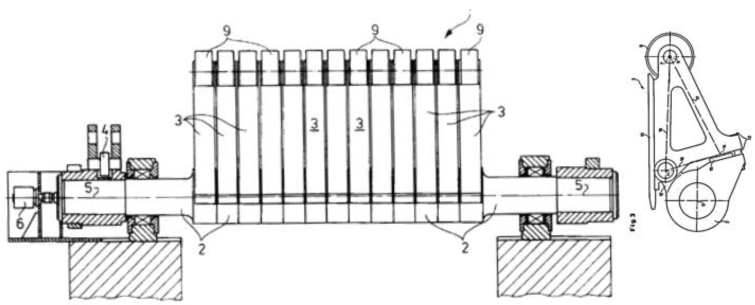

Figure 9 – Segmented Tension Roller (US 6,192,765)

Air Back Pressure Measurement

The Air Back Pressure Measurement Roller, shown in Figure 10 is an online web planarity test measurement method that also requires a taught web. Tension can be calculated from back pressure measurements using Equation {1}. Assuming the webline tension is high enough to remove all slackness in the web, this method would have high resolution and tension could be plotted as a function of crossweb position. US patent US 6,070,472 (SMS Group) is legally dead.

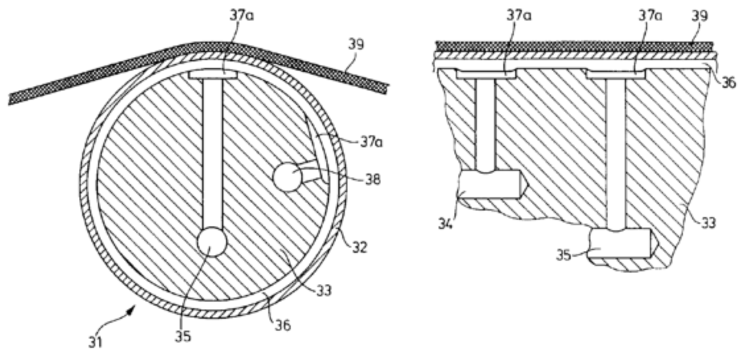

Figure 10 – Air Back Pressure Measurement (US 6,070,472)

$$\text{Tension per unit width} = \frac{\text{Pressure}}{\text{Radius}}$$ Tension-Pressure Equation {1}

<u>Wave Speed Method</u>

The Wave Speed Method [2], shown in Figure 11 is an online web planarity test measurement method that also requires a taught web. Tension can be calculated by measuring the wave speed and utilizing Equation {2}. Assuming the webline tension is high enough to remove all slackness in the web, this method would have high resolution and tension could be plotted as a function of crossweb position.

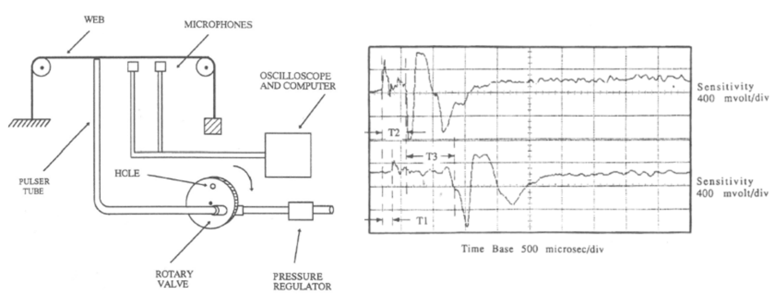

Figure 11 – The Wave Speed Method

$$c = \sqrt{\frac{T}{\rho_L}} \qquad Wave\ Speed = \sqrt{\frac{Tension}{Linear\ Density}}$$ Wave Speed Equation {2}

<u>Web Camber Measurement</u>

The Web Camber Measurement roller, shown in Figure 12 is an online web planarity test measurement method that specifically measures web camber. Virtually all web lines have loadcell rollers. Virtually all loadcell rollers consist of two independent loadcells, one on each end of the roller. Normally the signals from each loadcell are summed to give the total tension on the roller. A cambered web will exert more force on loadcell located on the inside of the curve (tight side). This method uses the difference in the signals to calculate the web camber. On most web lines, web camber could be measured with existing hardware. Web camber can be plotted as a function of time, as shown in Figure 13. This plot would represent a web with changing curvatures such as the web shown in Figure 5. US patent US 6,035,259 (Kodak) is legally dead.

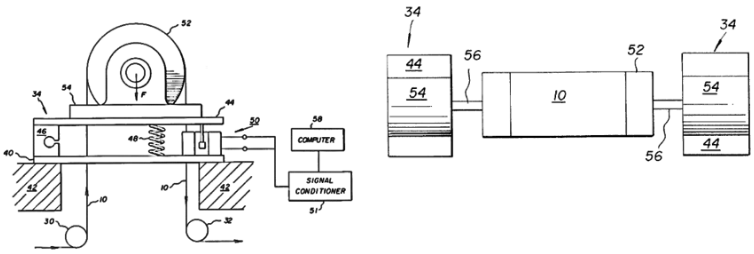

Figure 12 – Web Camber Measurement (US 6,035,259)

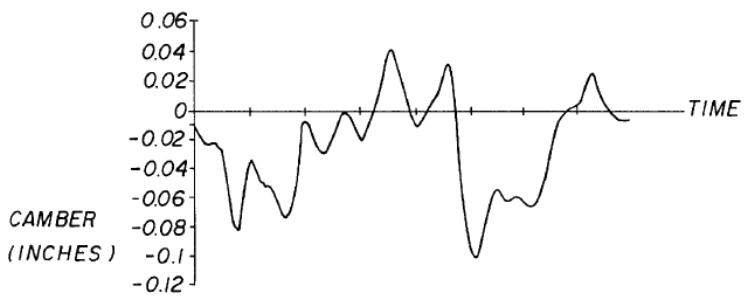

Figure 13 – Web Camber vs. Time Plot

2D-Surface Profile Map with Integrated Length

The 2D-Surface Profiler, shown in Figure 14 is an offline web planarity test measurement method. A web section is placed on the table, which contain an array of holes. The holes can be pressurized to float the web or vented to allow air under the web to escape. A beam spans the web in the crossweb direction (y) and supports a linear array of ultrasonic height (z) sensors. The beam is scanned the length of the sample to produce an x-y array of (z) height data. The web length along the scan was calculated using Equation {3} or {4}. The web length minus the scan length is divided by the scan length to calculate web bag in μm/m. Web bag was plotted vs. crossweb position, as shown in Figure 16. Note that the resolution of this test is in the single digits of μm/m! US patent US 6,178,65 (Kodak) is legally dead.

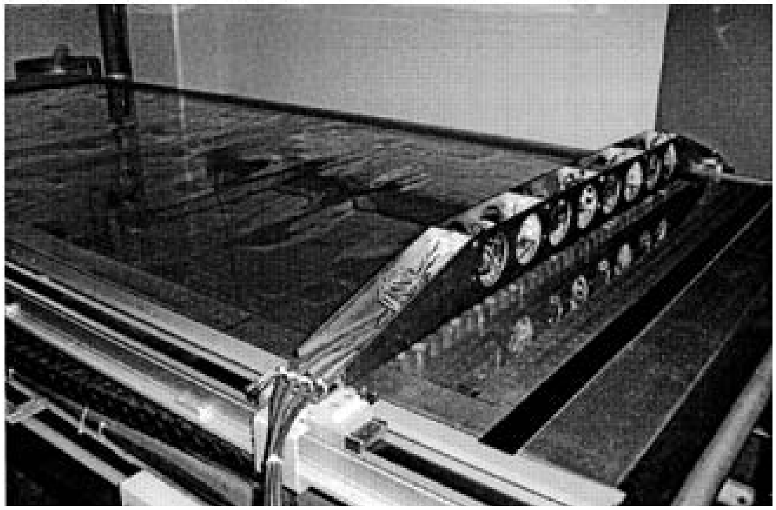

Figure – 14 2D-Surface Profiler (US 6,178,657 Kodak)

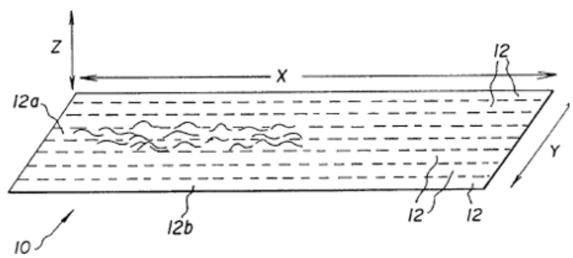

Figure 15 – Lengthwise Scan

$$\mathbf{L} = \sum_{1}^{i=n} \sqrt{(\mathbf{X_i} - \mathbf{X_{i-1}})^2 + (\mathbf{Z_i} - \mathbf{Z_{i-1}})^2}$$ Web Length Integration {3}

$$\mathbf{L} = \int_0^x \sqrt{1 + \left(\frac{dZ}{dx}\right)^2}\, \mathbf{dx}$$ Web Length Integration {4}

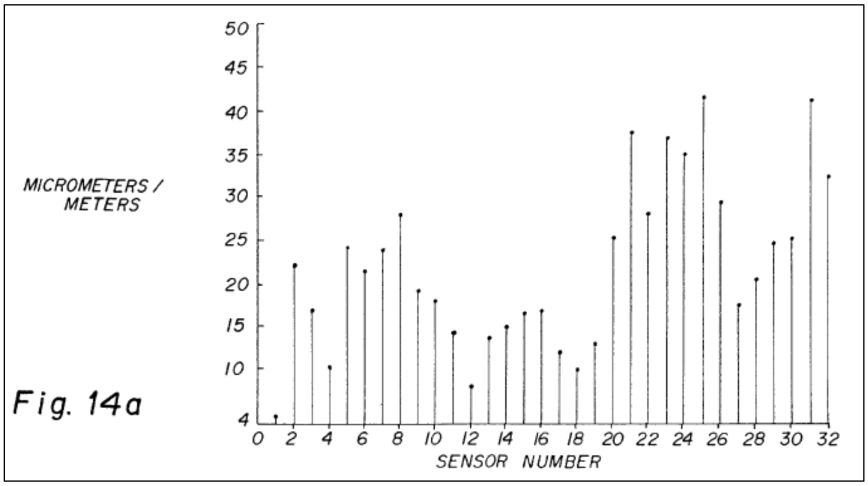

Figure 16 – Crossweb Plot of μm/m

WEB BAG STRAIN

Kodak Patent US 6,178,657 refered to the quantity plotted in Figure 16 as "Relative Differential Length". This quantity is not a length or a relative length, which would have the units of length, but is Δ Length/Length which is strain. This author prefers the term "Web Bag Strain", which be unit less, being calculated with the units of length/length. Strain is commonly referenced as micro strain, parts per million (ppm) or percent strain (%). As shown in Figure 17, 1% is very severe web bag strain and micro strain or ppm is probably more appropriate.

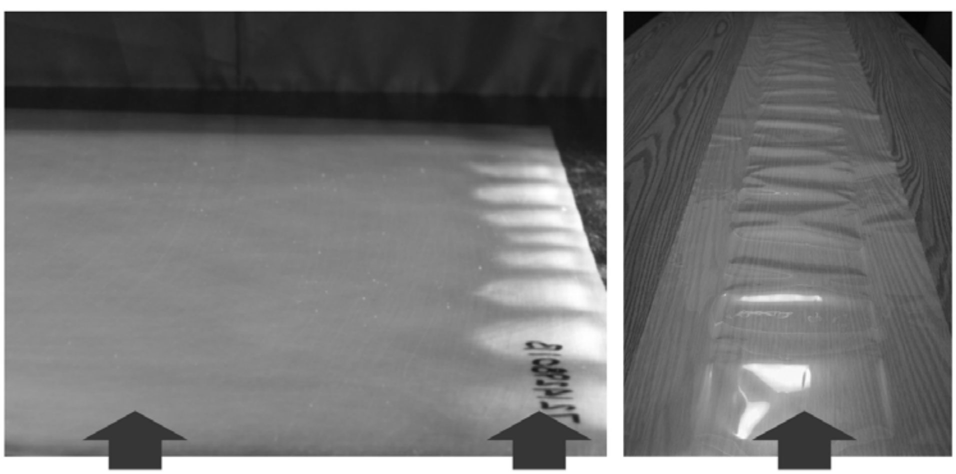

Figure 17 – Example Magnitudes of Web Bag Strain

METHODS OF CALCULATING WEB BAG STRAIN

Integrated Length

Equation {5} and Equation {6}, as discussed previously, can be used to determine in length of a scanned web sample. Equation 7 can be used to calculate the average web bag strain along a scanned line. The web bag strain calculated by Equation {7} can be plotted in a one dimension as a Web Bag Strain vs. Crossweb Position graph such as shown in Figure 16.

$$\mathbf{L} = \sum_{1}^{i=n} \sqrt{(\mathbf{X_i} - \mathbf{X_{i-1}})^2 + (\mathbf{Z_i} - \mathbf{Z_{i-1}})^2} \quad \text{Web Length Integration} \qquad \{5\}$$

$$\mathbf{L} = \int_0^x \sqrt{1 + \left(\frac{dZ}{dx}\right)^2}\, dx \quad \text{Web Length Integration} \qquad \{6\}$$

$$\varepsilon_{\text{Web Bag}} = \frac{(L - L_x)}{L_x} \quad \text{Web Bag Strain} \qquad \{7\}$$

Baggy web patchs, as shown in Figure 4 and Figure 15 would not be well represented such a one dimension plot. The bagginess magnitude in the patch would be diluted with the non-baggy areas in the same scanned line. A two dimensional plot of the Web Bag Strain could be generated using Equation {10} operating on the dz/dx derivative of the data array generated by a 2D-Surface Profiler, such as shown in Figure 14. Equation {10} can be derived from the definition of strain (Equation {8}) and the triangle shown in Figure 18. Substituting $(dz/dx)^2$ for x in Equation {9} and considering that if $(dz/dx)^2$ is small, the higher order terms can be considered zero. Equation {10} can be derived by substituting the first two terms of the power series into Equation {8} and simplifying.

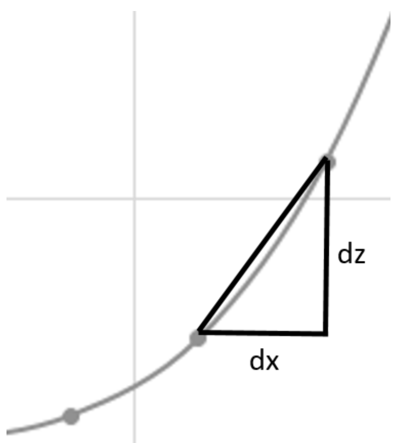

Figure 18 – Calculating Sample Length

$$\varepsilon = \frac{\Delta L}{L} = \frac{\sqrt{dx^2 - dz^2} - dx}{dx} = \frac{\sqrt{dx^2 - dz^2}}{dx} - 1 = \sqrt{1 + \left(\frac{dz}{dx}\right)^2} - 1 \quad \text{Strain Calculation} \quad \{8\}$$

$$\sqrt{1 + x} = 1 + x\left(\frac{1}{2}\right) + \frac{x^2}{2!}\left(-\frac{1}{4}\right) + \frac{x^3}{3!}\left(-\frac{3}{8}\right) + \cdots \quad \text{Power Series Expansion} \qquad \{9\}$$

$$\boldsymbol{\varepsilon}_{\textbf{Web Bag}} \cong \frac{1}{2}\left(\frac{dz}{dx}\right)^2 \quad \text{Strain at a Point} \qquad \{10\}$$

Web Bag Strain due to Catenary Sag

Flexible objects, such as power lines and webs, strung between two supports and acted upon by gravity will form the mathematical shape called a catenary. The web bag strain of a sagging web section can be found using Equation {20}. Equation {20} can be derived starting with the catenary Equation {11}, substituting into the arc length Equation {12} and integrating to find the arc length of ½ a catenary, shown in Equation {13}. The ½ a catenary arc length and ½ the span length are used in Equation {14} to determine the strain. The series higher order terms of the series expansions of sinh() and cosh() are used to simplify into Equation {20}.

Figure 19 – Catenary Sag of Power Lines

$$z(x) = C_1 \mathrm{Cosh}\left(\frac{x}{C_1}\right) - C_1 \quad \text{Catenary Equation} \qquad \{11\}$$

$$s = \int_0^{L/2} \sqrt{1 + \left(\frac{dz}{dx}\right)^2}\, dx \quad \text{Arc Length Equation} \qquad \{12\}$$

$$s = C_1 \mathrm{Sinh}\frac{(L/2)}{C_1} \quad \text{Length of 1/2 Catenary} \qquad \{13\}$$

$$\varepsilon = \frac{\Delta L}{L} = \frac{s - L/2}{L/2} = \frac{1}{\left(\frac{L/2}{C_1}\right)} \mathrm{Sinh}\left(\frac{L/2}{C_1}\right) - 1 \quad \text{Strain Equation} \qquad \{14\}$$

$$\sinh(x) = x + \frac{x^3}{3!} + \frac{x^5}{5!} + \ldots \quad \text{Series Expansion of Sinh()} \qquad \{15\}$$

$$\varepsilon \cong \frac{1}{6}\left(\frac{L/2}{C_1}\right)^2 \quad \text{Simplified Strain Equation} \qquad \{16\}$$

$$Z_{Max} = C_1 \mathrm{Cosh}\left(\frac{L/2}{C_1}\right) - C_1 \quad \text{Max Catenary Sag} \qquad \{17\}$$

$$\mathbf{cosh(x)} = \mathbf{1} + \frac{\mathbf{x^2}}{\mathbf{2!}} + \frac{\mathbf{x^4}}{\mathbf{4!}} + \ \dots \qquad \text{Series Expansion of Cosh()} \qquad \{18\}$$

$$\mathbf{C_1} \cong \frac{\left(\mathbf{L}/\mathbf{2}\right)^2}{\mathbf{2Z_{Max}}} \qquad \text{Constant 1} \qquad \{19\}$$

$$\boldsymbol{\varepsilon}_{\mathbf{Web\ Bag}} \cong \frac{\mathbf{8}}{\mathbf{3L^2}} \mathbf{Z_{Max}}^{\mathbf{2}} \qquad \text{Catenary Web Bag Strain} \qquad \{20\}$$

<u>Web Bag Strain due to Sine Wave Buckling (Lasagna)</u>

Shelton [3] used techniques similar to the one above to find the web bag strain (Equation {22}), based on a sine wave shaped buckled web (Equation {21}). This equation clearly shows that web bag strain cannot be measured by amplitude data only, as was attempted in the "Profile Height Test" shown above in Figure 6. Both Amplitude and period data is required.

$$\mathbf{Z(x)} = \mathbf{A\ sin}\left(\frac{\mathbf{2\pi}}{\mathbf{P}}\mathbf{x}\right) \qquad \text{Shape of Sine Wave Buckling} \qquad \{21\}$$

$$\boldsymbol{\varepsilon}_{\mathbf{Web\ Bag}} = \boldsymbol{\pi}^{\mathbf{2}} \left(\frac{\mathbf{A}}{\mathbf{P}}\right)^{\mathbf{2}} \qquad \text{Web Bag Strain for Sine Wave} \qquad \{22\}$$

CONCLUSIONS

1. Several current web bag measurement standards were summarized.
2. The term "WEB Bag Strain" was introduced.
3. Equations that can be used to calculate "WEB Bag Strain" were given, including three which may be new to the open literature.

REFERENCES

1. Roisum, D. R., "Baggy Webs: Making, Measurement and Mitigation thereof," Online Paper, www.roisum.com/, January 2001.
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3. Shelton, J. J., "Machine Direction Troughs in Web Spans and Corrugations in Wound Rolls," <u>Web Handling Research Center Report</u>, Aug. 1991.