# THE MECHANICS OF GROOVED FLEXIBLE SPREADER ROLLS

by

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## ABSTRACT

All known web spreading hardware work based upon one of three principles. Sometimes it is unclear which principle(s) apply to a given spreading device. The flexible spreader roller is such a device. In this paper we will employ engineering mechanics to determine by what principle these devices spread a web. If the analysis is successful we will be able to design a flexible spreader roll to remove the lateral slackness from a given web.

## INTRODUCTION

Flexible spreader rollers are made by covering a metal shell with a grooved rubber covering. The purpose of the metal shell is to give the roller substantial bending stiffness such that the roller does not bend appreciably due to the tension in the web. The rubber covering is fluted with either circumferential or spiral cut grooves. For those covers that are spiral cut, the angle of the spiral ($\alpha$) reverses at the CMD center of the roller as shown in Figure 1. In all cases, for both the circumferential and spiral cut grooves, the land angle ($\phi$) will reverse at the CMD center of the roller. In some cases a manufacturer will increase the depth of the cut grooves as a function of the distance away from the CMD center of the roller.

Swanson [1] established a basis by which (1) rollers could be quantified as anti-wrinkle devices and (2) a test by which spreading devices could be tested for their effectiveness in spreading. Of interest here is the latter which involved slitting the web upstream of the spreader roller. If the two web slits spread apart from one another at the spreader roller, this separation was measured and provided quantitative evidence of how well that spreader device performed. The flexible spreader roller was proven to be a spreading device in this analysis. The focus of this paper is to discern why this device spreads webs.

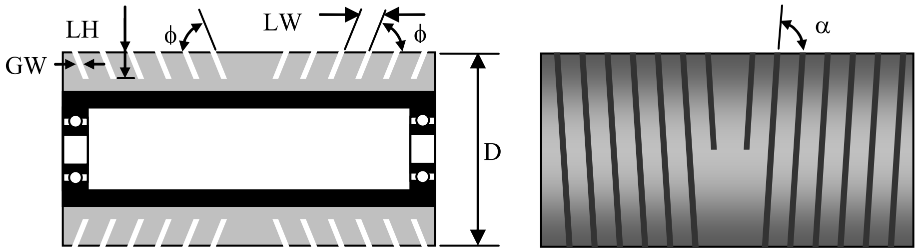
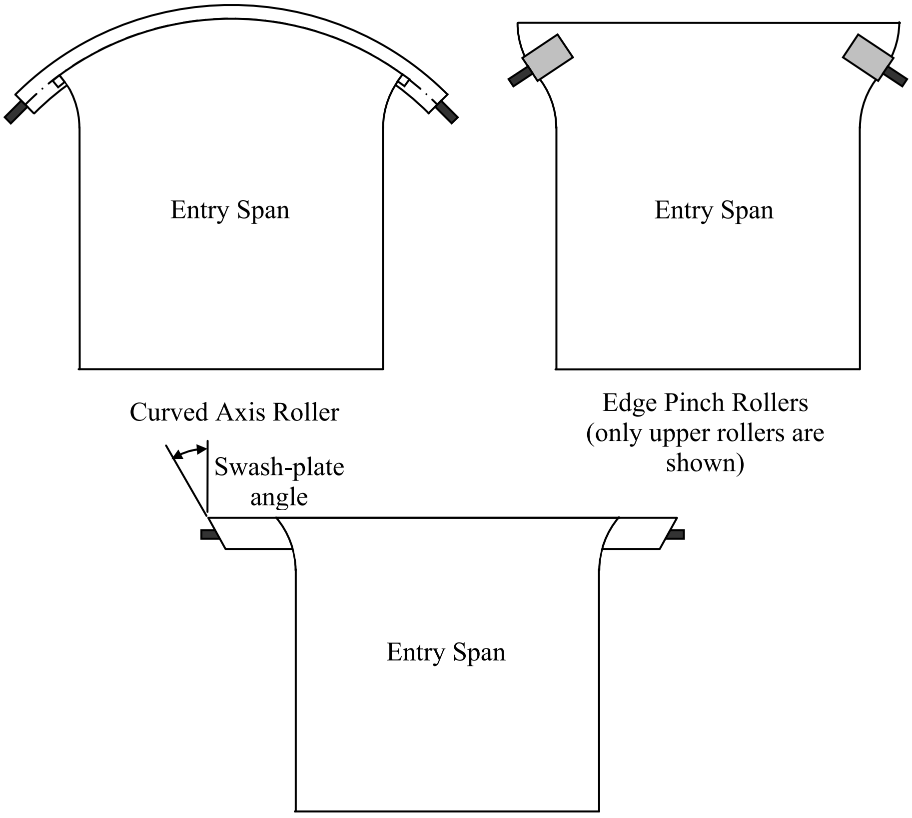


Figure 1 – A Flexible Cover Spreader Roller



Curved Axis Roller

Edge Pinch Rollers
(only upper rollers are
shown)

Expanding Surface Roller

Figure 2 – Spreaders that rely on the Normal Entry Principle

There are basically three principles that govern the behavior of spreading devices. The principles and examples of devices that spread by these principles follow:

1. The first principle will be called the ***normal entry*** principle. The term normal entry has been used for some period in the field of web lateral mechanics and is attributed first to Lorig [2]. This principle can be stated: A web will approach a downstream

roller normal to the axis of roller rotation. Devices that can effectively spread a web based on this principle include curved axis rollers, steer-able edge nip rollers, and rollers with expanding covers, refer to Figure 2. The curved axis roller can be described as a roller with various degrees of misalignment. The web on the operator side of the machine is steered toward that side of the machine by the curved axis roller. If the center of the machine and the web coincide, there is no misalignment or steering at the center. The web on the gear side of the machine is steered to that side of the machine. The result is that the web is spread and if the web was slit upstream of such a roller the web halves would spread or deflect apart. For a curved axis roller to spread effectively there must be good frictional contact between the web and the cover of the curved axis roller. Thus the steering forces presented upon the web by the roller are limited by the normal pressure of contact due to web tension and the radius of the roller, and the friction coefficient. Steer-able nip rollers work in a similar fashion except the friction limitation due to web tension is removed and the normal force is now due to nip pressure. Steer-able nip rollers have the potential to be the most aggressive spreading device, to the point they can tear a web in half. Another example of a spreader roller that relies on the normal entry principle is the expanding surface roller. These rollers have elastic coverings which are supported at their ends by swash plates that can be adjustable. The velocity vectors on the surface of this roller are all the same magnitude but vary in direction similar to the curved axis roller. The web velocity vectors attempt to align with the velocity vectors of the roller surface but may be limited by friction and the elasticity of the web. It should be noted that the bow radius, the steering angle, and the swash plate have been exaggerated in Figure 2 to explain the principle of operation. When spreading webs with high in-plane stiffness these parameters may be hard to distinguish visibly.

2. The second principle of spreading will be called the ***sliding*** principle. Under sliding conditions the direction an object travels will be due to external forces such as gravity or web tension and the slope of the terrain over which the object is sliding. Thus if we lock up all four wheels of our automobile at highway speed and if the road is lower on the left then the automobile will slip forward and left. This is how a so-called “D bar” spreads a web in a web line as shown in Figure 3. The D bar is smooth curved surface which is not a roller and does not turn or move. The D bar gets its name because the smooth curved surface has the shape of the letter “D.” Some D bars are adjustable in shape so that the apex can be adjusted to the center of a baggy lane. As a web is transported over this bar slippage must occur between the web and the bar. As the web slides over the inclined surface it will slide down the incline on either side which will result in web spreading, particularly if there was initial lateral slackness in the web prior to contact of the roller. Since the web is sliding the entry angle is not necessarily $90^{o}$ and some scratching of the web surface should be expected. A device that is similar to the D bar is the Dead bar. The Dead bar is similar to the D bar in that it is a stationary surface that the web must slide over. It is dissimilar to the D bar in that it is just a straight cylindrical bar with a smooth surface. The Dead bar is not a spreading device by Swanson’s [1] definition. If a web running over a Dead bar was slit, the two slits would not separate. A Dead bar is an anti-wrinkle device that attempts to prevent wrinkles by not providing sufficient traction between the web and the bar to sustain the cross machine compressive stress associated with the wrinkle. The D bar is a spreading device by Swanson’s definition.

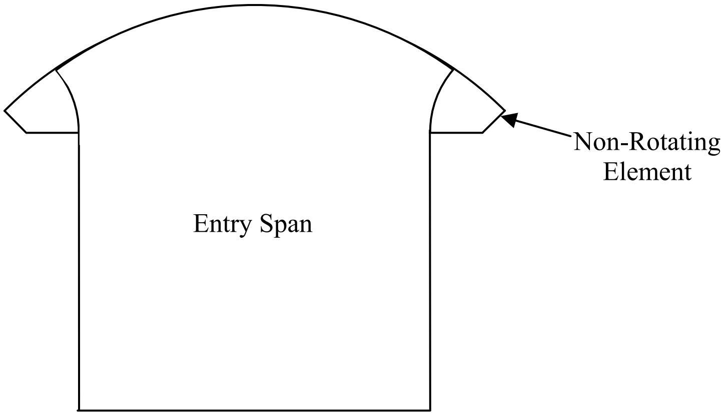


Figure 3 – A D Bar that works on the Sliding Principle

3. The third principle by which webs can be spread is the ***moment induction*** principle. A roller which has a variation in radius across its width will induce a variation in machine direction strain across its width. This strain will be responsible for inducing a variation in machine direction stress across the web width. If these stresses are multiplied times the area they act over and by the distance between the point where the stress acts and the center of the web and then integrated across the web width a steering moment can be calculated. Perhaps the simplest example of this behavior is given by a roller with a linear taper in radius across its width. The tapered roller will steer a web to the side of the roller which has the largest radius. Beisel and Good [3] derive the level of moment induced by a set radial taper and the amount the web should be steered given adequate friction to sustain the steering forces. A tapered roller is not a spreading roller, in fact Beisel and Good go further to calculate the degree of taper which will result in web troughs that will gather rather than spread the web. Concave rollers, bow-tie rollers, and rollers with tape bumpers are examples of rollers that spread webs using this principle. If a web is allowed to track to one side of these rollers a moment will be induced as discussed and the web will be steered towards the edge of the roller where the radius is largest. Webs that require spreading are troughed and if centered on one these rollers the two sides of the web will behave independently and they will be steered apart and spread as shown in Figure 4. Markum and Good [4] derive the amount of lateral slackness in a web that can be eliminated using concave and bow-tie rollers.

Now that the principles of spreading have been defined let us return to the flexible spreader roller. Carlson [5] purports the principle of operation of the flexible spreader roller is due to the rubber lands expanding laterally. The rubber lands deform laterally due to their geometry and to the pressure between the web and the rubber lands due to web tension. A schematic of the lateral expansion of the lands is shown in Figure 5. If the web remains in contact with the lands the theory is that any lateral slackness in the web would be removed and possibly stretched some amount. The flaw in this proposal is that as the web exits contact from the roller the rubber lands would return to their undeformed state and the web would return to its original slack width. It is apparent from Swanson's [1] tests that this is not the case; the flexible spreader roller can spread a web and it will remain spread downstream. Thus these devices must operate by some other principle, and since there are only three documented principles let us determine if in fact one of them can be used to successfully predict the behavior of this device. Also most spreading devices achieve the majority of their spreading effect in the entry span of web prior to actual contact of the spreading device. A common misconception is that the majority of the spreading occurs in the web while that web is in contact with the spreading device.

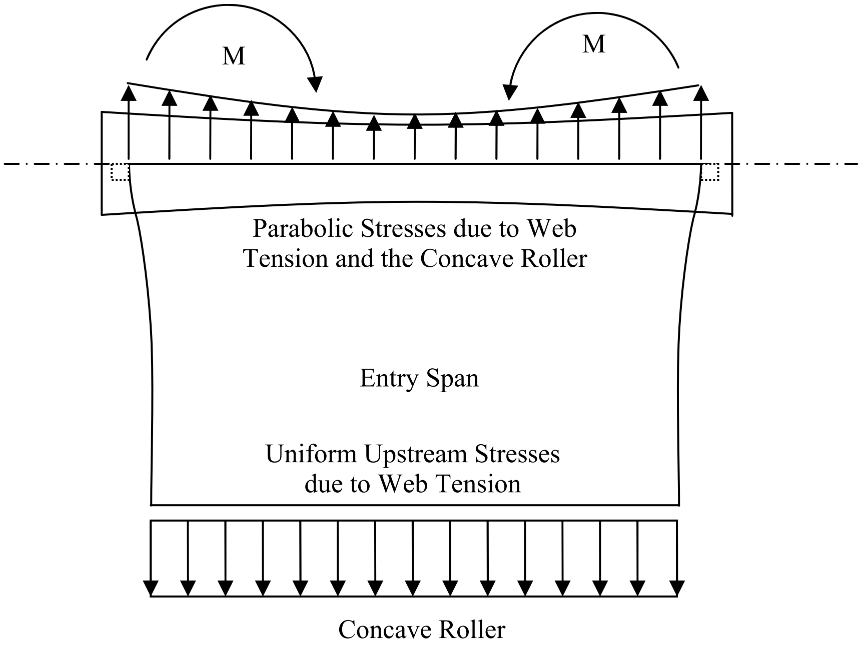


Figure 4 – A Concave Roller spreading a web by the Moment Induction Principle

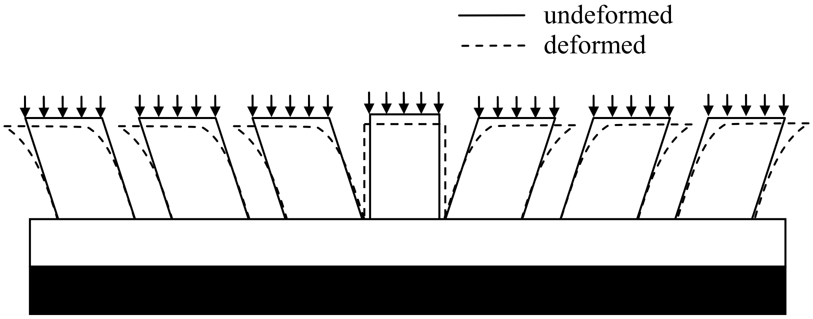


Figure 5 – Deflection of Rubber Lands due to Web Tension

The *sliding* principle can be eliminated by observation. Flexible spreader rollers should be mounted on low friction bearings and it should be safe to assume that the rubber lands are moving at essentially the same velocity as the web. The friction coefficient between most webs and the rubber lands will be 0.3 or greater when air lubrication is not a problem. Thus the potential for relative slip is low and the *sliding* principle does not appear to be a viable candidate.

The *moment induction* principle can also be eliminated by observation. For a uniform web that is subject to uniform web tension we can envision a nearly uniform pressure being exerted atop the rubber lands, again refer to Figure 5. Under these conditions there would be no propensity for the deformed radius of the lands to be any larger at the web edge than at the center of the roller. In fact the converse is probably true; the deformed radius of the center of the roller probably is greater than the deformed radius of the lands near the web edges. Often the grooves begin away from the center of the roller as shown in Figure 1 and sometimes the groove depth increases as the grooves progress towards the edges of the roller. These practices would result in a radial crown that would be maximum at the center of the roller and would decrease toward the edges of the roller when the web exerts pressure on the face of the roller. Rollers with crown are known to induce slackness and wrinkles in webs. For a crowned roller the moments in Figure 4 change sign and the web halves steer towards one another. To induce spreading the deformed surface of the flexible spreader would have to become concave. It would appear likely that if anything the deformed surface has a small degree of crown but since the roller spreads the web [1], we can conclude the *moment induction* principle is not responsible for whatever spreading does occur.

By observation we have eliminated the sliding and moment induction principles of spreading. All that remains is the normal entry principle of spreading as a potential candidate for the operating principle of this device. Let us now examine if the first principle of spreading can be shown to be applicable to the flexible spreader roller.

## LABORATORY INVESTIGATION OF FLEXIBLE SPREADER ROLLERS

A set of four flexible spreader rollers were obtained for a laboratory investigation. The rollers will be referred to herein by the color of the rubber covers. The parameters of these rollers were not developed as part of a “designed experiment,” they were simply four rollers that were available in the laboratory.

| Roller | Black | Blue | Brown | Green |
|---|---|---|---|---|
| LW (cm) | 1.09 | 0.85 | 1.02 | 0.84 |
| LH (cm) | 0.83 | 0.84 | 0.84 | 1.14 |
| GW (cm) | 0.25 | 0.48 | 0.25 | 0.51 |
| $\phi$ (deg) | $70^{o}$ | $60^{o}$ | $61^{o}$ | $60^{o}$ |
| D (2R- cm) | 7.62 | 10.16 | 10.795 | 11.43 |
| Durometer (IRHD) | 29 | 22 | 30 | 30 |
| $\alpha$ (deg) | $84^{o}$ | $77^{o}$ | $86^{o}$ | $86^{o}$ |
| NGR | 2 | 6 | 2 | 2 |

Table 1 – Parameters of Tested Spreader Rollers (NGR is the number of helical grooves cut on each side of the roller)

In this investigation a variation of Swanson's spreading test was employed [1]. A 2.54 cm wide polyester web (E = 4 GPa) which was 25.4 μm thick was transported over each of the four rollers in Table 1. Many of the variables in Table 1 were defined in Figure 1. The rubber hardness will be needed later in analysis. NGR is the number of grooves cut in the spiral pattern. The web was intentionally guided off the machine center in the span upstream of the test span as shown in Figure 6. The intention was to determine if a web would be steered by the flexible spreader roller. During a typical experiment the web velocity would be held constant at 15 mpm. Tension would be adjusted as close to zero as possible in the test section and the downstream lateral deformation was recorded using a Fife edge sensor. The tension was then increased in increments of 1.75 N/cm. As the web tension was increased it was evident that the web was being steered toward the edge of the flexible spreader roller, which is consistent with spreading had there been web on the other side of the roller. After the web edge position had stabilized at a given tension, the edge detector was used to measure the new web edge position. These tests were conducted on span lengths of 51, 102, and 152 cm on each roller.

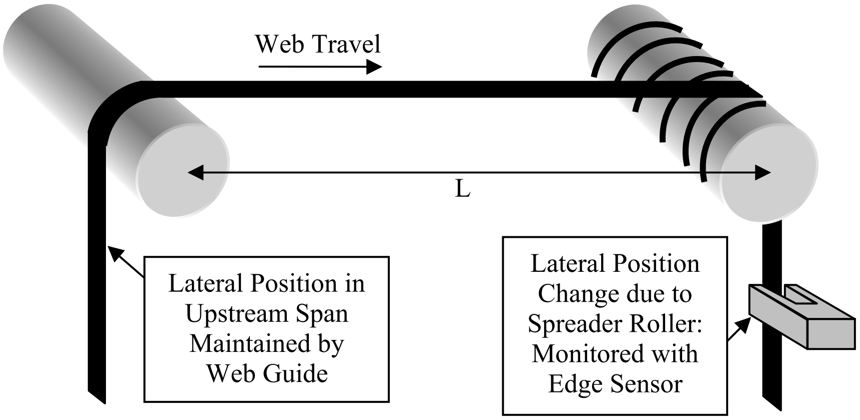


Figure 6– A Test to Determine the Ability of a Flexible Spreader Roller to Steer a Web

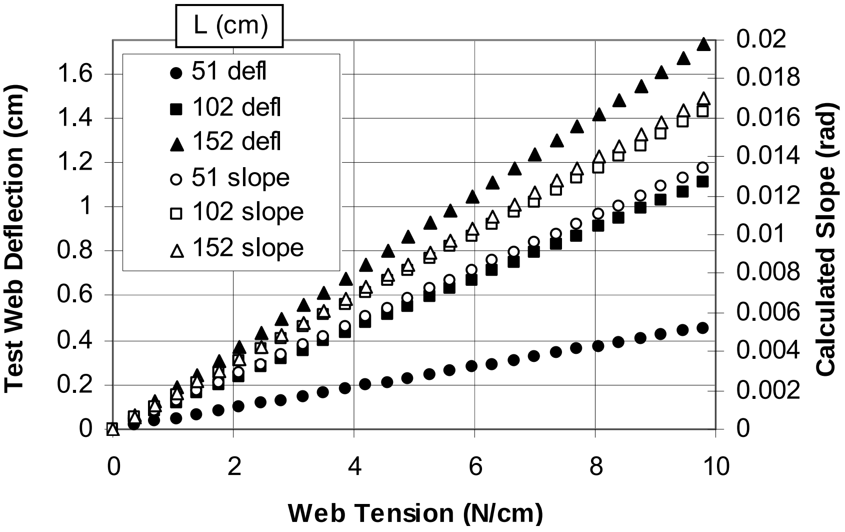


Figure 7 – Test Results for the Black Spreader Roller

The results of these tests for the Black roller are shown in Figure 7. Note the web deflection appears to be linear with respect to web tension for the three span lengths. Also note that the edge deflection appears to be proportional to the length of the entering span at a given web tension. If the flexible spreader roller does rely on the normal entry principle then the rubber lands must rotate about an axis that is normal to the entry web plane. This rotation is due to the contact pressure between the web and the spreader roller that resulted from web tension. The effect of this rotation is that the web is steered laterally; very similar to the way in which a web is steered by a misaligned roller as shown in Figure 8. As the web is steered laterally on the roller a steering force (F) develops between the web and roller. Shelton found that the moment in a web approaching a roller was zero [6]. This "beam" of web can be treated as a cantilever beam with a tip load (F). The lateral deformation (v) and the slope (θ) at the tip of the beam are documented as [7]:

$$v = \frac{FL^3}{3EI} \quad \text{and} \quad \theta = \frac{FL^2}{2EI} \tag{\{1\}}$$

In these expressions E is the modulus of elasticity of the web and I is the area moment of inertia (for a web this is $tW^3/12$ where t is the web thickness and W is the web width). If we compare the lateral deformation and the slope at the tip, the following expression can be used to determine the lateral deformation of a web due to a downstream misaligned roller:

$$v = \frac{2}{3} L\theta \tag{\{2\}}$$

Expression {2} neglects the effects of web tension and shear stiffness. Expression {2} was used to determine what misalignment or slope (θ) would have been necessary to produce the deformations measured during the experiments. These misalignments are presented in Figure 7. Note that even though the edge displacements are very different for the three entry span lengths, the misalignments that produced them are nearly identical. Whereas the edge displacements are shown to be both a function of web tension and entry span length, the misalignment appears to depend mainly on web tension. Thus it appears the web tension causes an out-of-plane misalignment of the land at the tangent point where the web first contacts the lands on the flexible spreader roller. Results for Blue, Brown, and Green rollers are shown in Figures 9, 10, and 11 and show similar behavior to that of the Black roller.

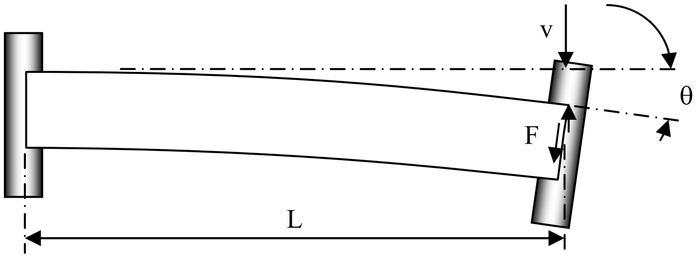


Figure 8 – The Lateral Deformation of a Web Due to a Misaligned Roller

Swanson [1] and Walker [8] had hypothesized that the flexible spreader must operate on the same principle as the curved axis roller and the expanding surface roller. They did so because they knew that flexible spreaders where capable of spreading a web more than the lateral deflection of the lands. They assumed a steering angle (θ) of the lands must be responsible for the spreading that was witnessed.

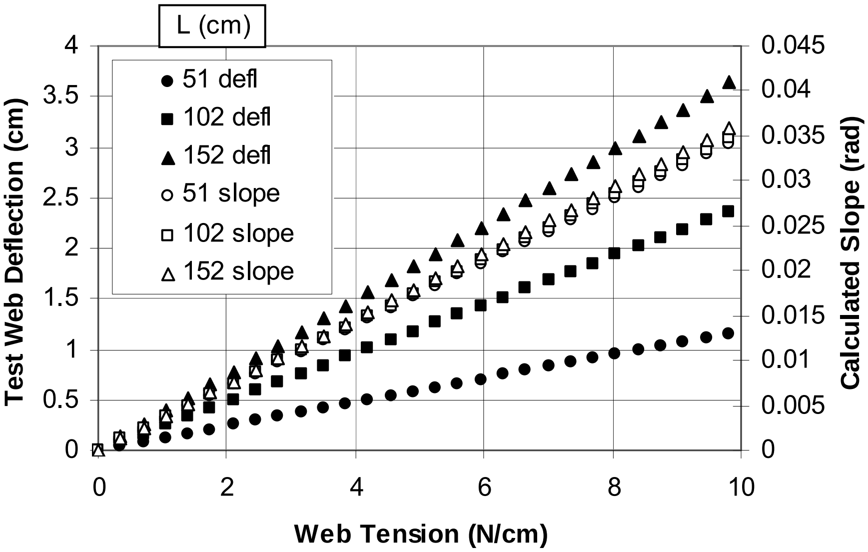


Figure 9 – Test Results for the Blue Spreader Roller

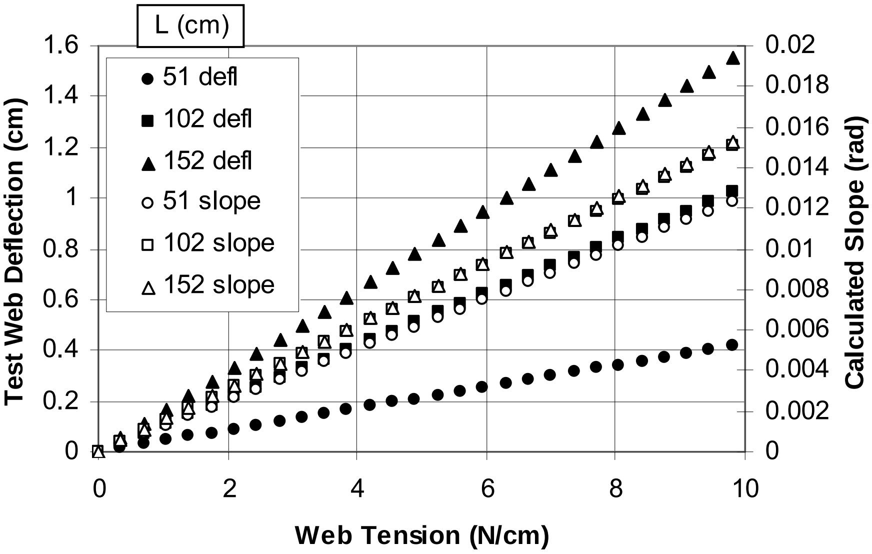


Figure 10 – Test Results for the Brown Spreader Roller

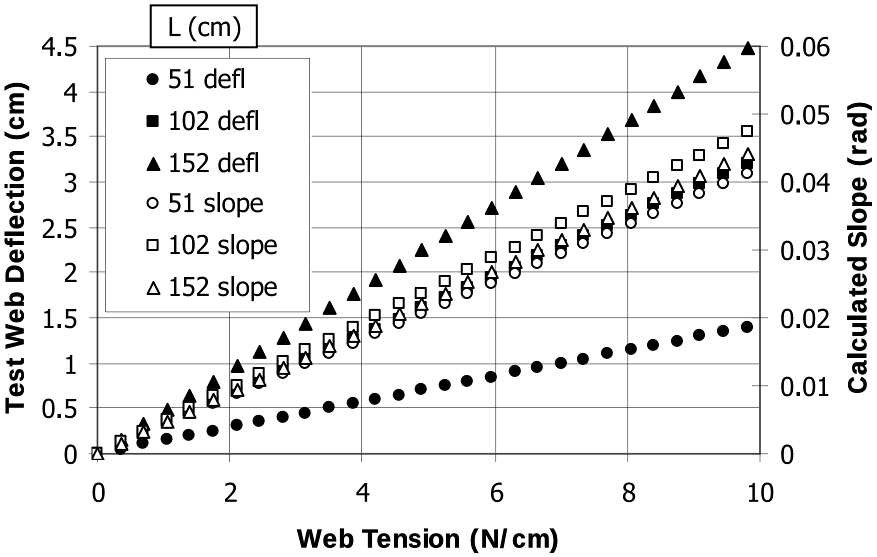


Figure 11– Test Results for the Green Spreader Roller

## THE MECHANICS OF GROOVED FLEXIBLE SPREADER ROLLERS

At this point we have established that flexible spreader rollers function based upon the normal entry principle. Next we will establish the relationship between the misalignment (that we have shown to induce the steering) and web tension. We will model the rubber lands and study their deformation which results from the pressure that is locally applied to the land due to web tension and the web throughout the angle of wrap. We will assume the helix angle ($\alpha$) to be zero and we will show it to be arbitrary in terms of the spreading effect.

In Figure 12 the cover of the flexible spreader is shown in a planar state for simplification. The points j and k would have identical coordinates if the cover was drawn in cylindrical coordinates. The curiosity is the deformation of the rubber lands due the local pressures (P) they are subjected to that result from the contact of the tensioned web and the surface of the roller. For an ungrooved roller surface the contact pressure between the web and the roller surface is calculated as the web tension ($T_w$) in units of load per unit width divided by the outside radius of the roller (R). For a grooved roller surface the contact pressure increases because pressure can only act at the top of the lands. The corrected contact pressure is:

$$P = \frac{T_W}{R}\frac{LW + GW}{LW} \tag{3}$$

To determine the deformation of the rubber lands due to this pressure the finite element method was employed. The rubber lands were modeled using 8 node 3 dimensional brick elements as shown in Figure 13. Entire lands were modeled and the nodes at the bottom of each land were fully constrained. Thus the stiffness of the uncut rubber bonded to the metal shell and the metal shell were assumed large in comparison to the stiffness of the land. The validity of this assumption will be discussed later. There were no constraints enforced on those nodes that were located on the y face cuts in Figure 12. The deformations of the nodes we wish to explore are in the vicinity of the contact pressure loadings and the nodes on these y-face cuts are so distant that their constraint will not affect those nodal deformations we are interested in. The validity of this assumption will be shown in the finite element results. The rubber was modeled as a linear isotropic material in these analyses. The modulus of the rubber was inferred through hardness readings taken with a handheld durometer whose output was recorded for each roller in Table 1. The hardness readings were converted to modulus using the expression [9]:

$$E = 145.7e^{0.0564*IRHD}\ \text{kPa} \quad (E = 20.97e^{0.0564*IRHD}\ \text{psi}) \tag{4}$$

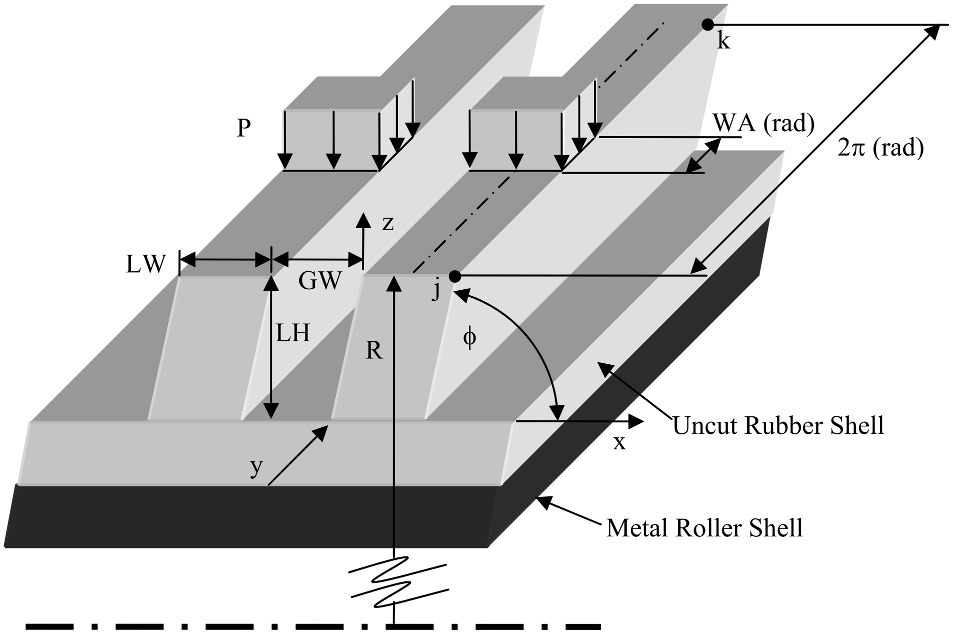


Figure 12 – The Cover of a Flexible Spreader Roller presented in a Planar Space

This expression is a curve fit of many compression tests conducted on natural and 5 different types of synthetic rubber per the ASTM specification[1]. The modulus of rubber is temperature and strain rate dependent. Expression {4} was developed for use at room temperature for conditions where the strain rates are approximately 1 m/m/min (1 in/in/min). For conditions where the operational temperatures are less than room temperatures or at high web velocities where the strain rate would be high the modulus of rubber can be expected to be higher than that given by expression {4} and thus the rubber lands will deflect less. The converse is also true.

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[1] ASTM D 575, "Standard Test Methods for Rubber Properties in Compression," Annual Book of ASTM Standards, 100 Barr Harbor Drive, West Conshohocken, PA, USA.

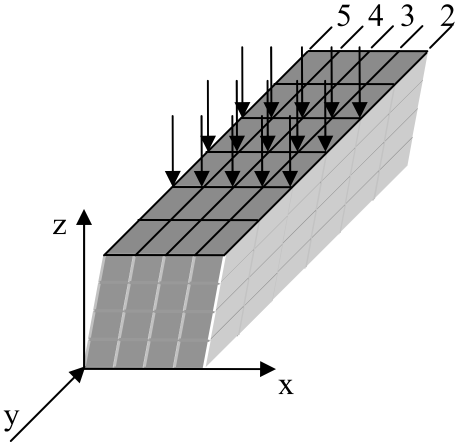

Figure 13 – Finite Element Modeling of the Rubber Lands

## RESULTS

The x deformation of a land on the Black roller is shown in Figure 14. These deformations are the result of a 34 kPa (4.93 psi) pressure acting radially inward on the land through a wrap angle of $\pi/2$ radians. The 34 kPa contact pressure may appear small but it is associated with a substantial web tension of 10.5 N/cm (6 pli). The legend in Figure 14 refers to the rows of nodes shown in Figure 13. Note that the lateral deformation is essentially zero prior to the web entry and after the web exit points. Thus the assumption that the y-faces would be unconstrained appears inconsequential; those faces could have been fully constrained without affecting the solution. Also note that at a contact pressure associated with a large web tension that the maximum deformation of the land is about 450 μm (0.018 in), which is small compared to the 0.4 to 1.7 cm of web steering deformation that was reported in Figure 7. The analysis of the roller is unaffected by the length of the entry span. The deformations of the lands are affected only by the web tension, the geometry of the cross section of the land, and the modulus of the rubber from which the land is composed. Please note throughout much of the angle of wrap the deformation of the land is nearly constant. If the same analysis is conducted for a wrap angle of $\pi$ radians the maximum deformation of 450 μm remains unchanged, but it occurs over a wider range of wrap or arc distance on the roller surface. On the fifth row of nodes the maximum deformation has decreased to 75 μm (0.003 in). All together this would appear to dispel the notion that the outward motion of the land is responsible for the spreading that has been exhibited by flexible spreader rollers in laboratory tests.

Now please note that at the web entry point that the land has already begun deflecting laterally in Figure 14 and that the land has a slope which would be counterclockwise about the Z axis in Figure 13. This slope is maximum for row 1 and proceeds to a smaller value at row 5 which can be seen more clearly in Figure 15. The slopes of the 5 rows of nodes were then averaged at the web entry point. This analysis was conducted for each of the 4 rollers shown in Table 1 for a web tension of 10.5 N/cm. The average slope at the entry point for each roller is shown in Table 2.

| Roller | Black | Blue | Brown | Green |
|---|---|---|---|---|
| θ (rad) | 0.0163 | 0.0408 | 0.0155 | 0.0439 |

Table 2– Slopes of Lands about the Z axis at the Web Entry Point for Web Tensions ($T_w$) of 10.5 N/cm (6 pli)

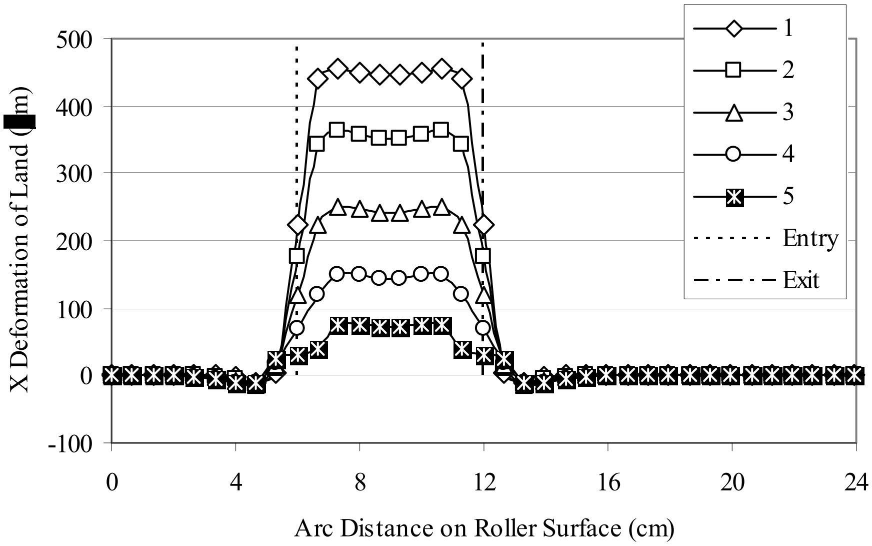

Figure 14 – Lateral Deflection of a Black Roller Land due to 34 kPa Contact Pressure

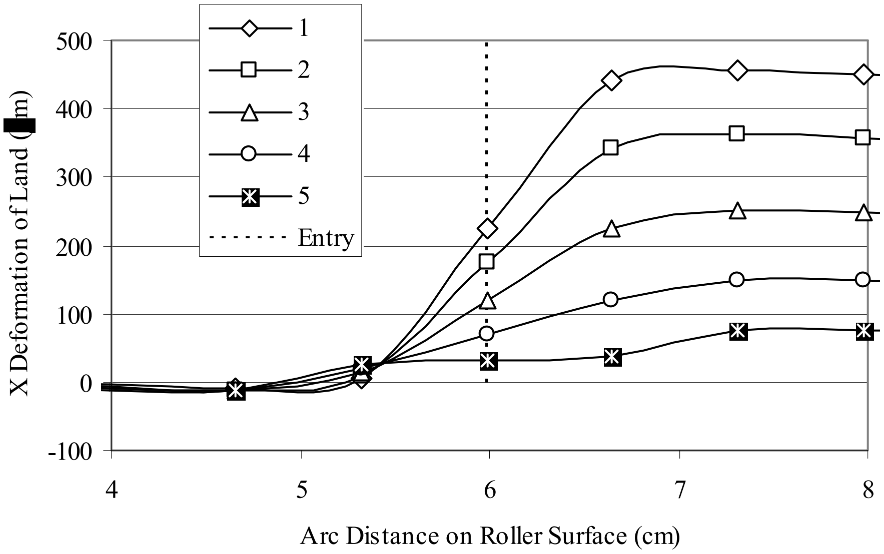

Figure 15 – Detail of Figure 14 showing the Slope of the Land at the Web Entry

With the slopes given in Table 2, the ability of a flexible spreader to steer or spread a web can be determined using expression {2}. For the flexible spreader the slope in expression {2} is dependent on the contact pressure between the web and the roller per expression {3}. The slopes in Table 2 for the 4 rollers were calculated for a web tension of 10.5 N/cm but per expression {3} the contact pressure was different for each roller depending on roller radius and the land and groove widths. If the slopes of Table 2 are normalized by web tension the amount of web steering for the 4 flexible spreader rollers can be predicted using the equations of the form of expression {2}:

$$v = \frac{2}{3} L\theta$$

$$v = \frac{2}{3}\left[\frac{0.0163}{10.5}\right] LT_w \quad \text{Black Roller}$$

$$v = \frac{2}{3}\left[\frac{0.0408}{10.5}\right] LT_w \quad \text{Blue Roller} \qquad \{5\}$$

$$v = \frac{2}{3}\left[\frac{0.0155}{10.5}\right] LT_w \quad \text{Brown Roller}$$

$$v = \frac{2}{3}\left[\frac{0.0439}{10.5}\right] LT_w \quad \text{Green Roller}$$

Expressions {5} require units of N/cm for the web tension ($T_w$) and cm for the web entry span length (L). These expressions are linearly dependent on entry span length and web tension which was the behavior shown in Figures 7, 9, 10, and 11. In Figures 16, 17, 18 and 19 the ability of expressions {5} to predict the behavior measured in the laboratory is shown. The agreement is satisfactory.

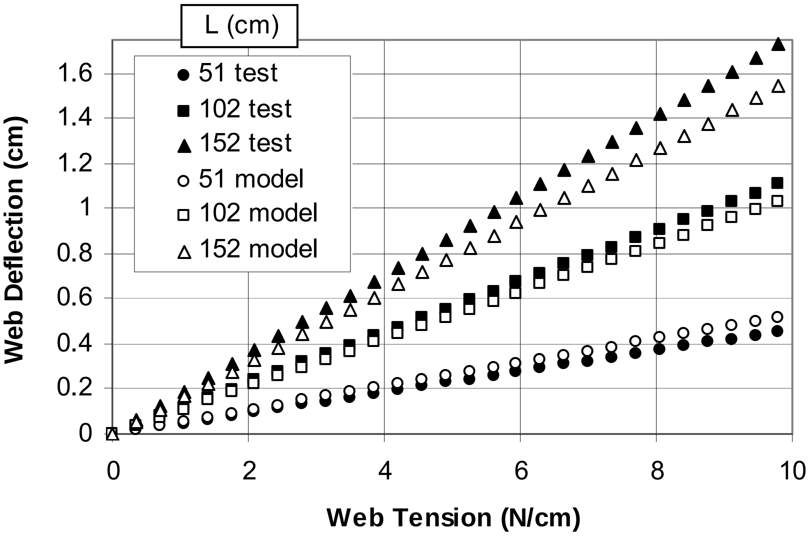

Figure 16 – Predicting the Spreading Deformation of the Black Roller

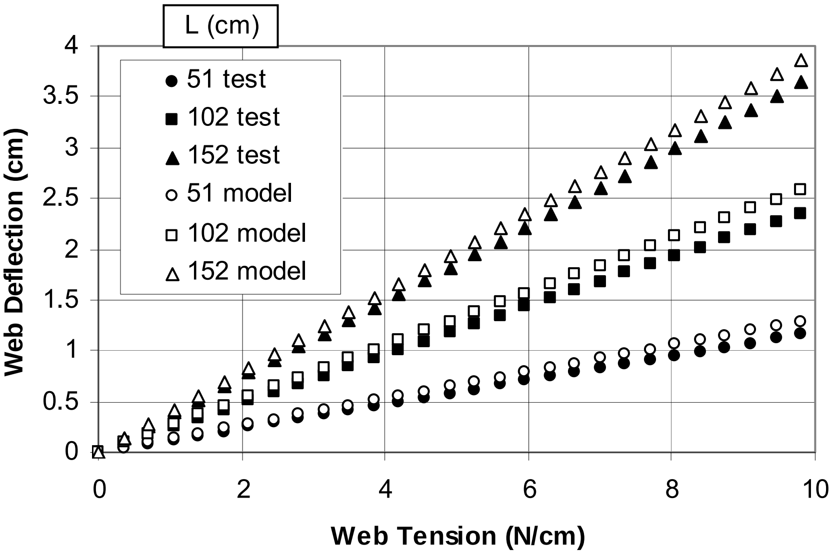

Figure 17– Predicting the Spreading Deformation of the Blue Roller

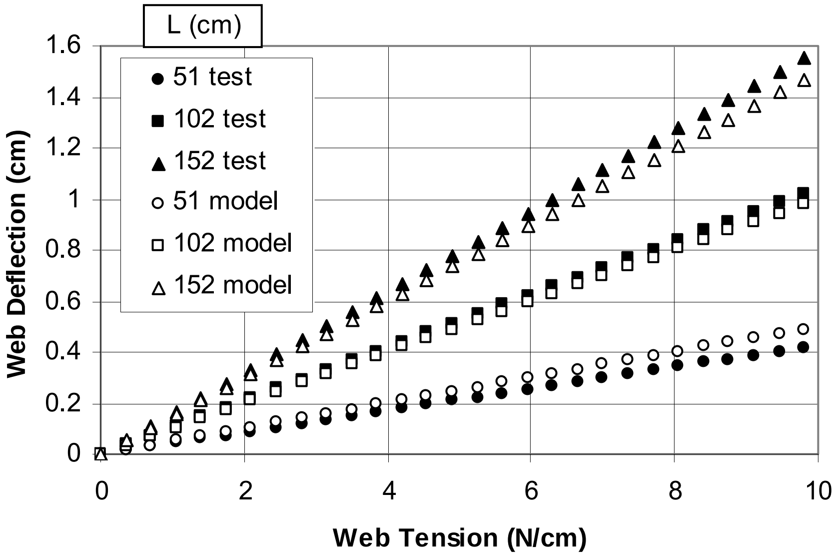

Figure 18 – Predicting the Spreading Deformation of the Brown Roller

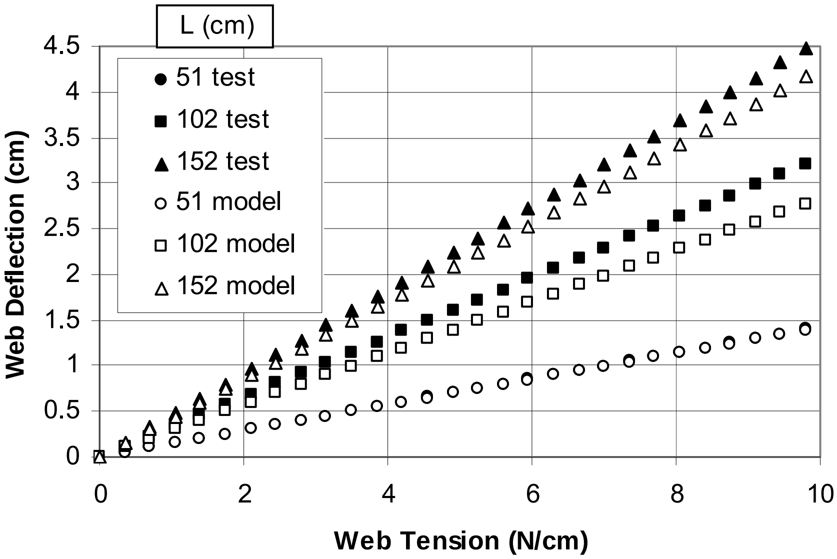

Figure 19 – Predicting the Spreading Deformation of the Green Roller

## CONCLUSIONS

Conclusive proof has been presented that the flexible spreader roller is a device that spreads webs based upon the *normal entry* principle of spreading. It has been shown that the amount of spreading can be predicted provided the slope or rotation of the rubber land about the z axis can be ascertained at the entry point of the web upon the roller.

Perhaps what makes the flexible spreader roller different from other normal entry spreaders is that web tension is required to generate this rotation. This also may be a limitation if a web cannot be run at high enough tension to remove the amount of lateral slackness that may be present. If a lightweight non-woven web must be processed that cannot be handled at tensions greater than 0.5 N/cm only a few millimeters of lateral slackness could be removed with any of the four rollers examined. With other normal entry devices the slope or rotation of the web at the point of normal entry is inherent or variable in the device. With the curved axis roller the slope is dependent on the bow plane, the radius of the curved axis and the cross machine distance from the center of the roller out to some point on the roller surface. With the expanding surface rollers the slope is dependent on the angle of the swash plates and the cross machine distance from the center of the roller out to a point on the roller surface. The slope of edge pinch rollers can be set by the operator.

Not all spreading devices can spread the web in a line where the web must be able to travel in both the forward and the reverse direction. The flexible spreader does have this capability. If the direction of web travel is reversed in Figure 13 the Exit now becomes the Entry and vice versa. Note that the Entry and Exit slopes in Figure 13 are essentially the same thus the same spreading ability would be expected independent of the direction of web travel. The manufacturers of spiral grooved flexible spreader rollers do have a preferred direction of the rollers in installation, typically shown with a direction arrow. It is possible for wrinkles to become captured between the deforming lands of a flexible spreader. With a spiral groove this captured web will be either forced towards the center of the roller or towards the web edge depending on the direction of installation, usually it is preferable to force the trapped material to the edge. Some manufacturers circumferentially groove flexible spreader rollers ($\alpha=0$). In this case there would be no preference.

In Figure 20 are some additional test results showing the ability of the Blue roller to spread a web with an entry span of 102 cm (40 in). The results show the effect of wrap angle to be minimal as discussed earlier. The chart also shows the roller achieves about 80% of the spreading in the reverse (R) direction that it achieved in the forward direction (F). It may be that there is a secondary effect of the spiral angle when the web direction is reversed but was not studied further since few have the need to run web lines in both forward and reverse directions.

It would appear that to maximize the spreading effect of the flexible spreader that parameters should be refined that would maximize land deflection. This should maximize the slope at the entry point of the web onto the roller. Decreasing land width, increasing land height, decreasing land angle and decreasing durometer would maximize the slope ($\theta$). There are understandably process limits for these parameters as well that will limit how much they can be increased or decreased. It may be difficult, for instance, to use materials with durometers less than 20 IRHD that would also have a reasonable service life.

It is important with many spreading devices that their entry span is set long enough to allow the desired spreading. It is obvious in expressions {2} and {5} and in the test data shown in Figures 16-19 that the potential spreading increases linearly with entry span length.

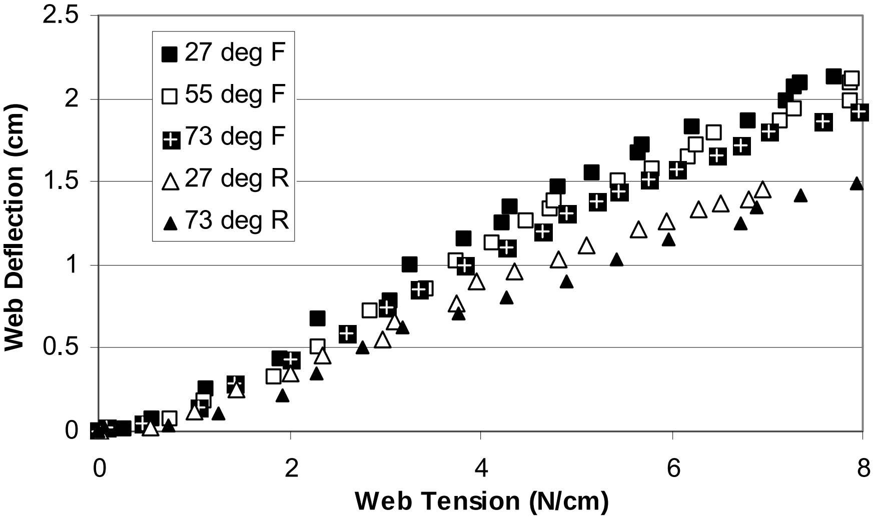

Figure 20 – Test Data showing the Effect of Wrap Angle and Web Direction

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*Analysis of Flexible Spreader Rollers*

**J. K. Good & R. Markum,**
Oklahoma State University,
USA

| **Name & Affiliation** | **Question** |
|---|---|
| Bernie Becker, ALCOA | This is relating to the deformation of the lands, yet in foil, people say in a hard surface roll with this same pattern will spread. What are you thoughts on that? |
| **Name & Affiliation** | **Answer** |
| Keith. Good, Oklahoma State University | This is no different than a spiral tape on a rigid roller. Ron Swanson proved in his paper at the Fourth IWEB that this type roller neither spreads nor prevents wrinkles. It may look like you are taking trough out of the web that gets caught between the spiral grooves and visually it may be pleasing, but you are really not spreading the web. If you slit your web down the center, the two halves would not steer apart after crossing a rigid roller with spiral grooves. If your web did spread it would be due to some other effect like web thickness variation which would have resulted with an idler that is not spiral grooved. |
| **Name & Affiliation** | **Question** |
| Bernie Becker, ALCOA | So many of the people at the plants just swear that that is the case – that these are spreaders. |
| **Name & Affiliation** | **Answer** |
| Keith Good, Oklahoma State University | It's easy to swear. There is some benefit to the grooves because they do provide a place for excess web, which has not been spread, to reside. So the grooves serve as an accumulator for the excess web. The benefit is that the web may not have to wrinkle. But since there is no spreading you are simply passing an un-spread web downstream to wrinkle on a downstream roller. |
| **Name & Affiliation** | **Question** |
| Bob Lucas, Winder Science, LLC | With respect to the flexible spreader rolls, that are grooved and supposed to spread: If you have the opportunity to actually take a tape measure and measure the overall width of the web, check the web width at the exit of one of these spirally grooved rolls. Do not be surprised if the width of the web is narrower. In the process of the web trying to conform to all of these grooves, the accumulative length of the grooves is basically forcing that roll to act as a gathering device. It may temporarily keep the paper from wrinkling at the spreader roll, but it is setting the paper up to wrinkle on the next roll. |
| **Name & Affiliation** | **Answer** |
| Keith Good, Oklahoma State University | Don't misinterpret my reason for presenting this work. I am not trying to sell flexible spreader rolls by any means. I'm trying to tell you how they work. You saw from my charts, that it is a device that requires tension to work. If you are running a lightweight web such as a nonwoven or |

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| | something like this you may find that the web tension needed to cause the slope of the rubber land at the contact point for spreading exceeds the tensile strength of the web. If it is crepe tissue or something like that, you are probably pulling the crepe and quality of the product out to try to get spreading. I am not saying that they are the cure all spreader device. My goal was to prove to you how they work so you will know when they should work for you. They can work well in some cases and may be a solution for you. |
| **Name & Affiliation** | **Question** |
| Ron Swanson, 3M | What I tell people, this is directed to Bernie Becker, when they say that spiral rolls spread: I tell them about the experiments I did and how I split the web in half upstream of various rollers that were supposed to spread the web. I tell them I split the web in half; take the razor blade, split the web in half and see if it comes apart. They usually believe you then.<br>Keith, I am surprised that it is that turning the roller around made as much difference as it did. It still spread? Are you telling us something? |
| **Name & Affiliation** | **Answer** |
| Keith Good, Oklahoma State University | First of all in the modeling, I neglected the helix angle of the cut because the helix angle does not seem to affect the spreading when run in the forward direction. The model performed admirably when estimating the spreading in the forward direction. The roller properties that do affect the spreading are the rubber hardness and all the land dimensions that affect the bending deformations of the lands which result in producing the rotation of the land about the out-of-plane axis at the point of first contact between the web and roller. So in my research I saw no effect of helix angle. The circumferential grooved rolls are more common in Europe. The spiral groove is more common in the US. With circumferential grooved rolls, I would expect no effect whatsoever and you should get equal spreading whether you run the web forwards or backwards over the roller. The spiral grooved roller is a bit more complex since the rubber land is spiraling through a three dimensional space. The spreading produced by running the spreader roller in reverse was about 80% of the spreading produced when running the spreader in the forward direction. We ran very few tests with the rollers reversed and thus there is less confidence in those test results. We had high confidence in the tests which were run in the forward direction, all tests were repeated three times and they repeated well. We ran the tests in reverse because we surmised from our modeling that the flexible spreader roller should spread in reverse and in fact it did. So with more testing it is possible that we might find that |

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| | the spreading in reverse may be even closer to the spreading when running forward. The point is somewhat mute though because of the potential for the web becoming pinched or trapped between two consecutive lands. When this occurs with the web running forward the web maybe drug laterally until the pinched web is released at the exit. If the roller is running in the reverse direction and this occurs the result is that the web gathers into a rope at the machine center which is unacceptable. So there are good reasons for not running the spiral grooved flexible spreader in reverse and thus how much they spread when running in reverse is of less importance. |
| **Name & Affiliation** | **Question** |
| Dilwyn Jones, Emral Ltd. | I was a bit surprised that normal entry might still apply. There is a very short length where the angle of the land is actually tilted. For most of the wrap it is going to be straight because this is a uniform tension and therefore it will come in straight. I expect there is going to be some serious straight, but I was wondering if more of a friction force model might be better than a normal entry type of model. |
| **Name & Affiliation** | **Answer** |
| Keith Good, Oklahoma State University | The test results speak for themselves by conforming to the $v$ is $2/3\ L\theta$ expression which confirmed that the flexible spreader was a normal entry device. One you have confirmation that you have a normal entry device the modeling of friction becomes unimportant because you know you had sufficient friction forces for the web to gain normal entry. Also it takes very little friction force to produce normal entry. So the spreading is being governed by kinematic boundary conditions (an out-of-plane slope) and not kinetic laws as limited by friction. The majority of the spreading occurs in the entry span prior to the spreading roller as was proven in the test results I presented. If this spread web then passes over the roller there will be some lasting residual spreading in the downstream span. |
| **Name & Affiliation** | **Comment** |
| Dilwyn Jones, Emral Ltd. | I am convinced you are right about the out-of-plane deformation of the land causing spreading. |
| **Name & Affiliation** | **Comment** |
| Kevin Cole, Grid Computing Solutions | The spreading is happening even before you get to the roller and even though there is a little bit of motion back, that is the second order lateral offset.<br>The other comment I wanted to make was that these results were generated for a narrow web that entered the spreader roller with offset. For a web which is much wider it will resist the normal entry rule. You are going to have spreading the extent the web will allow it. And then there |

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| | is going to be relative slip between the web and the roller. Sort of like a concave roller in that sense. |
| **Name & Affiliation** | **Answer** |
| Keith Good, Oklahoma State University | In some sense, the people that make these things acknowledge this. In some cases they vary the depth of the rubber groove cut, it is shallow at the center and gets deeper as you go toward the edges. If all lands are subject to equal pressure due to web tension the varying groove depth would produce less out-of-plane rotation for those lands near the center and more for those near the outside edges. You also have to be careful with this because the varied groove depth produces a roller cover that is radially more flexible at the edges than it is at the center. When subjected to a web under tension the deformed state starts appearing like a crown roller. Maybe not a spreading device, but a gathering device. |
| **Name & Affiliation** | **Comment** |
| Bob Lucas, Winder Science, LLC | Isn't it amazing how long that product has been in the industry and has been accepted by some sort of dogma and yet this relatively simple test has never been done? |
| **Name & Affiliation** | **Answer** |
| Keith Good, Oklahoma State University | I think the reason many of these problems have never been solved is time. Web wrinkles can be devastating in terms of profit loss but wrinkles are one of many problems that are faced daily in web process lines. My point is if you purchase a spreading device and if it eliminates wrinkles locally or it provides the amount of web spreading you desire you might not care how the device worked. With limited time you move forward to solving the next problem. The profit yielded by understanding how a device works comes from developing custom spreader devices for your particular web and web line. What I have shown you for this device is that you can adjust the amount of spreading you get by increasing either the web tension or the incoming span length. There are limits of course, the web may develop CMD tensions which ultimately limit the amount of spreading you can obtain. The in-plane stiffness of the web may be greater than the shear stiffness of the rubber. The goal of using a spreading device is not to induce large tensile CMD stresses in most cases. The goal is to remove lateral slackness in the web that could have many causes and to get the web flat and planar prior to entering a critical web process or a winder or a nip where wrinkles would be unacceptable. If you know how much lateral slackness you have you can use the method I have shown to produce a flexible spreader roller that will remove that slackness. |

## DISCUSSION III

**Leaders: D. Perdue,** Goss International Inc. and **P. Fussey,** AET Films

| **Name & Affiliation** | **Question** |
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| Steve Lange, Procter & Gamble | This is a question for Tim Walker concerning the concave roller. I agree that they're effective spreaders, and I've used them. The question I have is what effect do they have on lateral stability? What if you have a web lateral offset error? Does it amplify it? No effect? |
| **Name & Affiliation** | **Answer** |
| Tim Walker, TJ Walker and Associates | Obviously, if the web is off center on these devices they would steer towards the side that the web is off center. Hopefully the web is not so far off center that it is totally off one taper and only contacting the other taper, because the steering forces are all in one direction. As long as the web remains partially on each taper, there's a spreading effect. There certainly would be instability. If web approaches the concave roller off center, the web will move more off center. Perhaps the question should be, do we want the web to enter a roller off center and then exit wrinkled, or do we want the web to enter the roller off center and then exit more off center and not wrinkled? I'd pick the latter. |
| **Name & Affiliation** | **Question** |
| John Shelton, Oklahoma State University | This is a follow-up to "the bigger is not always better" rule-of-thumb: There was an accumulator manufacturer who somehow discovered concave rollers and if one was good, more was even better yet. So, they modestly concaved every roll in the accumulator and started up a diaper line with a centered web. It shot off to the right side, literally off the rolls. Then they re-webbed the machine and the web shot off to the left side. Narrow webs can have low bending stiffness and if too many spreaders are installed in succession of if a few devices are installed with a variation in diameter that is to radical a bi-stable response can result. |
| **Name & Affiliation** | **Answer** |
| Neal Michal, Kimberly Clark | This question is for Tim Walker on using rollers with steps in the radius profile rather than parabolic or some other form of continuous concavity. Sometimes steps are used to produce a more permanent spreading solution than tape at the edge of rollers. Is there any benefit to stability if the roller just has the edge steps? One thing that we've seen in our wovens is that because we need such a little step to spread that it's really hard to find the spreader roll, so we typically machine a step that you can find with your thumbnail. I was just wondering what your thoughts were |

regarding web instability when the web gets off center for a roller with a stepped radius versus a concave spreader roller.

| **Name & Affiliation** | **Question** |
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| Tim Walker, TJ Walker and Associates | I usually avoid the step approach. If you can get by with a small step and that spreads your web effectively, great. The step approach is most common because the operator can do this by wrapping tape around the roller edges. The problem with using tape is that once enough wraps are laid on to the roll edge to generate the spreading needed that there is also a considerable shear induced in the web at the point the tape begins. And often a little wrinkle results right at the shearing point. If you employ a linear taper, or a parabolic profile you avoid that negative effect of the step.<br>To answer your question concerning stability one needs to study the destabilizing moments that are induced as a result of the web tracking off the center of the roller. When the web is tracking down the center of either roller the moment is zero. For the concave roller the moment increases continually with lateral offset of the web. For the stepped radius profile the changes in moment can be more abrupt, particularly as the web tracks over the edge of the step. So I favor the linear or the parabolic profile over the stepped profile for stability reasons as well.<br>I'm not advocating these rollers. They're a tool to use when you have a problem. Maybe your problem is you have a heated foil that wants to wrinkle, or you are moisturizing paper and the web wants to wrinkle, or you have an accumulator that goes out of alignment when it accumulates and wants to induce web wrinkles. You often start a trial with a piece of masking tape at roll edges. If that's acceptable, you're done you have solved your problems for five cents. If the tendency to wrinkle is greater you find that you need more than one band of masking tape. Maybe you put on one band of tape, then two bands next to it to build a taper with the masking tape. You have created a masking tape bow-tie roller. If you need this spreading for the life of the machine, why do it with masking tape? Let's machine it in. But if you have big web width changes or big off center changes, these are the negatives of trying to permanently machine a roller radius profile. Yes, there are there are dangers of using these rollers incorrectly, but again, there are a lot of times where they save the day and allow the web line to run. If you have a persistent wrinkle in a web process that you can't get rid of this is a very inexpensive solution to go from 100% waste to zero. |

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| **Name & Affiliation** | **Answer** |
| Ray Comeau, Dofasco Inc. | I work for a steel company, so I'd just like to make a comment about the tracking and accumulator that was just mentioned by John Shelton. We use convex rollers instead of concave rollers and we do so because the convex roller will center the web in the machine, we have less concern with wrinkling and we have very long spans of steel strip. |
| **Name & Affiliation** | **Question** |
| Duane Smith, Black Clawson | Just to add to what Keith Good findings were, I had a situation where a flexible spreader was installed backwards. It was not going to be easy to change, and we did prove that it was a spreading device by again, putting the center slit in there and watching it spread, so we do have some empirical data that backs us up. Now, we didn't turn it around and see if it produced 80% of the spreading that it would have had it been installed correctly, but it was still a very effective spreader. You have shown us that the length of the entry span is important. You have also commented on the residual spreading in the web after the roller and how it might be slightly less. Would you comment on this and also on the importance of the exit span length? Is it indeed true that the exit span is not critical when you're using a flexible spreader? And also, I guess that would apply to Tim, with the concave roller too. |
| **Name & Affiliation** | **Answer** |
| Keith Good, Oklahoma State University | Duane, I have not conducted studies on how much of the spreading is retained downstream. For many spreaders the effect of the spreader is brief. I produced a chart for the Black roller that displayed the lateral deformation of the land in its contact region with the web. I would have you note that this chart projects the exit angle of the web would be equal in magnitude but opposite in sign to the entry angle. Thus it would seem reasonable to keep the exit span relatively short if you want to retain the majority of the spreading you gained in the entry span. |
| **Name & Affiliation** | **Question** |
| Unknown | We do witness troughs in exit spans after spreading devices sometimes. |

| **Name & Affiliation** | **Answer** |
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| Keith Good, Oklahoma State University | No spreading device will keep a single web spread for any great distance. If CMD tensile stresses were generated those will be lost in a span distance of one web width or less downstream.<br>Yes, some devices will cause troughs in the downstream span. A concave roller with too much diameter variation can induce troughs in the downstream span. Deflecting idlers will gather the web further as the web proceeds further downstream and at some point you may need to spread the web again. So, this is why it is important that you don't follow the more is better rule and that you limit the amount of diameter variation you machine in your rolls. The tendency is to design the roller to remove the maximum lateral slackness that is witnessed in the web and if that incoming lateral slackness is not constant that can sometimes induce some of the instability problems. These are good devices as long as the radius profile is not too aggressive. |
| **Name & Affiliation** | **Question** |
| Tim Walker, TJ Walker and Associates | The whole point of my paper is that you engineer these correctly and don't go crazy with them. The length of the exit span is important and often you do put the spreader close to the critical point where the web must be spread and planar. So if this spreader is just upstream of a nip or a winding point, then you probably want a short exit span. A short exit span is nice and stiff and usually less wrinkle sensitive than a long one. |
| **Name & Affiliation** | **Answer** |
| Paul Fussey, AET Films | I have a question for Dave Roisum. Could you go a little bit more into depth on your modified s-curve/z-curve for winder set up for telescoping and do those breakpoints that you're seeing physically in a roll, having to do with sort a typical breakpoints you see on a radial or tangential stress plot, where you do see breakpoints at certain areas, …in terms of being able to predict rather than react? |
| **Name & Affiliation** | **Question** |
| Dave Roisum, Finishing Technologies | I'd suggest you take a look at the new book on winding that Keith Good and I have written entitled Winding: Machines, Mechanics, and Measurements. It is available for review in the lobby. The text has pictures and explanations. But I will explain briefly. The way to think about it is the applied winding torque is exceeding the available friction down near the core, so there is a certain amount of layers that are sliding near the core. That is the area you don't want to loosen. You want to take that and hold that maximum tension until you're way beyond that slippage region. It's a little more involved to say how you actually get a z-curve out it, but an operator taught me this. The operator figured this out while running the same |

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| | product over a two year running period. They only had one problem to solve and that was to reduce the amount of telescoping. Day in and day out, they took a curve that they could warp that they started out from a linear curve, then they increased the taper more and once they got maximum taper, which would be as high as it would go at the bottom and as low as you could go at the end, then they started to gently warp this thing. Over the course of a year, looking at this roll, the roll taught them that the optimal winding tension profile was the z-curve for maximum resistance to telescoping. You can get to the curve you need with winding models or by empirical methods to determine the breakpoints. |
| **Name & Affiliation** | **Answer** |
| Dan Perdue, Goss International | This question is closely related to Dilwyn's paper. This comes up from time to time, not necessarily with the heavy webs that he was talking about but with what I might consider to be more normal web densities, like paper and the thin films that we have. What is the maximum distance that you can transport a web between your rollers? We have a general rule of thumb. Are there others? What's the rule of thumb based on? Are there technical criteria? How far apart can I place my rollers and what goes wrong when they are too far apart? |
| **Name & Affiliation** | **Question** |
| Tim Walker, TJ Walker and Associates | Part of it comes back to this debate of where do cambered webs go. From Ron's work, I have been taught from that, that cambered webs steer laterally towards their long side. To me this implies that the edges of a baggy center web wants to steer towards the center and wrinkle the web, especially in long spans. The wrinkling of a baggy web in a long span is the top concern. And some of the other mechanisms of wrinkling, that I call tracking wrinkles, from deflection from diameter variations, from the web that's expanding from moisture or heat or viscoelastic recovery. All those are worse in long spans, and so my philosophy is to tend to go towards short spans of twice the web width, 1.5 times the web width or even shorter. The negative effects of short spans are the equipment errors that can create wrinkles. There are more rollers in the web line that may have misalignment, taper, etc. I ask people if they have more control of machine quality or web quality. Of course we have much greater control of the machine quality. Often it is difficult to improve the web quality. Long spans are more sensitive to bad or poor quality webs, short spans are more sensitive to bad equipment, so I tell people short is the way to go. |
| **Name & Affiliation** | **Answer** |
| Kee-Hyuniam Shin, Konkuk University | The ratio between the width and the length can affect wrinkling, based on our experiments and then our simulations. It can generate a stress distribution based on |

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| | that ratio depending on the material thickness. The span length also affects the time constant, depending on the length of the span and the speed of the web, which affects the transient behavior of the web. |
| **Name & Affiliation** | **Question** |
| Unknown | One observation on the cambered web issue: If you are looking at a uniform web that is approaching a misaligned roller, your point of reference for the misaligned web would be where the web was tracking before you misaligned the roller. You would measure the displacement after you misaligned the roller from that point. With a cambered web, you really ought to look at it the same way. You really ought to look at the relaxed position of the web, before the camber takes effect and does any steering. If you look at Ron Swanson’s work, you find that most of the steering from that relaxed position is towards the long side of the camber. What we wind up looking at and focusing on is the displacement of the center line of that curved web from the center line of where a uniform web would have been, which is a very small quantity. In Ron’s test it was a fraction of a millimeter and that fraction of a millimeter was only 2.7% of the total deflection that the cambered web steered. So one thing that Ron did prove is that the web deflects toward the long side but the majority of the steering deflection takes it back to the center line. You get very close to that center line. If you look at all of this data, it says that. So the only test data we’ve got on a cambered web basically said the web deflects toward the long side and winds up almost on the center line where a uniform web would have been, like within a percent or so. For a uniform web, we are usually happy if we can predict its tracking with a few percent accuracy. So we are quibbling about a very, very small error. |
| **Name & Affiliation** | **Answer** |
| Dilwyn Jones, Emral Ltd. | In my paper the displacements were taken from the straight web center line, not from the relaxed state. In most practical cases, I believe the steering effect would be small. You bring the web more or less back to the straight running condition. Take out all of the natural camber. However, I think in one or two cases, I showed that you got a bigger steering effect to the short side than that is a quite large amount. I think it needs to be looked at experimentally. |
| **Name & Affiliation** | **Question** |
| Steve Lange, P & G | I happen to have a web that I am processing that is traverse wound, it’s a narrow web. It has built in camber on each end of the roll, so as it moves from one end of the roll across to the other side the camber shifts. It basically goes from no camber in the middle, camber one direction on one end of the roll and one on the other. I can definitely tell you it shifts to the long side depending on the shape of the |

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| | camber. I'll have to collect the data and show you all maybe next time. At least experimentally, or empirically, that's what I observe with that particular web. |
| **Name & Affiliation** | **Answer** |
| Tim Walker, TJ Walker and Associates | I think we should make some baggy center web and perform the Swanson spreading test. Let's plunge a knife in the center of a web with a baggy center and see where the halves steer. |
| **Name & Affiliation** | **Question** |
| John Shelton, Oklahoma State University | This question is posed for Dilwyn Jones. I believe at IWEB in 1997 I published data acquired in 1971 taken on the machine used for my thesis research. The 1971 cambered web test was conducted using a web that was cut out of a flat web by a machinist. He used a template and cut the cambered web out of a thick flat web of thick oriented polystyrene with a modulus of elasticity of 450,000 psi. When the tension was very low, about ¼ - ½ critical, the web steered to the short side. When the tension approached the critical value, that is when you got rid of nearly all the slackness, the web steered toward the long side. When the tension was increased to three times the critical value the steering vanished, it approached zero. Zero was not very well defined, it was erratic. As Ron Swanson would attest to, it's very difficult to take data on a cambered web because of imperfections. So I have observed a few cases where the web going toward the tight or shorter side. But as Bruce Feiertag has observed, the norm is that a cambered web steers toward the loose or long side when running over parallel cylindrical rollers. You were not talking about a taught web, were you? |
| **Name & Affiliation** | **Answer** |
| Dilwyn Jones, Emral Ltd. | A taught web, with no sag, did not steer. It went straight in the model. |