Practical Considerations for Zero Speed Splice Unwinds

Neal Michal, Technical Leader
Kimberly-Clark Corporation
Global Nonwovens - Process & Technology Development
Phone: 770.587.7378
Fax 920.225.3459
E mail nmichal@kcc.com

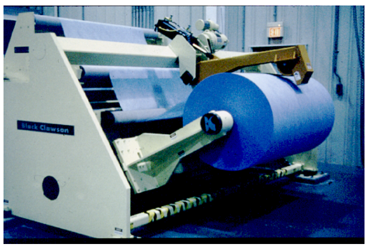
Executive Summary

A web is defined as a continuous strip of flexible material. Most web products are stored in a wound roll before converting into a final product. The converting process requires the web material to be unwound from the roll. There are two broad categories of unwinds: Start/stop and continuous operation. There are two types of continuous unwinds: Flying splice and zero speed splice. This presentation will focus on zero speed splice unwinds. It is common for unwind splices to be the number one source of waste and delay in a converting process. Many of the process upsets during an unwind splice are associated with poor tension control. Failure modes include troughing, wrinkling, neck down, "Z" folding, edge flip over, web collapse, and web break.

This presentation will attempt to answer questions about when this type of unwind is needed, how they work, challenges, and optimization. This presentation will also highlight the needs that industry has for better equipment. Fundamental research for web handling has been primarily focused on a single roller in an open span. Several papers have described relationships for traction, air lubrication, and wrinkling. There have been a handful of publications for multispan festoons and little to no information for zero speed unwinds. Many of the published papers are not well understood. A combination of fundamental and applied research is needed to develop value priced robust solutions.

Types of unwinds
There are two broad categories of unwinds: Start/stop and continuous operation.

A simple unwind stand is often used to provide a web to a process but will be limited in speed. The addition of a drag belt is often used to slow down the roll when the machine stops.



A more sophisticated start/stop unwind will drive the roll to provide for tension control. Often this is done with a surface drive belt like the one shown to the left. Note that this unwind also provides for chucking and lifting the roll from the floor. Both of these unwinds will require the machine to come to a complete stop to load a new roll.

Included with permission of Black Clawson Converting Machinery

For the purpose of this presentation a 'continuous' unwind will allow a new roll to be spliced into the web process without shutting down. A continuous unwind is a business requirement for many converting, laminating and manufacturing processes.

One common approach is a two station indexing turret in combination with a surface drive belt as shown below.

This unwind allows one to splice new rolls into the process without stopping. This approach is often referred to as a 'flying splice'. The new roll (on the left) is prepped with splice tape. As the expiring roll (on the right) unwinds to the core the surface drive belt is lifted. The turret is indexed clockwise 180 to bring the new roll into position. The new roll can be accelerated by hand into the process. The surface drive belt is then lowered onto the new roll. This process can work reasonably well for narrow webs up to several hundred feet a minute. Additional equipment such as a paster roll and driven nips can extend the operating range of this unwind. A downside is that there is a significant tail that can not be sold into the final product. This drives up waste. It is common to miss a splice as machine speeds increase.

As the roll grows in size & weight drives are added to the spindles to bring the roll to web speed as shown on the unwind to the left. Spindle drives are also ideal for rolls that are slippery or would be damaged by direct contact with the surface belt.

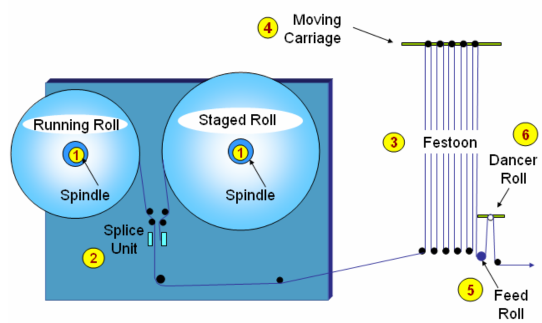
Included with permission of Black Clawson Converting Machinery

This unwind uses a sophisticated splicer mechanism. The timing of the paster roll is important to insure a reliable splice. Poor timing can result in a missed splice or a long tail. Control of the web speed for the new roll is critical to reducing the tension disturbance to the downstream process. An equipment vendor demonstrated at the last AWEB conference that this unwind design can provide a reliable high speed splice once these parameters have been optimized.

The next continuous unwind is defined by how the splice is made. A 'zero speed splice unwind' brings the expiring roll to a stop to allow the splice to take place. Once this has occurred the new roll is brought back to web speed. This type of unwind requires an accumulator to pay material out to the process that continues to run during the splice. The accumulator is often referred to as a festoon.

A zero splice unwind always has a perfect speed match in between the webs – zero. This provides time to make a positive splice. Some splicer designs provide for a splice that can be sold into the final product. Additional advantages are the ability to splice into severely mis-shaped rolls and rolls with a wider range of diameters.

This paper will focus on a zero speed splice unwind.



Included with permission of Martin Automatic Inc

Major Components – Zero Speed Splice Unwind
The major components of a zero speed splice unwind are as follows:

- Two driven spindles – control the speed of the unwinding rolls and provide for the ability to splice in a new roll. A cantilevered air loaded chuck is normally used for narrow webs. A set of two air loaded chucks are often used to end support a wide roll.
- Splicer assembly – splices the new roll into the expiring roll. Three common types of splices are tape, heat seal and ultrasonic.
- Festoon – provides web storage for zero speed splicing with uninterrupted machine operation. The festoon consists of a moving carriage and a set of fixed rollers.
- Various idlers to transport the web from the unwinding roll thru the unwind and into the downstream process

- Feed roll or feed nip is commonly located at the end of the festoon to provide material at a constant federate to the downstream process. A well designed feed roll is preferred over a nip.
- A dancer roller can be added to the end of the unwind to set nominal tension to the downstream process

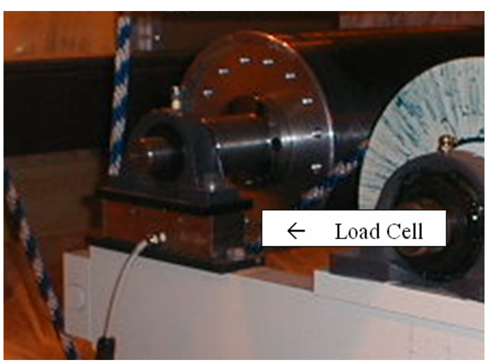
Tension Control

Tension is the most important parameter for any web process. If the tension is too low, the web will tend to wrinkle, flutter or weave in the cross machine direction. At extremely low tensions the web will Z-fold or collapse completely. At extremely high web tensions the material will break. There is a wide range of tensions in between these two extremes in which negative things can occur but may not be obvious. For example if the tension is simply too high the web will neck down due to Poisson's ratio.

The tension in the festoon can be controlled by a number of methods. One approach for lightweight webs is to load the moving carriage against the moving web by a series of cables attached to an air cylinder. (There are perhaps a dozen other methods to provide tension within a festoon.)

A statics calculation will provide for the average tension across the festoon. It is important to remember that this is an average tension. During steady state operation the tension at the end of a festoon will be significantly higher than at the entrance due to accumulated bearing drag. The tension in a conventional festoon will always be a compromise. The most important aspect is to provide for a reliable unwind splice. There are many other factors to be considered such as material strength, material quality, total neck down and tension disturbance to the downstream process to name a few.

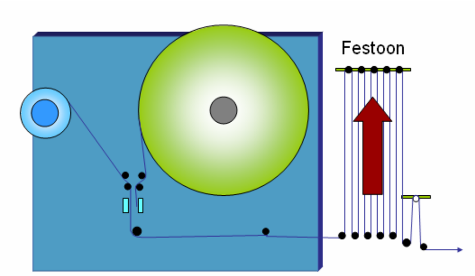
It is a best practice to calculate tensions to establish good run settings with limits. A rule of thumb is to operate your web process at 10% - 25% of the material's yield point. A suggested range of acceptable tension is +/- 10% of nominal.



The best way to understand your web process is to directly measure the web tension. Cantilevered load cells are often used for narrow webs. Wide web processes normally mount an idler mounted on top of load cells. It is important for the load cell roller to very well balanced (G1.0 or better) and mounted properly to avoid machinery vibration.

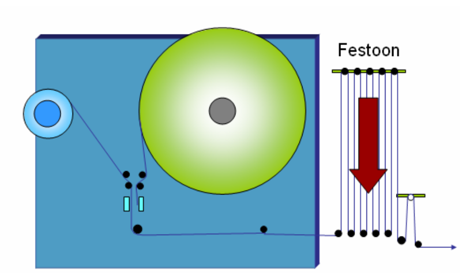
Splice Sequence
There are a number of ways to sequence the web splice. One approach will be discussed.

During steady state operation it is common to keep the carriage low to avoid wrinkles.



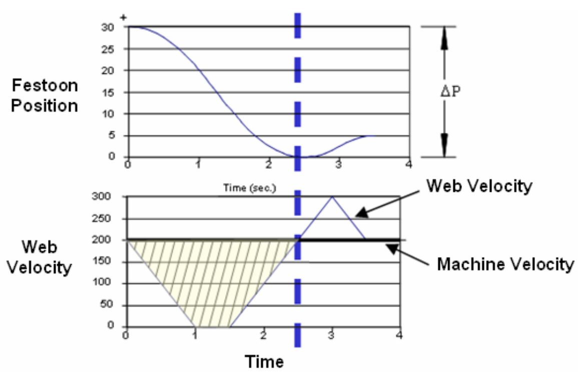
As the expiring roll triggers the splice sequence the spindle drive will be accelerated to a higher speed.

This will allow the moving carriage to rise to the desired splice height.



The next step is to decelerate the expiring roll to a complete stop. The splice will then take place. As the splice bars open up the new roll is accelerated to back to nominal web speed.

Several important factors play into a well executed web splice: machine speed, material type & strength, allowable range of web tension, material width, and downstream process requirements. Often a good running web process is simply the best compromise between various desires.



The timing of the splice and the storage requirements for the festoon are often mapped using graphs of festoon position and web velocity. This allows one to determine requirements for festoon capacity based on acceleration and deceleration rates.

Optimization
<u>Tension Zones</u>
As mentioned before it is important to establish your tension zones. Where you decide to operate your equipment will provide for a certain process capability. It is common for people to make the mistake that someone else figured out where the process should run and never do the calculations. Do the math – it is easy. Be warned – you may find that you enjoy the search for the *right* answers. You may also find that other people will *thank you* for paying attention to the details that make the process run better.

Tare out the Carriage Mass

Recall the previous assumption that the moving carriage is loaded against the web using an air cylinder. With this design it will be important to 'tare out' the mass of the carriage. You need to document how much force (air pressure) is required to float the carriage. Any force (air pressure) above this will be directed to web tension. Be careful to note what pressure was required to float the carriage. How do you set this pressure? Is it constant or does it drift over time? A small drift in actual process tension can cause poor web handling. This becomes more important at higher speeds with more delicate webs.

Load Cells

The best way to finalize your calculations is to install a tension feedback idler. How close are your calculations to the indicated tension? Once you have validated your calculations with your load cell readings you can now move to process optimization.

Design of Experiments

A simple design of experiments is recommended to find your good run settings for web tension, air pressure, festoon height, and accel / decel rates. A more complex design of experiments is recommended to find out what your process capability is. Can your process deal with lighter webs? What will you do if you receive materials with floppy edges or baggy lanes? What setting can you adjust to keep your process running smoothly?

Analyze your Splice Failures

One of the most frustrating things that can happen is to miss a splice. It is important to analyze your splice failures. Did the material run off of the core? Did the splice make but then failed later in the process? How did the splice fail? Did it fail in a brittle fashion adjacent to the splice? Did the splice catch on something downstream? There are several dozen reasons why a splice may fail. Work with your operating teams to hunt down the splice failure like a detective at the scene of a fatality. It was a fatality – it was a web process fatality. The evidence will be found at the scene of the crash – at the tail end of the expiring roll or the leading edge of the new roll. We use continuous unwinds for the economics of not having to shut down. Invest the time to find the failure. Categorize each splice failure by its 'mode of failure'. The signature of the evidence will match the signature of the root cause. Get out there and find the signature of the problem. Be a good web process detective. Be warned – you may enjoy finding and eliminating the root problem.

Analyze any Loss of Web Handling

On occasion you will make the splice but the web will wrinkle badly or collapse completely. It is very important to know when this takes place, where it began, and what it looked like. Eye witness accounts are often unreliable. If you are failing 5% of your splices and the rolls last one hour you have to stand guard by the unwind for four solid days to catch five failures. With any luck you will be in the break room drinking a cup of coffee when a failure occurs. There is a better way.

Three Options

You now have three options. One is to do nothing. Sometimes that is acceptable. A better option is to set up a team to document the process for several days in a row – night and day. Use every means available to you to chase down any issue. This approach is brute force but it works very well if done properly. Enlist the help of the machine operators. They don't want to see any more splice failures and are willing to work with you if you are serious about resolving the problem at hand. The final approach is to install data acquisition equipment. This can take many forms. Trend charts in combination with load cells, web sensors, and cameras are the most common.

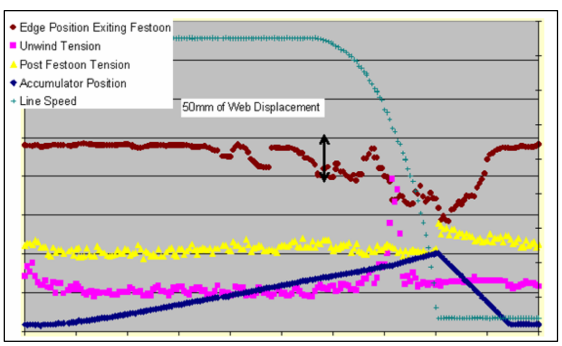
Trend Charts

Trend charts of your process parameters is a very important tool to understand and optimize your process. A simple trend of your process tension will give you insight into a splice failure. You can go back in time to analyze the data. Do you see any abnormal process tensions leading up to the splice? What is the tension profile of the splice event? This will be discussed further in the next section.

Cameras and Digital Video Recorders

Perhaps 90% of all splice failures can be caught and analyzed with a $300 digital camcorder. Make sure you have the ability to advance frame by frame in replay mode. The use of permanent cameras and a digital video recorder (DVR) is becoming common place. They are often designed to give you the ability to retrieve four days of data. That will allow you to analyze failures from the past weekend on Monday afternoon. Who likes to get called in on the weekend?

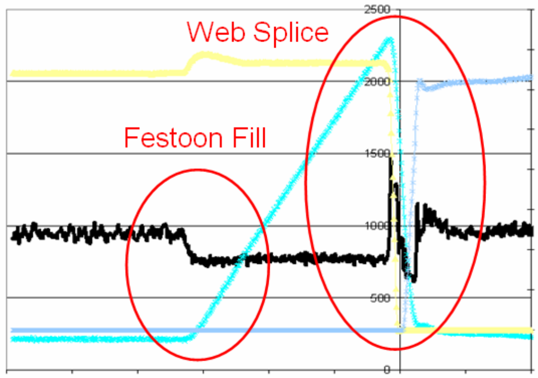
Web Width Sensors



Wide processes are negatively impacted by width loss. Narrow processes are negatively impacted by web weave. All processes are negatively impacted by wrinkles. All three of these can be detected with a combination of web width sensors and cameras. An analog signal from your sensors can be imported into your trend charts as shown to the left.

Trend Plot of Tension - Zero Speed Unwind Splice

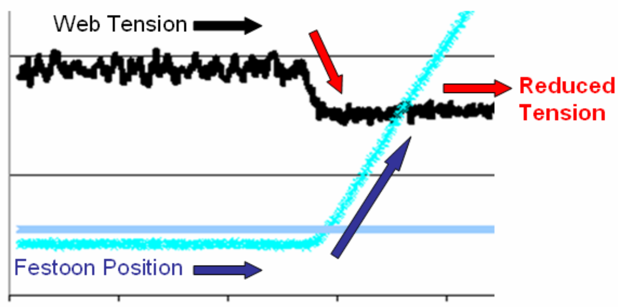
Trend charts are often the key to understanding what happened and how to make corrections. It is common for unwind splices to be the number one source of waste and delay in a converting process. Many of the process upsets during an unwind splice are associated with poor tension control. Let's take a look at a tension plot of a zero speed splice event.



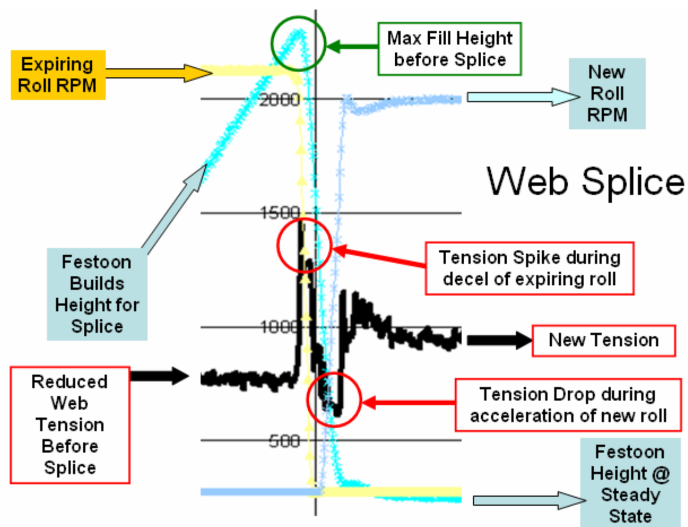
There are two important time periods of interest. The first is when the unwind begins to fill the festoon. The festoon fill phase is the first departure from steady state conditions. It is common to see troughs in open spans and wrinkles across rollers to appear. The second time period of interest is the splice itself. A lot of things take place in a very short period of time. It is important to sort thru the details to better understand what you are looking at.

We will now look at these two zones separately.

This graph zooms in on the festoon fill phase.



The web tension is black. The festoon height is shown in light blue. Note that before the festoon begins to raise that the tension was in steady state. At the same time the festoon begins to raise the web tension drops a significant amount to a new steady state condition. Recall that the expiring roll is accelerated to a new (higher) speed to fill the festoon. The web is driving the idlers. The web has to give up tension to accelerate the idlers.



This graph details the splice event. Recall that the splice is accomplished by decelerating the expiring roll to a complete stop. It is during this time that the tension spikes. The spindle drive is stopping the roll. The web from the roll is trying to stop the idlers. At the same time the moving carriage is being pulled down by the web. Once the roll has been stopped the splice bars close to make the splice. The moving carriage continues to be pulled down as the downstream process removes web from the festoon. When the splice is complete the splice bars open. The new roll is then accelerated to line speed which begins to drop the tension from its peak. There is a short time period required after the splice to bring the festoon height and web tension back to their previous steady state conditions.

Questions for Optimization

More information leads to more questions. Here is a list of questions that one should try to answer when optimizing an unwind process.

- What tension is needed to run well?
- How much tension spike can my web / splice take?
- What is the lower tension limit to insure good web handling?
- How fast do I fill the festoon?
- When do I see wrinkles?
- Where do I see the wrinkles?
- What do the wrinkles look like?
- Does my web weave or shift?
- How fast do I decelerate the expiring roll?
- How fast do I accelerate the new roll?
- How should I control my unwind?
- What should the festoon look like?
- How should my rollers be designed?
- Do I need a feed roll or a dancer?
- Is my problem due to the material, unwind design, or process settings?
- How can I adjust my process settings to run an off-spec web?
- What unwind design will have a wider process capability window?

Research Status and Needs

Current

Fundamental research for wrinkling has been solely focused on a single roller in an open span. Most information on zero speed splice unwinds is empirical and internal to the companies that own this equipment. There have been a couple dozen published papers that describe wrinkling, traction, and air lubrication. Virtually all of these have been developed at the Web Handling Research Center at Oklahoma State University under the leadership of Dr. Keith Good. There have been a handful of papers that describe the air to web interaction. There are four published papers describing accumulators. Only John Shelton's paper, "Dynamics of a Web Accumulator" presented at the fifth International Web Handling Conference (June 1999) gives a detailed description of the tension dynamics inside of an accumulator. Dr. Shelton also published the only paper describing the lateral dynamics of a multi-span system. Many of the published papers are not well understood. Most of this information has not been condensed into improved equipment design.

Needed

Several areas need to be investigated. For lightweight webs the interaction of the air with the web is an important driver to process capability. A festoon has multiple spans. How does one span interact with another one? How does this change at higher speeds? What general arrangement helps to reduce negative span interactions?

Finite element codes have demonstrated great capability to predict wrinkles due to a single mis-aligned roller in an open span. What will happen when an entire moving carriage is out of alignment? Traction is a driver for the generation of wrinkles. What is the effective coefficient of friction between a web and a roller at speed? What does this look like for a highly porous web like tissue or nonwovens? What should the idlers look like? What is the trade off for larger roller diameters that promise reduced wrinkles?

A computer model that describes the dynamic behavior of a festoon is needed. This needs to be validated. How important is the rotational inertial with respect to the translational inertia? A couple of vendors have introduced driven rollers to replace idlers in the festoon. Should we drive our rollers? How many and where should they be located? How important is frictional force required to move the carriage? What other web handling aids can be used to improve an unwind?

Industry Needs

A combination of fundamental and applied research is needed to develop value priced robust solutions.

The increase in the price of oil has put a strong pressure on companies to produce lighter webs at high speeds. Lighter webs require improved tension control. Can a mechanical design change provide this or do we need non-traditional controls? If one simply reduces basis weight more floppy edges and baggy lanes are expected. Improved equipment designs are needed that will have a wider process capability window. Fundamental research is available for review now. Higher operating speeds will need stronger splices that can be produced in less time. Improved splice designs are needed for lightweight webs to be able to withstand difficult process conditions beyond the unwind. Many companies have downsized their organizations. Turn key equipment installations are needed that require less technical support to install and startup.

Open innovation is needed. Strategic partnerships between OEM's, research organizations and end use customers are desired to develop solutions that meet the needs of industry.