PRACTICE APPLICATION AND DESIGN OF CONCAVE ROLLERS

by

T. J. Walker
T. J. Walker And Associates, Inc.
USA

ABSTRACT

A concave roller is an effective and inexpensive wrinkle-preventing roller design. By definition, a concave roller (a.k.a. a reverse-crowned roller) is a roller with a larger diameter at the edges than at its center. But a definition is not an engineering specification. What is the right amount of diameter variation? What is the best way to shift from large to small diameter? This paper will present a simple, logical approach to specifying a concave roller's profile tailored to roller and web properties.

Beyond a concave roller's anti-wrinkle effects, they also have a lesser known web-to-roller traction benefit. Most air lubrication and traction models only consider cylindrical rollers. Concave rollers induce crossweb tension variations, creating crossweb differences in air lubrication and web-roller coefficient of traction. By combining concave roller tensioning with air lubrication and traction models, this paper will show how a concave roller will maintain good traction and better control under higher lubricating layers than a cylindrical roller of the same surface roughness or texture.

NOMENCLATURE

h	Web thickness, in. or m
h_o	Air layer height, in. or m
r	Nominal roller radius, in. or m
Δr	Change in roller radius from center to edge, in. or m
Δr_{eff}	Effective change in roller radius from center to edge, in. or m
w_{web}	Web width, in. or m
w_{flat}	Width of flat central section of bowtie roller, in. or m
w_{taper}	Width of single tapered section of bowtie roller, in. or m
w_{edge}	Width of flat edge section of bowtie roller, in. or m
A_{cyl}	Area of strain-width for cylindrical roller, in. or m
A_{flat}	Strain-width for flat portion of concave roller, in. or m
A_{taper}	Strain-width for tapered portion of concave roller, in. or m
A_{edge}	Strain-width for edge portion of concave roller, in. or m

E	Web modulus, psi or N/m^2
F_T	Total traction force available between web and roller, lbf or N
R_q	Effective roughness of web-roller contact, in. or m
$R_{q,web}$	Roughness of web surface, in. or m
$R_{q,roller}$	Roughness of roller surface, in. or m
T	Web tension, lbf/in or N/m
V_r	Surface speed of roller, in/s or m/s
V_w	Surface speed of web, in/s or m/s
$\bar{\varepsilon}$	Average web strain from tension, dimensionless
$\bar{\sigma}$	Average web stress from tension, psi or N/m^2
σ	Critical stress to damage the web
θ	Wrap angle, radians
η	Air viscosity, lbs-s/in^2 or N-s/m^2
μ_F	Coefficient of friction, dimensionless
μ_T	Coefficient of traction, dimensionless

BACKGROUND

Cylindrical rollers are the default design for all web processes. Well-engineered idler rollers are designed with specifications on straightness, cylindricity, eccentricity, balance, bearing drag, inertia, surface material, and surface roughness. Considering one roller in reference to another, rollers are placed considering parallelism, wrap angles, span lengths, and the need to route the web from process to process. Given the perfect web and well-optimized roller design and layout, a web line should operate essentially free of significant crossweb tension variations or slippage and associated wrinkles or scratches.

But the real world creeps into our ideal web and optimized roller plan. Real webs are baggy or interact with processes that change web quality. Real web lines are imperfect with rollers constrained by process needs and financial considerations. Even well-engineered web lines may see wrinkles or scratches as they degrade over time or when products evolve and add challenges of changing thickness, width, modulus, temperature, or other critical parameters.

The real world needs solutions to reduce waste associated with wrinkling and scratching. The simplest changes to a web line design are optimizing tension and moving, adding, or subtracting idler rollers. When these fail to resolve a problem, the next line of attack is to seek a special roller design.

Many special roller designs are marketed by equipment suppliers as anti-wrinkle rollers. The common anti-wrinkle and spreader rollers use the strong mechanism of misalignment and good traction, including bowed, skewed nip, flat expander, and flex expander rollers. The less marketed, but proven effective solutions are rollers that use the mechanism of diameter-induced tracking and good traction – the concave roller (a.k.a. reverse-crowned, bowtie, hourglass, tapered, tape collared, and tape-bumpered rollers).

Web process operators have known for years that adding tape bands to both edges of a roller will eliminate wrinkles and scratching. Many engineers know that concave rollers need to be designed with web width, thickness, modulus, tension, and roller diameter in mind, but may not know how to optimize a concave roller design for their web and process.

Air lubrication is a well-known problem leading to loss of traction between web and roller as process speed to tension ratios increase. The most common anti-lubrication solution is to modify the roller's surface by increasing roughness or adding grooves. In many cases these are an acceptable alternative, but either solution may create a surface that is difficult to clean, creates unacceptable impressions in sensitive webs or coating, or induces wrinkles in thin films. A concave roller profile is a non-obvious solution to improving web-roller traction without roughening or grooving.

ANALYSIS OF THE PROBLEM

In the application battle of misalignment-based vs. diameter-based spreaders, the marketing campaign by equipment suppliers reaping the profits of misalignment-based spreader rollers continues to wind over the less glamorous, poorly understood diameter-based spreading cousins, but concave rollers have many benefits that should not be ignored.

The benefits of a concave roller profile include:

- Eliminate wrinkles created by misalignment, twisting, lateral motion, web bagginess, and web expansion,
- Tighten baggy edges or lanes,
- Shift web-roller pressure from center to edges,
- Improve traction, allowing higher speed to tension ratios without slippage.

A concave roller has the following advantages over other anti-wrinkle roller options:

- Simple design = Least expensive anti-wrinkle roller,
- No rubber surface = less prone to wear or damage,
- No rubber hysteresis = less drag and associated tension losses,
- No rubber required = easily work in high temperature, chemically harsh, or abrasive applications,
- Mechanically simple = less maintenance,
- Bonus: Increased traction at high process speed / tension ratio conditions.

If the concave roller has so many beneficial uses and advantages over other anti-wrinkle roller options, why are the other options more popular?

- Concave rollers without anti-lubrication considerations (too smooth) will have the opposite of the intended effect – creating wrinkles,
- An overly aggressive concave roller profile may lead to shear wrinkles, slackness at the web's center, and yielding at the web edges.
- Radial changes that are too small or too gradual are ineffective,
- Concave rollers created by tape collars may shed and contaminate a product or process,
- The concave roller's simple design is difficult to market,
- The low-cost of a concave roller makes it a less-profitable product compared to other special roller designs,
- Concave rollers are difficult or impossible to design for processes that require large width changes or have webs with greatly differing strain conditions,
- Lack of knowledge of the principle of operation and how to engineer the correct concave roller profile for a given application.

The last point may be the most important one. Many papers have presented the case for a concave roller's anti-wrinkle benefits, but few have provided advice on how to tailor a concave roller's design to a given process. This paper presents one approach to engineer the 'bowtie' profile of a concave roller.

Beyond a concave roller's anti-wrinkle effects, they also have lesser known web-to-roller traction benefit. To date, most air lubrication and traction models only considered cylindrical rollers. In these models, increasing tension will postpone the traction loss for air lubrication and decreasing tension will encourage lubrication. A concave roller profile induces crossweb tension variations, creating crossweb differences in air lubrication and web-roller coefficient of traction.

It may seem that the net effect of a concave roller's induced tension variations would have no net effect on overall traction since air lubrication is non-linear effect. By combining concave roller tensioning with air lubrication and traction models, this paper will show how a concave roller will maintain good traction and better control under higher lubricating layers than a cylindrical roller of the same surface roughness or texture.

SOLUTION TO THE PROBLEM

A concave roller profile tailored to process conditions requires two steps (#1 and #2 below). Calculating the traction benefits of the concave roller compared to a cylindrical roller requires three more steps.

1. Find the average strain vs. width to find the web energy (area of strain-width).
2. Select a concave roller profile and calculate the effective radial change and strain vs. width.
3. Find the lubricating air layer vs. width for a given process speed and air viscosity.
4. Find the traction coefficient vs. width based on air entrainment, friction coefficient, web roughness, and roller roughness.
5. Find the total available traction for a given wrap angle by integrating the traction coefficient over the web width.

Find the average strain vs. width

The average strain in a web is easily found from tension, web thickness, and web modulus by equation {1}.

$$\bar{\varepsilon} = \frac{\sigma}{E} = \frac{T}{hE} \qquad \{1\}$$

For a cylindrical roller and an ideal web transported between well-aligned rollers, each lane across the web width carries the same strain and a plot of strain vs. web width is uniform and has an 'area' of average strain times web width (see Figure 1).

For a concave roller, the strain vs. width plot will reflect the induced strain in the web from the variations in roller radius. The strain change from the smallest radial lanes to the largest will be proportional to the radial change divided by the nominal roller radius, assuming the radial change is small relative to the web strain and web can conform to the concave roller profile without going slack in the center.

$$\Delta\varepsilon = \frac{\Delta r}{r} \qquad \{2\}$$

A concave roller may cause strain variations across the web width, but the total energy in the web or the area under the strain vs. width plot must remain constant {3} (See figure 1).

$$A_{concave} = A_{cyl} = \bar{\varepsilon} w \qquad \{3\}$$

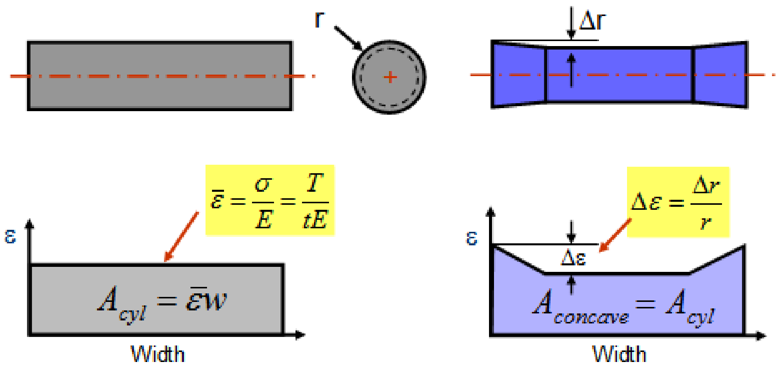

Figure 1 – Comparing Areas of Strain-Width for Cylindrical and Concave Rollers

The area, $A_{concave}$, of the strain-width plot for a simple linear taper 'bowtie' roller can be broken down into two zones: A_{flat}, the strain-width area of the baseline tension over the entire web width and A_{tapers}, the strain-width of the two taper zones representing the added strains of any web lanes running on the larger than the minimum radius as shown in Figure 2 and equations {4} and {5}.

$$A_{tapers} = 2\left(\frac{\Delta\varepsilon w_{taper}}{2}\right) = \frac{\Delta r w_{taper}}{r} \qquad \{4\}$$

$$A_{flat} = \varepsilon_{flat} w \qquad \{5\}$$

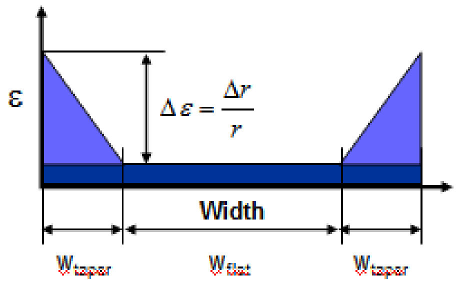

Figure 2 – Strain-width plot of concave roller with center flat and tapered edges

The sum of the two strain-width areas is the total strain-area of the concave roller and equal to the strain-width area of a cylindrical roller as shown in equation {6}. Substituting equations {3}, {4}, and {5} into {6} creates equation {7}.

$$A_{cyl} = A_{flat} + A_{tapers} \tag{6}$$

$$\bar{\varepsilon} w = \varepsilon_{flat} w + \frac{\Delta r w_{taper}}{r} \tag{7}$$

Select a concave roller profile and calculate the effective radial change and strain vs. width.

The equations so far have assumed the web width is exactly equal width of the concaver roller's combined flat and tapered widths. Three cases should be considered: 1) the web width is less than the flat width and the taper are unused and have no effect, 2) the web width is such that the web edges end on the tapers, and 3) the roller taper stops before the end of the roller, creating a short cylindrical bands at the roller's ends and the web is wide enough to reach into these zones. In each case, the effective radial change, Δr, is determined by where the web edge ends in relation to the roller profile as show in Figure 3.

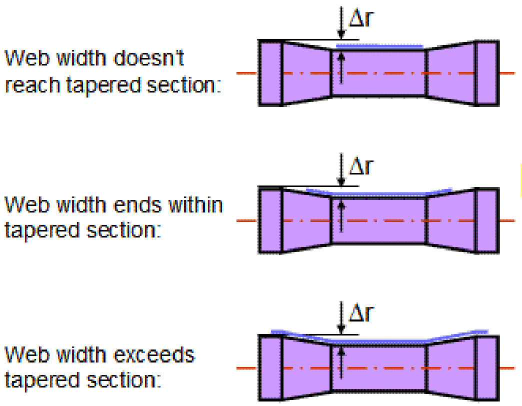

Figure 3 – Effective radius vs. web width and concave roller profile

Using the web width and roller profile widths, the effective Δr is found using the cases and equations {8}, {9}, or {10}.

Case A $\quad w_{web} < w_{flat} \qquad \Delta r_{eff} = 0 \qquad$ {8}

Case B $\quad \left(w_{flat} + 2w_{taper}\right) > w_{web} > w_{flat} \qquad \Delta r_{eff} = \Delta r\left(\frac{w_{web} - w_{flat}}{2w_{taper}}\right) \qquad$ {9}

Case C $\quad w_{web} > \left(w_{flat} + 2w_{taper}\right) \qquad \Delta r_{eff} = \Delta r \qquad$ {10}

Case B, the web partially up the taper, is likely the most common case for the use of the linear profiled 'bowtie' roller, shown in Figure 4. Now that an effective Δr can be calculated from web width and roller profile, the actual strain-width values can be found.

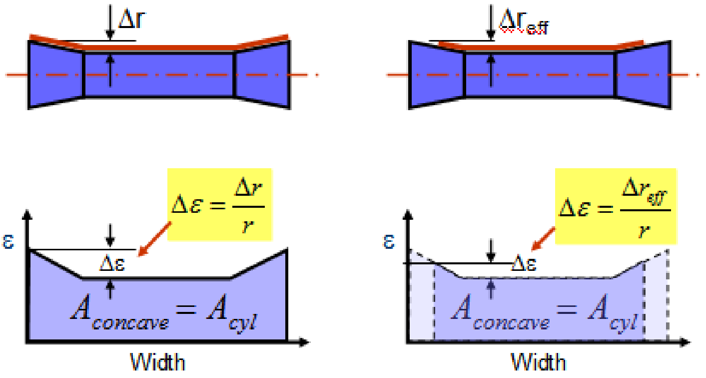

Figure 4 – Effective radial change for narrower webs

Equation {7} can be rearranged, solving for ε_{flat}:

$$\varepsilon_{flat} = \bar{\varepsilon} - \left(\frac{\Delta r_{eff}}{r}\right)\left(\frac{w_{taper}}{w}\right) \tag{11}$$

The strain at the edge will be the baseline strain in the flat zone found in equation {11} plus the strain change of equation {9}, creating equation {13}, the edge strain, ε_{edge}:

$$\varepsilon_{edge} = \varepsilon_{flat} + \Delta\varepsilon = \bar{\varepsilon} - \left(\frac{\Delta r_{eff}}{r}\right)\left(\frac{w_{taper}}{w}\right) + \frac{\Delta r_{eff}}{r} \tag{12}$$

$$\varepsilon_{edge} = \bar{\varepsilon} + \left(\frac{\Delta r_{eff}}{r}\right)\left(1 - \frac{w_{taper}}{w}\right) \tag{13}$$

If $\varepsilon_{flat} = 0$, the edge strain simplifies to:

$$\varepsilon_{edge} = \frac{\Delta r_{eff}}{r} \tag{14}$$

These equations allow a simple calculation of the web's strain-width profile for a give concave roller design. Other concave roller papers have calculated similar functions, but the key to successful application of a concave roller is to select a profile tailored to a given web. To do this, we need some guidelines on what are the goals of the concave roller and what are the reasonable limits to their use.

Roisum [2] recommends "a rough starting point would be a reduction of diameter at the center of about 10% of MD strain induced by web line tension or draw control." Also in [2], Roisum includes a linear profile 'bowtie' roller diagrams, indicating flat width that is 40% the total roller width, but doesn't indicate if the web and roller width are equal.

Feiertag [5] provides an example of lowering center tension to 50% average strain and a bowtie profile indicating 60% flat and includes equation similar to {7}.

Markum and Good [4] recommend “minimum web line tension that must be applied to ensure that negative machine direction stresses do not occur in the cylindrical region” and “stress at the web’s edge must not exceed the yield stress of the material.”

From my experience, I recommend a new set of concave roller application rules that improves upon these previous recommendations as shown in Figure 5.

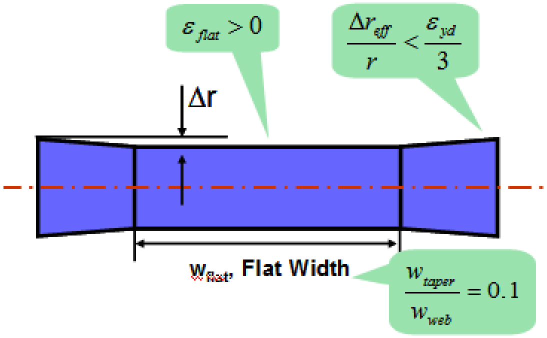

Figure 5 – Recommended concave roller design parameters

Concave roller guideline #1. *The tension in the smaller diameter zones of the concave roller should be greater than zero.* To keep $\varepsilon_{flat} > 0$, the product of the two ratio should be less than the average web strain, as shown in equation {16}:

$$\varepsilon_{flat} = \bar{\varepsilon} - \frac{\Delta r_{eff} w_{taper}}{r w_{web}} > 0 \tag*{\{15\}}$$

$$\left(\frac{\Delta r_{eff}}{r}\right)\left(\frac{w_{taper}}{w_{web}}\right) < \bar{\varepsilon} \tag*{\{16\}}$$

Concave roller guideline #2. *To create the most aggressive concave roller, the high strain should be moved as far as possible to the web’s edges.* The goal of a concave roller is to exert opposing moments on the two sides of the web, inducing a bending that combined with the parallel entry rule, drives the two sides of a slit web laterally or spreads a single wide web [3][4]. To achieve this goal of maximum moments and spreading, I recommend a more aggressive ratio of the taper width relative to the flat central zone, using a 10-80-10 taper-flat-taper ratio. Combining this recommended taper width and equation {16} leads to the appropriate effective radius:

$$\frac{w_{taper}}{w_{web}} = 0.1 \qquad \frac{\Delta r_{eff}}{r} < 10\bar{\varepsilon} \tag*{\{17\}}$$

Concave roller guideline #3. *Avoid reaching the yield stress at the web’s edges with a safety factor of 3:1.* The safety factor allows for the likely lateral variations in tension from roller misalignment and web bagginess, so instead of simply saying the edges stress should be less than the yield stress, I advise a 3:1 safety factor. To keep edge stress from reaching 1/3 of yield point and $\varepsilon_{flat} > 0$:

$$\frac{\Delta r_{eff}}{r} < \frac{\varepsilon_{yd}}{3} \qquad \{18\}$$

$$\frac{w_{taper}}{w_{web}} < 3\left(\frac{\bar{\varepsilon}}{\varepsilon_{yd}}\right) \qquad \{19\}$$

The calculations so far have been for case B, where the web width is within the tapered zones of the concave roller profile. A similar analysis can find the equation for Case C, where the web is wider than the tapered zone, reaching into the out cylindrical bands, as shown in Figure 6.

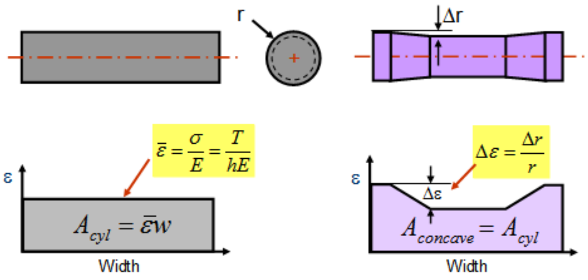

Figure 6 – Comparing strain-width plots, considering tapers and flat edges

In case C, the area, $A_{concave}$, of the strain-width plot for a simple linear taper 'bowtie' roller is broken down into three zones: A_{flat}, the strain-width area of the baseline tension over the entire web width, A_{tapers}, the strain-width of the two taper zones representing the added strains of any web running on larger than the minimum radius, and A_{edges}, the strain-width of the two edge zones as shown in Figure 7 and equations {20} and {21}.

$$A_{edges} = 2\Delta\varepsilon w_{edge} = \frac{2\Delta r w_{edge}}{r} \qquad \{20\}$$

$$A_{cyl} = A_{flat} + A_{tapers} + A_{edges} \qquad \{21\}$$

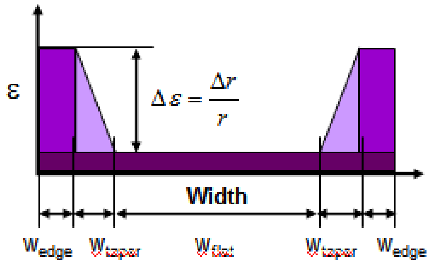

Figure 7 – Strain-width plot of concave roller with tapers and flat edges

The sum of the three strain-width areas is the total strain-area of the concave roller and equal to the strain-width area of a cylindrical roller as shown in equation {21}. Substituting equations {3}, {4}, {5}, and {20} into {21} creates equation {22}.

$$\bar{\varepsilon}w = \varepsilon_{flat}w + \left(\frac{\Delta r}{r}\right)\left(w_{taper} + 2w_{edge}\right) \tag{22}$$

Equation {22} can be rearranged, solving for $\varepsilon_{\mathrm{flat}} > 0$:

$$\varepsilon_{flat} = \bar{\varepsilon} - \left(\frac{\Delta r}{r}\right)\left(\frac{w_{taper} + 2w_{edge}}{w}\right) \tag{23}$$

The strain at the edge will be the baseline strain in the flat zone found in equation {23} plus the strain change of equation {9}, creating equation {24}, the edge strain,$\varepsilon_{\mathrm{edge}}$:

$$\varepsilon_{edge} = \bar{\varepsilon} + \left(\frac{\Delta r}{r}\right)\left(1 - \frac{w_{taper} + 2w_{edge}}{w}\right) \tag{24}$$

Figure 8 show an example comparing the strain-width plot of a cylindrical and concave roller (only the right half of the roller is plotted in Figures 8 through 13, given roller symmetry about the center axis). The values used in this example are listed in Table 1.

Note: The example concave profile roller is designed according to all three concave roller guidelines, avoiding center slackness and keeping the edge stress below one third of the materials yield stress.

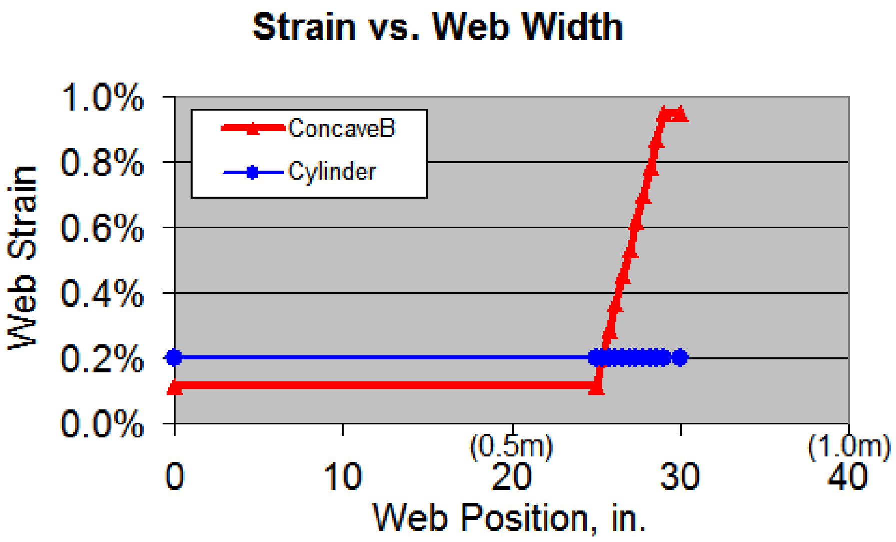

Figure 8 – Web strain vs. width

Find the lubricating air layer vs. width

The air layer is created from hydrodynamic lubrication between a moving web and roller that is commonly used in web handling traction modeling was first shown to exist by Knox and Sweeney [6].

$$h_0 = 0.643r\left(\frac{6\eta(V_W + V_R)}{T}\right)^{2/3} \qquad \{25\}$$

Good, Kedl, and Shelton [7] presents three cases of air lubrication. When the air layer, h_0, is less than the effective combined surface roughness of the web and roller, R_q, the coefficient of traction is the same as the coefficient of friction. When the air layer is greater than three times the R_q, then the traction coefficient is essentially zero. If the air layer is between one and three times the R_q, the coefficient of traction can be estimated by a linear proportional decrease governed by equation {27}.

$$h_o < R_q \qquad \mu_T = \mu_F \qquad \{26\}$$

$$R_q \le h_o \le 3R_q \qquad \mu_T(h_o) = \mu_F\left(\frac{3R_q - h_o}{2R_q}\right) \qquad \{27\}$$

$$h_o > 3R_q \qquad \mu_T = 0 \qquad \{28\}$$

Combining this relationship across the width and tension variations of a concave roller generates the Figures 9 and 10. These plots show how the entrained air layer is uniform for a cylindrical roller, but varied across concave roller. On the concave roller, the air layer is thicker in the low tension center lanes and smaller at the high tension edges. As speed increase (see Figure 10), the concave roller's center lanes continue to entrain more air than a cylindrical roller, but the edges continue to entrain less.

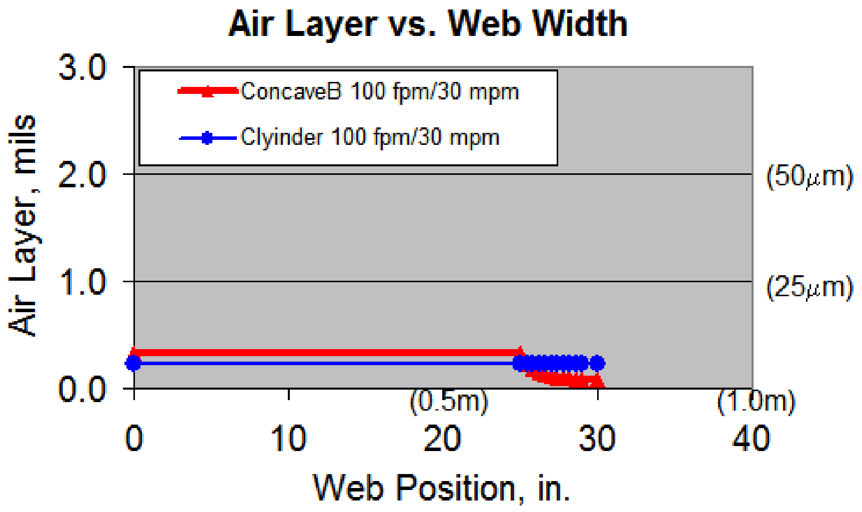

Figure 9 – Air layer vs. width at 100 fpm (30 mpm)

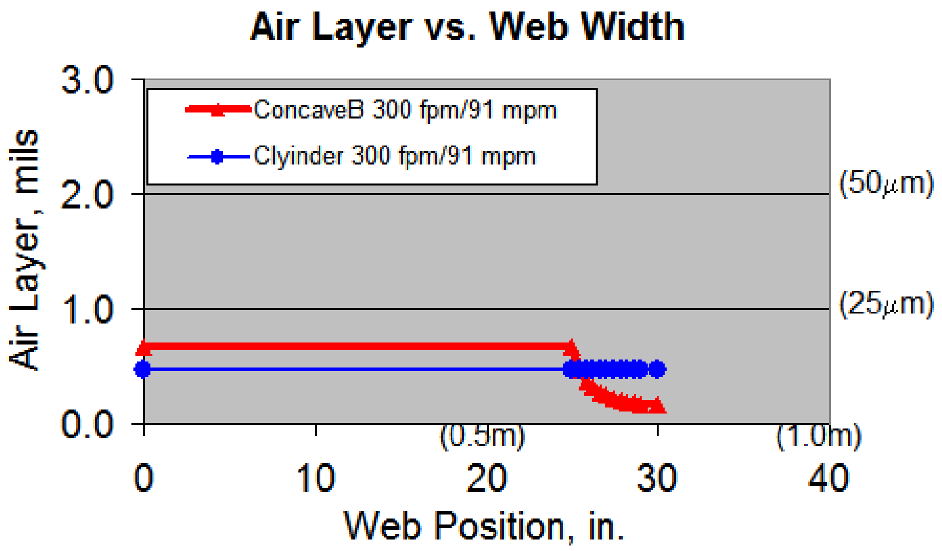

Figure 10 – Air layer vs. width at 300 fpm (91 mpm)

Find the traction coefficient vs. width

Figure 11 and 12 show how the entrained air layer interacts with the combined roughness of the rollers, R_q, leads to show the lane-by-lane coefficient of traction across the concave and cylindrical rollers.

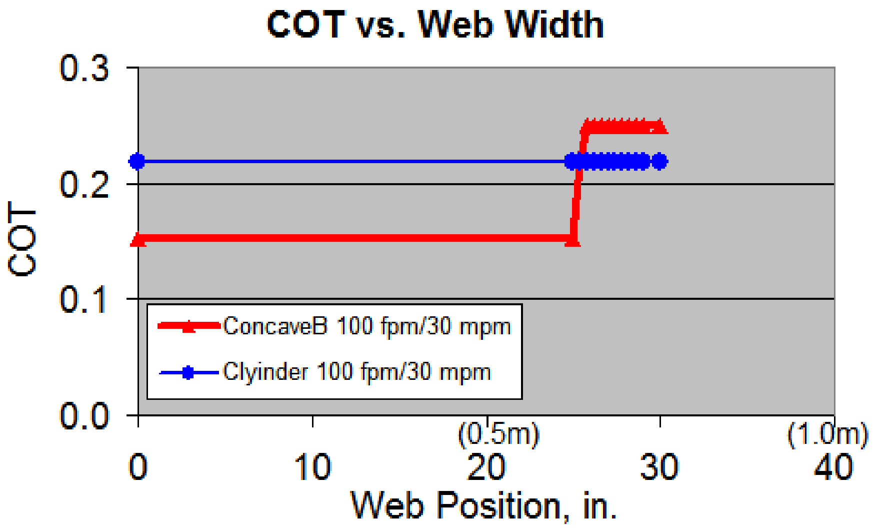

Figure 11 – Coefficient of traction vs. width at 100 fpm (30 mpm)

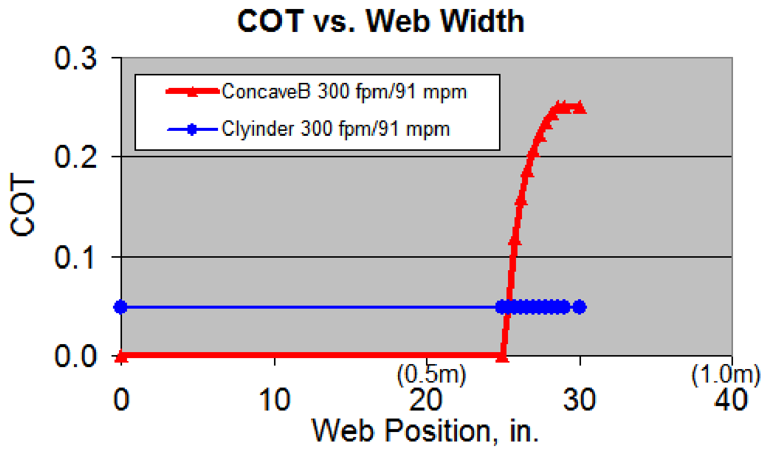

Figure 12 – Coefficient of traction vs. width at 300 fpm (91 mpm)

<u>Find the total available traction for a given wrap angle</u>

Integrating coefficient of traction over the web width and multiplying by the wrap angle calculates the total traction for a cylindrical roller vs. a concave roller over a wide speed range.

$$\mu_{T,eff} = \int \mu_T(w)dw \qquad \{29\}$$

$$F_T = \mu_{T,eff} T w \theta \qquad \{30\}$$

Though the concave roller center lubricates sooner, the high tension edges prevent lubrication at high speeds, quickly creating a traction advantage of concave roller over cylindrical roller (see Figure 13).

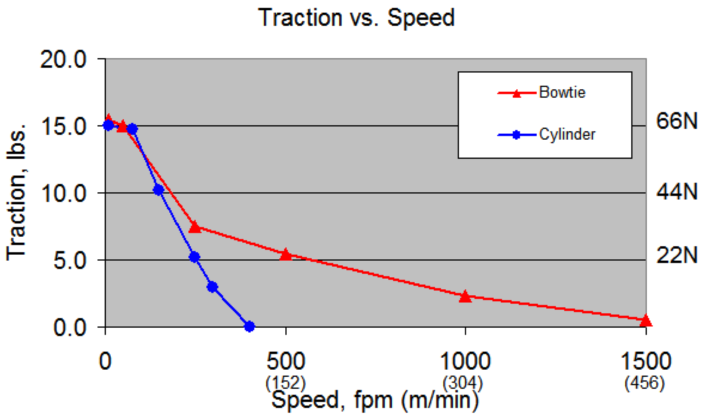

Figure 13 – Total traction force vs. speed for cylindrical and bowtie rollers

Tension	1.0	lbf/in	175	N/m
Thickness	0.001	in.	0.0254	mm
Width	60	in.	1524	mm
Modulus	500000	psi	3445	MPa
Critical Stress	20000	psi	138	MPa
Wrap Angle	57	degrees	1.00	radians
Speed	100	fpm	30.5	m/min
Viscosity	2.6E-09	lbs-s^2/in	4.6.E-07	N-s/m^2
COF	0.25	--	0.25	--
Web Rough	0.03	mils	0.762	microns
Nominal Roller Radius	3.000	in.	76.2	mm
Edge Flat Length	4.0	in.	101.6	mm
Taper Face Length (ea)	4.0	in.	101.6	mm
Center Flat Length	50.0	in.	1270	mm
Concave Roller Radial Change	0.025	in.	0.635	mm

Table 1 – Values used in comparing cylindrical and concave rollers

CONCLUSIONS

Concave rollers are a proven effective and economical remedy to reduce wrinkle waste. This paper presented a simple protocol to calculate the redistribution of strain as a function of concave roller profile, web properties, and process condition. Beyond calculating concave roller strains, a set of three guidelines were presented to select an optimized profile that avoid center slackness and edge yielding, while applying an aggressive moment on the web.

Concave rollers also create a significant benefit to web roller traction. Concave rollers induce crossweb tension variations, creating crossweb differences in air lubrication and web-roller coefficient of traction. Integrating concave roller tensioning with air lubrication and traction models shows how a concave roller will maintain good traction and better control under higher lubricating layers than a cylindrical roller of the same surface roughness or texture.

REFERENCES

1. Delahoussaye, R.D. "Analysis of Web Spreading Induced by the Concave Rollers," Proceedings of the Second International Conference on Web Handling, Oklahoma State University, Stillwater, OK, June 6-9, 1993.
2. Roisum, D.R., "The Mechanics of Web Spreading," Proceedings of the Second International Conference on Web Handling, Oklahoma State University, Stillwater, OK, June 6-9, 1993.
3. Swanson, R.P., "Testing and Analysis of Web Spreading and Anti-Wrinkle Devices," Proceedings of the Fourth International Conference on Web Handling, Oklahoma State University, Stillwater, OK, June 1-4, 1997.
4. Markun, R.E. and Good, J.K., "Design of Contoured Rollers for Web Spreading," Proceedings of the Sixth International Conference on Web Handling, Oklahoma State University, Stillwater, OK, June 10-13, 2001.

5. Feiertag, B., An Application Seminar on Web Handling, Web Handling Research Center at Oklahoma State University, 1991 to present.
6. Knox, K.L. and Sweeney, T.L., “Fluid Effects Associated with Web Handling,” Industrial Engineering Chemical Process Design Development, 1971, Vol 10, No.2.
7. Good, J.K., Kedl, D.M., and Shelton, J.J., “Shear Wrinkles in Isolated Spans,” Proceedings of the Fourth International Conference on Web Handling, Oklahoma State University, June 1-4, 1997.

Practice Application and Design of Concave Rollers	**T. J. Walker,** T. J. Walker and Associates, USA

Name & Affiliation	**Question**
Dave Roisum, Finishing Technologies	I'm glad you're conservative. I like to even be more conservative because I'm going to consider a couple of things that might happen. You could easily have a 10 to 1 modulus range running across the machine, or maybe you run one grade right now then five years from now they decide to go to a stiff material like paper or foil. Now everyone has forgotten these rolls are concave and then we get in trouble. The more conservative we are with the concavity the less trouble will result.
Name & Affiliation	**Answer**
Tim Walker, TJ Walker and Associates	I would agree with that. This is not a roller you can design for a polyethylene web and then go run an aluminum web on it the next day and see any benefit. If you design it for polyethylene; you are going to ruin aluminum. It's really a good design if you've got a process that runs a product very consistently with the widths and the strain ranges are minimally changing. And, you're right, if you put in a special roller and people forget it's special, and over time they say why is that roller doing funny things, I thought it was just like all the others. That causes trouble. But I've seen enough bowed rollers that are put in and are causing more trouble than concave rollers. So I often advocate that the bowed roller shouldn't be the solution and the concave roller should certainly be considered.
Name & Affiliation	**Question**
Keith Good, Oklahoma State University	I think it's always wise to remember that there are limits to all things. So, what happens when the entrained air layer becomes sufficient cause the web airborne, first at the center and later at the edges? This happens in web production lines where the web that is being transported does not change in contrast to Dave Roisum's comment but the desire to increase web velocity and make more web and profit exists. Likewise perhaps the web can be thinner to save on cost but now the tension per unit width needs to decrease. Both trends result in increased air entrainment. So you follow a set of design rules using current web line operating parameters, time passes and either tension goes down, velocity goes up, or perhaps your surface roughness wears away. One day you find you have several devices in your web line that want to gather the web together to the center of the machine. I think it's good to remember those boundaries or limits and maybe your concave roller design accounts for the increases in velocity, decreases in tension, and reduction in surface roughness that you think may occur during the service life of the roller. Do you agree?

Name & Affiliation	Answer
Tim Walker, TJ Walker and Associates	Yes, I totally understand what you are saying. Yes, this is an engineered device; it's not for a fool to use. It's not foolproof and that is one of the reasons why it isn't used enough. But, it shouldn't be something that people are afraid of and are worried that it's going to be misused. It's a very effective tool and I've seen it save the day in many applications. Hopefully this presentation will reduce the fears of using these devices.