APPLIED WEB HANDLING CONFERENCE 2008

Anatomy of a Wrinkle

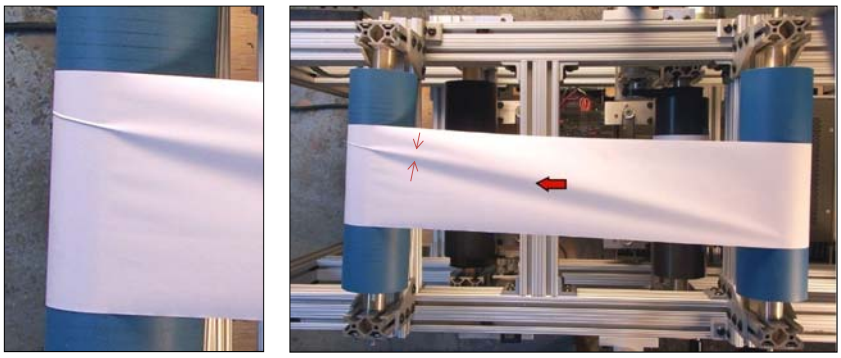
Jerry Brown

Essex Systems

© 2008 Jerald Brown

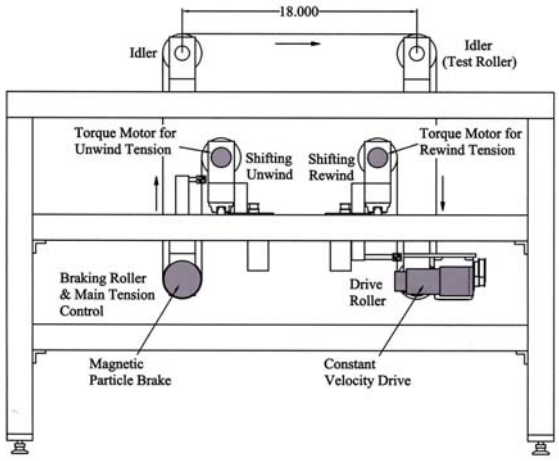
May 2008 | Minneapolis Minnesota

Shear wrinkle at a misaligned roller



One of the most common defects in web handling
Compressive stress
Propagation
Physics understood. IWEB Paper in 1997, “ Shear Wrinkles in an Isolated Span”
Elastic instability
Trough geometry
Coefficient of friction

Lab machine



Specially constructed for this type of study.

Capable of running very slow and stopping gently for photos.

Handles all common materials. Special attention given to Latex,

Latex in these studies 5.5” wide, 0.026 inch thick, 250 psi modulus

10” rollers, 3 inch diameter, coated with polyurethane

0 – 20 FPM

0.5to 6 Lb Tension

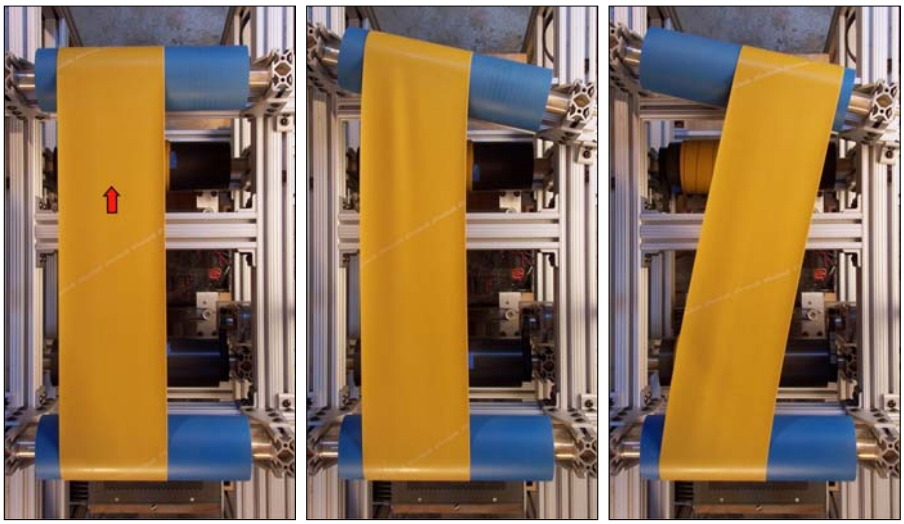
18 inch test span

Web typically 25 Ft long

Two fundamental principles

- Normal entry rule
- Normal strain rule

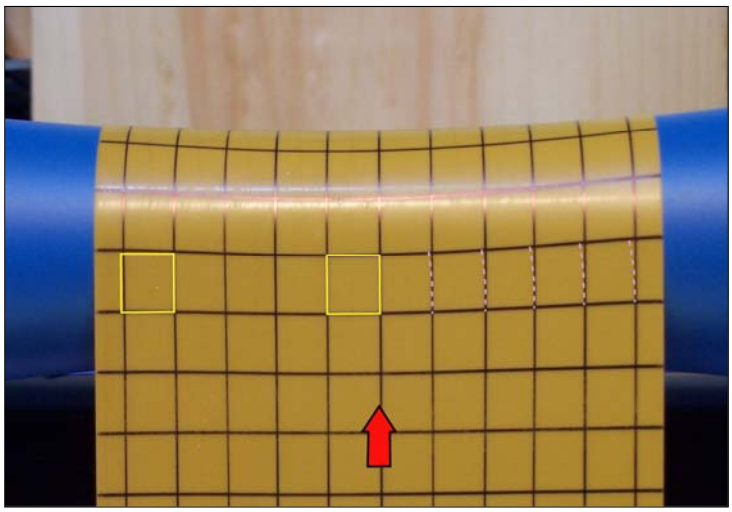
Normal entry rule



A web entering onto a roller will align its direction of travel perpendicular (normal) to the roller axis. If the web is not initially perpendicular, it will travel laterally on the roller at a rate proportional to the tangent of the angle between the web and the roller until it reaches perpendicularity.

The blue coating on the rollers is polyurethane

Normal strain rule



In a steady state, the ratio of the stretched lengths of an infinitesimal patch of the web at the entries of two successive rollers is proportional to the respective ratios of the web velocities at the two rollers (provided the strains and velocities are measured normal to the roller axes). In other words, if the web speeds up by 1% relative to the previous roller, it will have to elongate by 1% to insure that the mass flow is the same at the two locations.

Black grid drawn on web before experiment.

Yellow boxes drawn on the photo

Web stretched at edge relative to center

Horizontal grid lines have taken the shape of a smile

Without normal entry rule, the vertical black lines would “toe” in like violet dashed lines

Normal entry rule forces them spread outward to meet roller perpendicular to axis

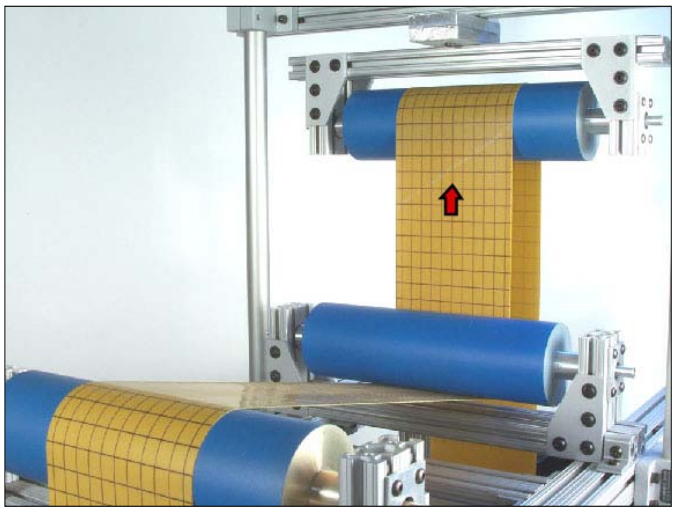
All wrinkles have the same cause

- Compressive CD stress at entry to a roller
  - Roller misalignment
  - Roller deflection (reverse bow)
  - Tension drop across a driven roller
  - Expansion to temperature increase
  - Twist

Twist is an ideal case to study

- Wrinkle forms in center of web
- It's aligned with machine direction and doesn't move laterally
- Formation is easily controlled by adjusting angle of twist

Experimental setup



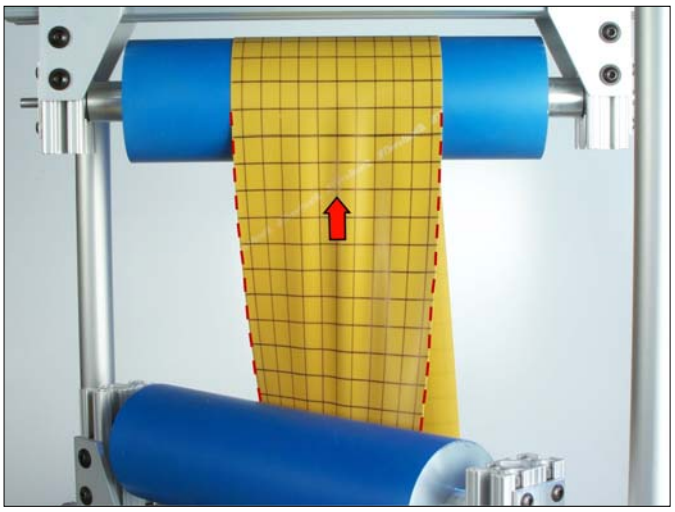
Arrangement inspired by experiment by Dr. Good and one of his students, P. Staughan at described at 1999 IWEB conference.

Tension = 6 Lb

Span 8.5 inches long

Angle of twist 45 degrees (point at which wrinkles form)

Deep troughs form at 45 degrees



Camera line of sight is perpendicular to roller.

Dashed red lines trace out web edges

The appear tapered – wider at top than the bottom

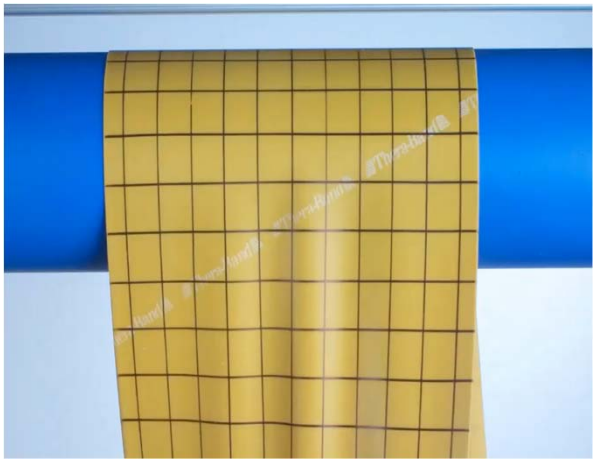
Some of it is due to the angle of view

However, there is real taper

Except at the rollers, the edges of the twisted geometry have come closer together

Imagine that the dashed red lines are isolated strings and the top roller is twisted 180 degrees. The strings would touch halfway down the span

Wrinkle formation (video)



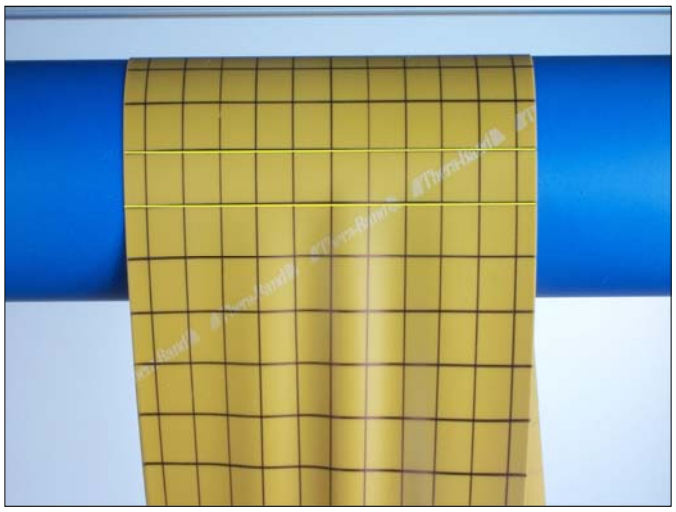
Web right after twisting the roller 45 degrees.

Troughs are already visible, indicating that twist has produced some compressive stress.

We'll watch a stop-motion video of the wrinkle formation and then take a look at some of the critical steps in still frames.

Note: The web is always moving from bottom to top. The web will sometimes look like it is moving backward, because the photos were taken about every half inch of web motion.

Web has advanced a few inches

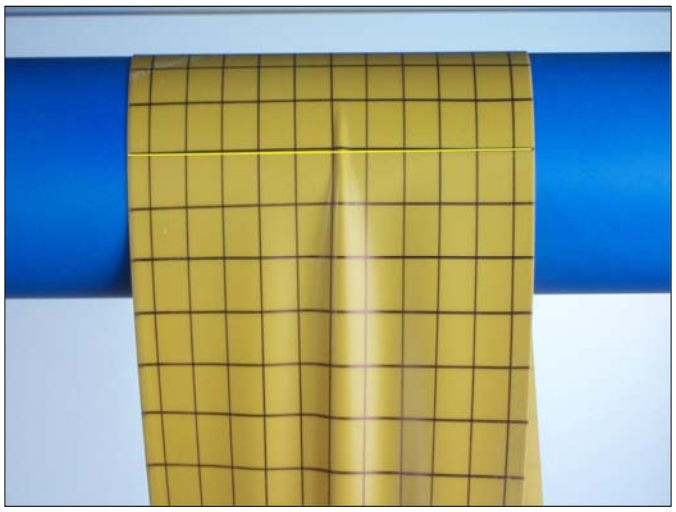


Web has advanced a few inches

Straight, yellow horizontal line was drawn on photo

Notice the slight frown in the black grid

Wrinkle begins to form

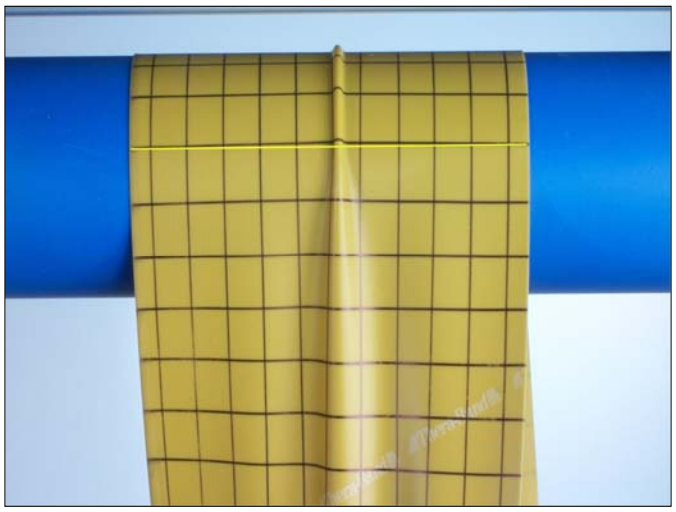


Web has moved some more.

Now the normal entry effect is bringing excess material to the center, increasing compressive stress

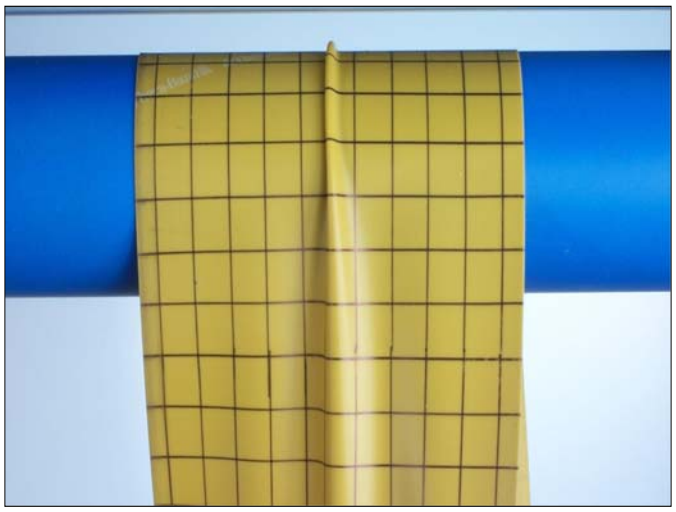
The frown has become more pronounced

Wrinkle continues to grow



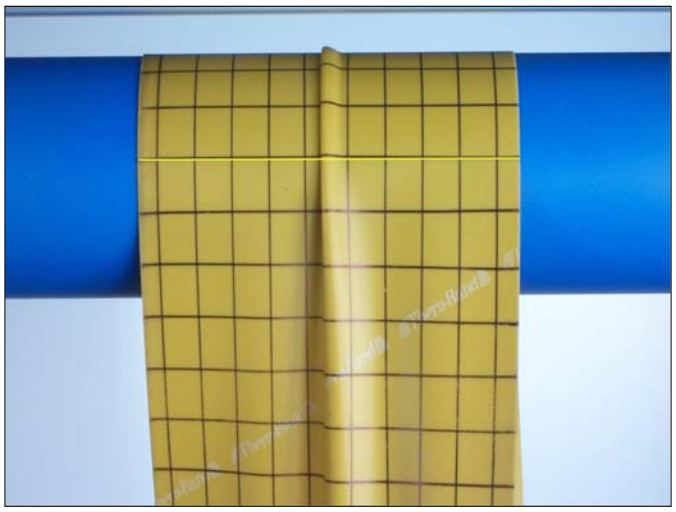
Material continues to move into the wrinkle

Wrinkle begins to fold



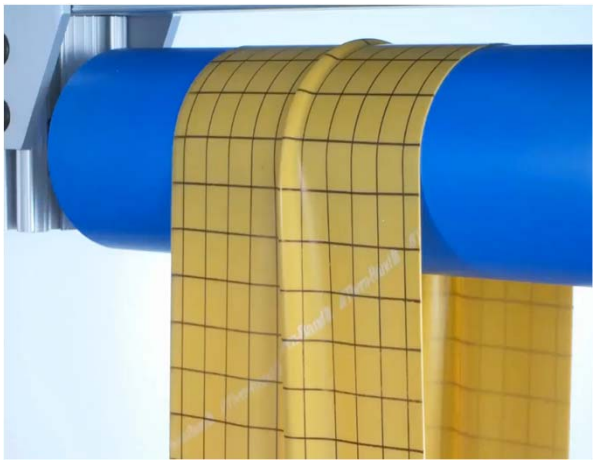
The wrinkle has grown so high that it is now unstable

Fold continues to grow



The fold grows until the web becomes narrow enough for the normal entry rule to stop working.

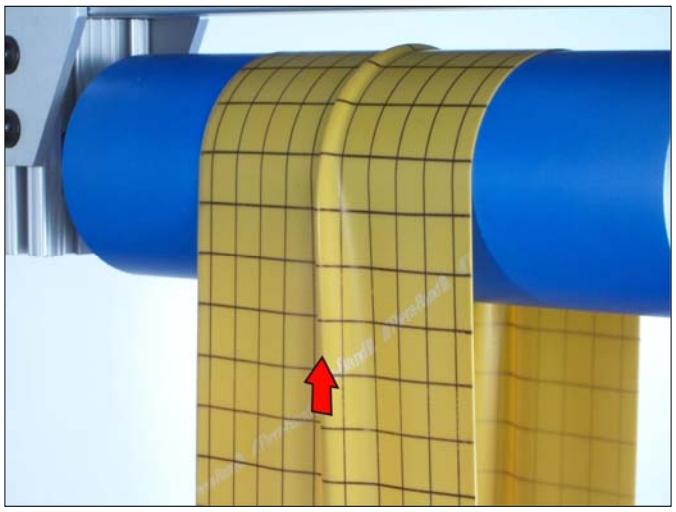
Effect of realignment (video)



The top roller has been rotated back into alignment while leaving the web in it's wrinkled state. Then, the web is allowed to advance in the same direction as before.

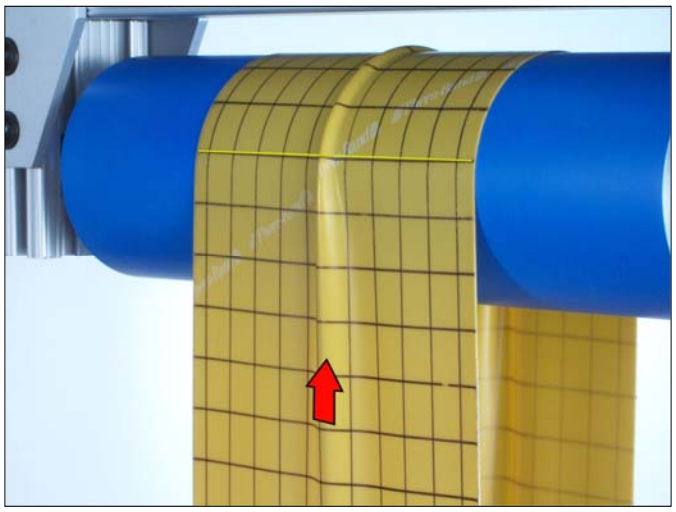
First, we will watch what happens in a stop-motion video and then look at a few of the frames in more detail

Initial realignment



Remember, the web is always moving in the direction of the red arrow

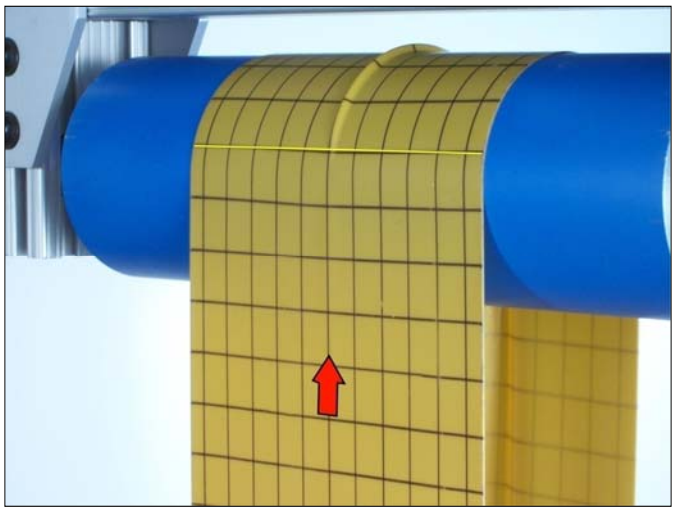
Wrinkle begins to unfold



Note that the frown has turned into a smile as it spreads back out.

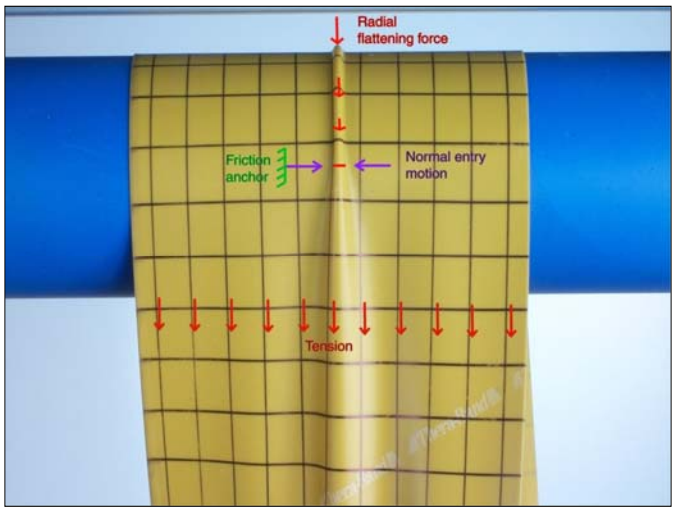
That's evidence of the normal entry rule at work.

Wrinkle almost gone



Spreading continues to eliminate the wrinkle

Forces acting on a wrinkle



Interaction of roller curvature and web tension produces a radial force pushing the web against the roller surface.

It is acting over all of the area of contact between the roller and the web, including the wrinkle.

The radial pressure and the bending stiffness of the web are resisting formation of the wrinkle

So, the role of compressive stress in the entry span is to produce a trough that changes the web's lateral geometry. The normal entry effect drives material into the wrinkle from both sides, increasing the compressive stress.

Then, if the trough is deep enough, the compressive forces are driven up to the point where the web becomes unstable and "pops up" off the roller surface

Friction between the web and the roller provides a reaction

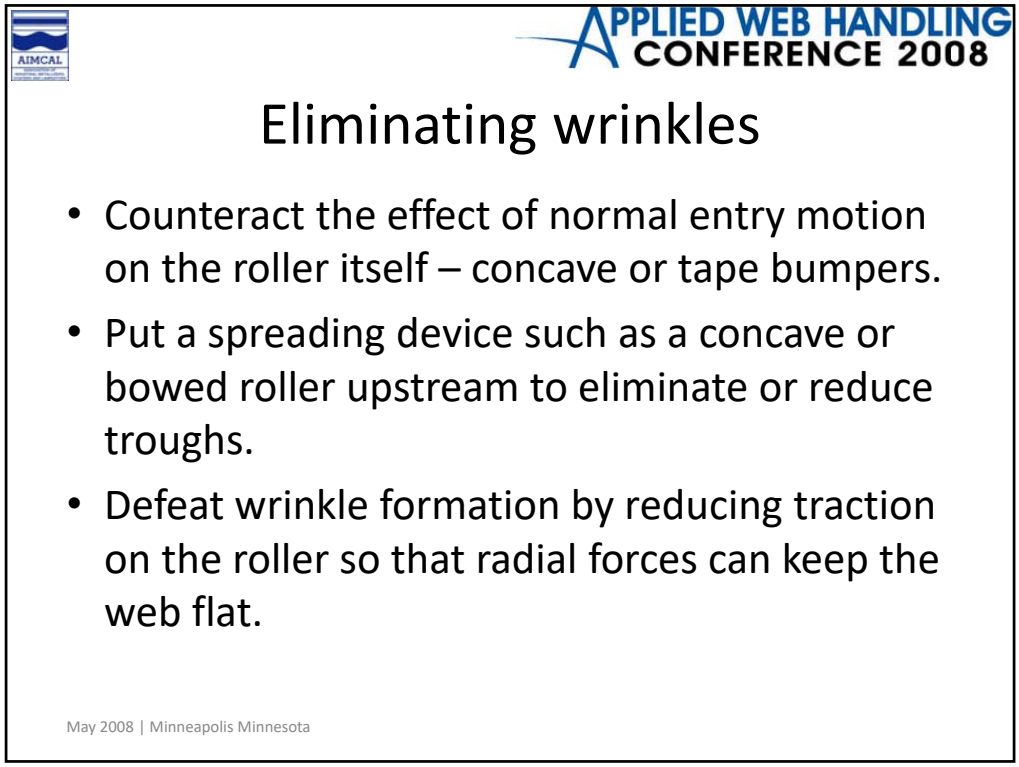
force for the normal entry forces to work against.

An important conclusion

- Trough formation in the span causes the effect of the normal entry rule to amplify the compressive stress on the roller above the level that would exist in the span without the trough.

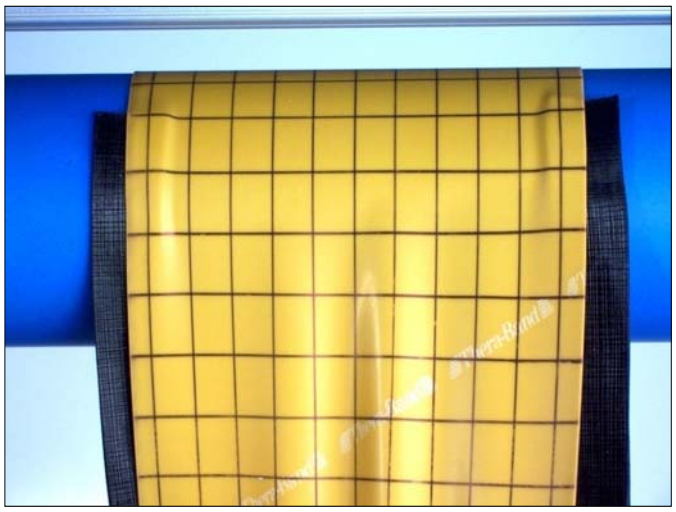
It goes this way

- Formation of a wrinkle on a roller is preceded by formation of troughs in the span.
- Movement of trough material into the space above and below the plane of the span causes the web to gather laterally upstream of the line of entry onto the roller.
- As the web gets closer to the roller, it flattens out. The normal entry rule requires the paths of web particles to be normal to the roller axis. The only way this can happen is for the web on the roller to be compressed enough to match the “effective” width of the troughed web in the span.



Consideration of the previous explanation suggests three methods for eliminating wrinkles.

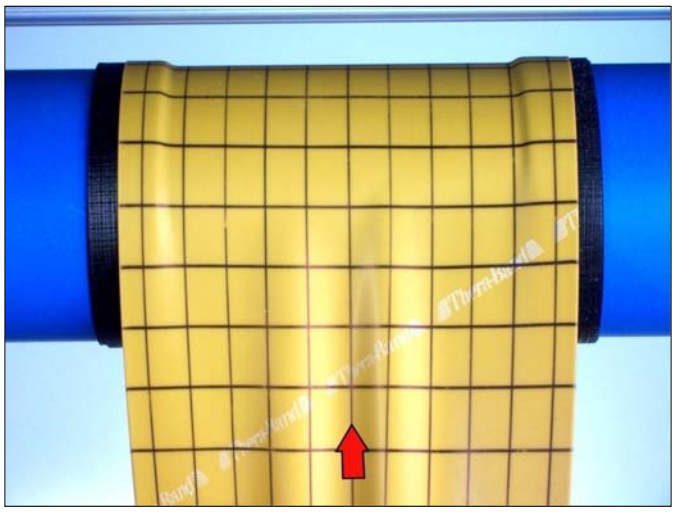
Application of tape bumpers



After twisting the web 45 degrees, tape bumpers were introduced in a way that didn't alter the initial conditions.

The bumpers had to be 1/16 inch thick to prevent wrinkles.

Concave roller – tape bumpers

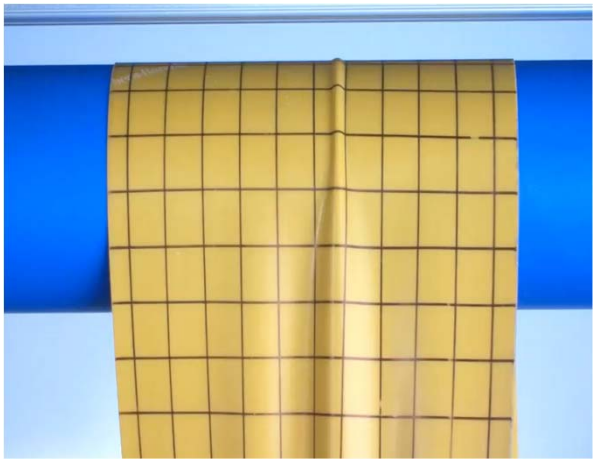


This shows the web after it has advanced several feet.

The spreading is barely adequate to prevent wrinkles.

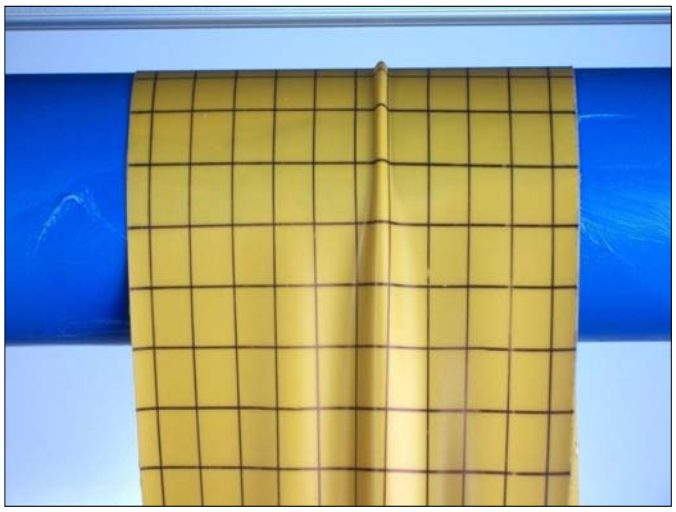
If the wrinkles were allowed to form before the previous step the spreading wasn't strong enough to remove them. It only slowed down their growth.

Elimination of traction (video)



First, a wrinkle was allowed to form

Initial wrinkle

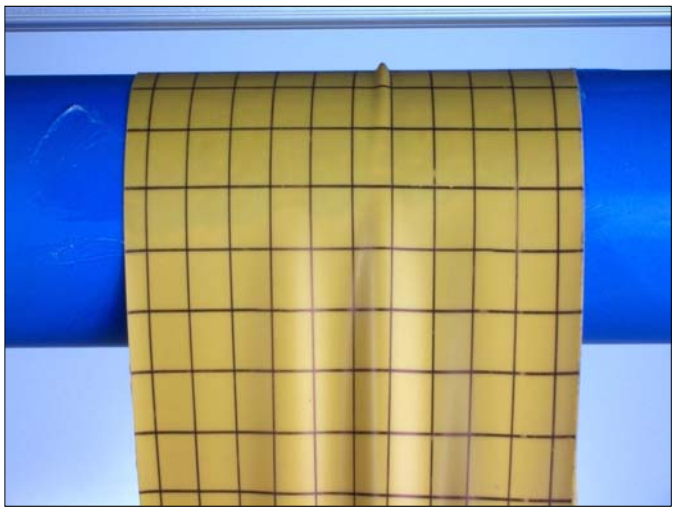


Then, petroleum jelly was smeared on the roller and underside of the web just ahead of the line of contact between the web and roller.

Obviously, this isn't something that can be done on a process line. It is done only to demonstrate what happens when the roller becomes very slippery – something hard to do with latex on a polyurethane-coated roller.

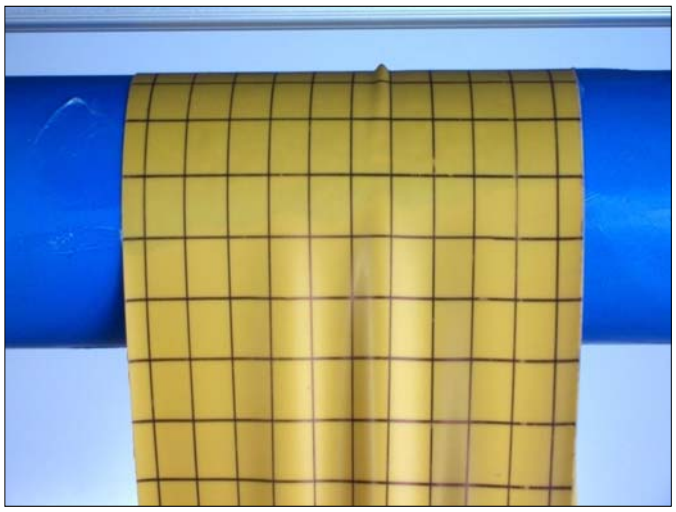
First, we will watch a stop-motion video of the results and then, as before, look at some still frames.

Wrinkle beginning to flatten



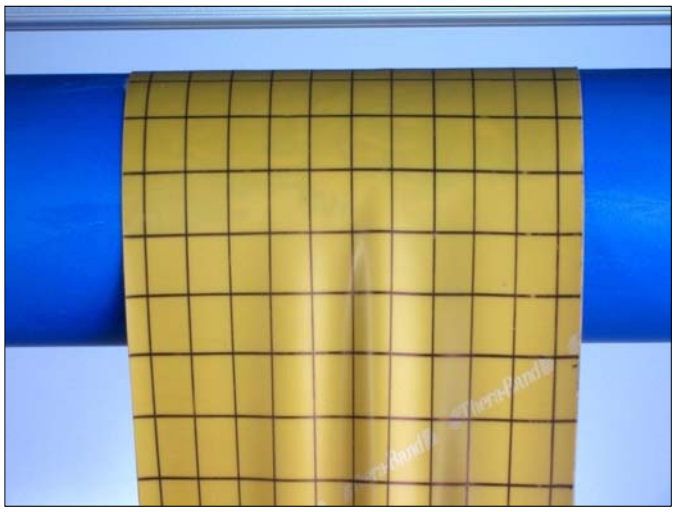
As the greased area moves underneath the web, the wrinkle begins to disappear

Wrinkle almost gone



As the greased area moves further, the material in the wrinkle continues to slide outward.

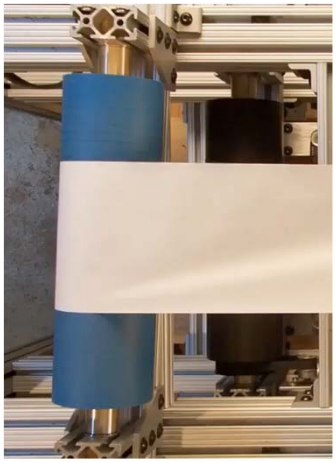
Wrinkle gone



Notice that the horizontal black lines are frowning.

Without traction, the normal entry rule can't operate.

Wrinkle in paper web (video)



Remember this wrinkle at the beginning of the presentation?

Let's try tape bumpers on it.

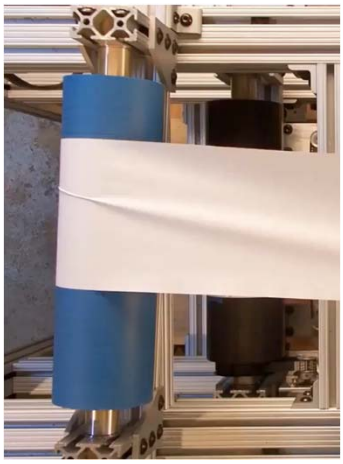
First, we'll try masking tape – 5 mils thick

Video

That didn't look so good. The main wrinkle disappeared. But, new ones formed at the top bumper.

Maybe 5 mils was too much.

Scotch tape – 2 mils (video)



Here are some thinner bumpers – 2 mil scotch tape

APPLIED WEB HANDLING CONFERENCE 2008

QUESTIONS?

Essex Systems

Jerry Brown

May 2008 | Minneapolis Minnesota