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ABSTRACT

A web is defined as a continuous strip of flexible material. Continuous web processes provide cost savings to manufacturers and converters. Converting processes use unwinds to provide a continuous supply of web material. Accumulators are often used for unwinds to allow a splice without stopping the web process. Accumulators are also used for winders to allow a roll transfer while the process continues to run. Webs are stored in wound rolls under stress and spend most of the time in storage before being converted into a final product. The combination of stress and time cause the web to have floppy edges, baggy lanes, and web camber. Accumulators must be capable of processing these non-ideal webs.

Web tension is the most important parameter for any web process. Individual span tensions vary significantly within the accumulator during steady state operation. Individual spans undergo extreme tension differentials during the accumulator fill and feed process. Poor tension control within an accumulator can lead to waste and delay. Symptoms of poor tension control within the accumulator include web instability, web weave, wrinkling, and neck down. Failure modes include total web collapse and ultimately web breaks.

Web tension collected from an accumulator will be presented. An emphasis will be given to the dynamic fill and feed operation of the accumulator. It will call attention to the challenges of proper accumulator design and control.

A survey of industry needs for improved equipment and process capability will be offered. Fundamental research for web handling has been primarily limited to a single roller in an open span. There are several dozens of published papers that describe traction, air lubrication, and wrinkling. There have been a handful of papers that describe accumulators with little to no validation. Equipment builders have not improved their designs based on published papers. As a result, most accumulators are operated using a trial and error approach.

WHAT IS AN ACCUMULATOR?

Description

An accumulator is a web storage device. They provide a large amount of web storage in a small footprint. Accumulators are used on many processes. Accumulators are used when the web needs dwell time to cool or relax before the next operation. Accumulators are used on web processes that have different sections of the machine that are required to run at different velocities. Accumulators are located before a winder to allow a roll transfer. Accumulators are used on unwinds to provide time to make a high quality splice. [1]

This paper will present data collected from an accumulator used in conjunction with a zero speed splice unwind.

An accumulator consists of multiple web driven rollers that move in relation to each other to provide the proper amount of web storage. Many different designs are available. One common arrangement consists of two sets of rollers. The lower set is fixed in position within a frame. The upper set of rollers is mounted on a carriage that moves in a vertical plane. [Figure 1]

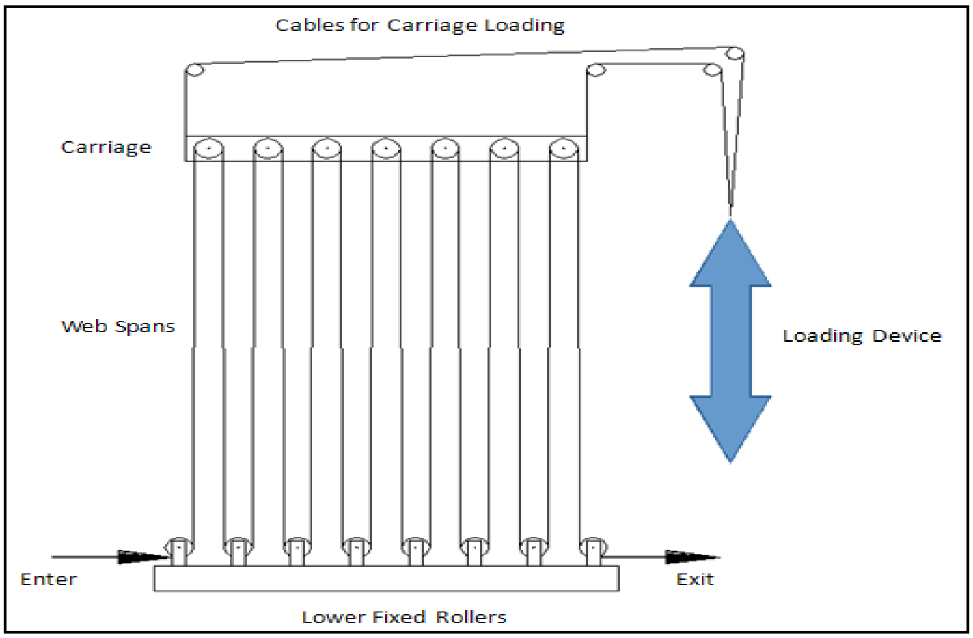


Figure 1 – Industrial Accumulator – General Arrangement

Carriage Control

During normal operation the carriage is loaded against the lower set of rollers thru the web spans by a loading device. Pneumatic cylinder(s) are common for small accumulators because of their low cost. Hydraulic cylinders are used in the aluminum and steel industries because of heavy forces that are required. Cables or chains are often used to connect the loading device to the carriage due to their low cost. Some accumulators use electromechanical arrangements to provide better alignment of the carriage rollers.

A nominal amount of force is required to offset the mass of the carriage and idlers. This is often referred to as tare force or bias force. Additional loading above the tare force will provide tension to the web spans. This force will be evenly distributed across all of the web spans when the web process is stopped. For example an accumulator with eight rollers on the carriage will have 16 web spans. Each span will receive 1/16 of the net force applied to the carriage (net = total – tare). A statics calculation will provide average tension across the spans based on the loading device used and how it is operated.

Web Span Tension During Operation

Referring to Figure 1, during steady state operation, the web will move from left to right. The tension at the exit of the accumulator will be higher than the entrance due to the frictional torque required to rotate each set of bearings per roller.

Total frictional torque will vary based on many things to include: number of bearings, bearing diameter, idler diameter, bearing construction, alignment, condition of the bearing, lubrication, bearing temperature and speed. It is common to see more than a 10% increase in tension across the accumulator during steady state conditions. This differential is often overlooked because load cells are not installed or calibrated accurately. The mass of the roller(s) does not contribute to tension increase during steady state operation.

Tension will vary radically in each individual web span during dynamic fill and feed operation. ‘Fill’ is when the accumulator builds volume (carriage rises) by collecting material from the upstream process. ‘Feed’ is when the accumulator volume decreases (carriage lowers) to provide material to the downstream process.

The tension differential during a dynamic fill and feed operation will vary based on: rate of acceleration / deceleration, the number of rollers, and the ‘effective inertia’ {J/R^2} of the idlers. [2]

Process Challenges

Web tension is the most important parameter for any web process. As a rule of thumb the nominal tension should be 10% - 25% of the breaking force for the web. [3] During steady state operation a web traveling through an accumulator may see a tension increase that exceeds this guideline.

During dynamic fill and feed operations it is common to find tension variations of an order of magnitude beyond the nominal tension. These tension excursions are very important for low modulus webs like tissue, nonwovens and delicate laminates. This paper documents tension variations of +700% / - 80% from nominal during dynamic fill and feed operation within an accumulator.

As a direct result it is common for accumulators to be a leading source of waste and delay in a high speed converting web process. Many waste and delay events are closely associated with tension excursions within the accumulator.

If the tension is too low the web will begin to flutter out of plane and may fold over on the edges or complete collapse. If the tension is too high the web will neckdown due to Poisson’s ratio. If the web is necked down in one section of the machine it is subject to ‘expansion wrinkles’ in a downstream section of the machine that has lower tension. [4] At extreme tensions the web will break.

Wide processes are most affected by edge fold over, neckdown and expansion wrinkles. Narrow processes often struggle with wrinkles, web weave and web breaks within the accumulator. These challenges are magnified by non-ideal web properties such as floppy edges, baggy lanes, and cambered webs. [Figure 2]

Figure 2 – Cambered Web & Wrinkles in the Accumulator

EXPERIMENTAL SETUP

Accumulator Description

Process data was collected from an industrial accumulator mounted on an unwind during normal operations. The accumulator has 17 rollers: eight on the carriage and nine on the lower frame. The rollers are lightweight carbon fiber and use low friction roller bearings. The vertical stroke of the carriage is 5.1m which provides 81.6m of total web storage. Details for the accumulator and the web process are as follows. [Table 1]

Accumulator Info	
# Total Rollers	17
# Fixed Rollers	9
# Carriage Rollers	8
# Web Spans	16
Roller Diameter	165.1 mm
Roller Mass	7.28 kg
Roller Length	3.6 m
Roller Inertia	43603 kg*mm^2
Accumulator Stroke	5.1 m
Total Accumulation	81.6 m
Spindle Drive Info	
Motor Base Speed	1,765 rev/min
Gear Ratio	11.375:1
Operating Parameters	
Machine Speed	259 m/min
Deceleration Rate	91.4 m/min/sec
Acceleration Rate	91.4 m/min/sec
Stop Time	2.7 sec

Material Info	
Web Material	Polypropylene Spunbond
Young's Modulus	55 MPa @ 1% Strain
Basis Weight	13.6 g / m^2
Web Width	3.162 m
Material Caliper	0.1016 mm
Poisson's Ratio	3 @ 1% Strain
Load Cell Info	
Manufacturer	ABB
Model #	PFTL301E
Calibration	400 N

Table 1 – Accumulator and Web Process Information

Splice Sequence

A lightweight nonwoven material was unwound at speed of 259 m/min with the carriage set to 35% fill height. A splice sequence begins with filling the accumulator to splice height by increasing the speed of the spindle above steady state speed. Once the carriage is at ‘splice height’ the spindle decelerates to a stop at 91.4 m/min/sec. The splice bars clamp momentarily before the next spindle accelerates at the same rate back to steady state 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. [1]

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 machine speed, acceleration and deceleration rates. [Figure 3]

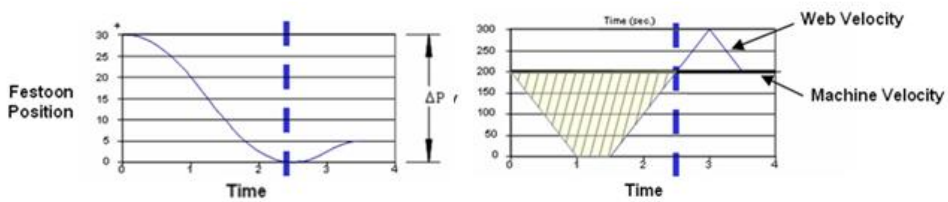


Figure 3 – Example of Festoon Capacity Graphs

Controls Overview

The accumulator that was studied was in position loop control. A linear position sensor mounted on the moving carriage was used to trim the speed reference of the speed regulator. Other control methods have been used to control the accumulator such as closed loop tension control using either the entering or exiting load cell.

Data Collection

A total of five process parameters were collected every 100 milliseconds using the machine's programmable logic controller:

1. Accumulator Entry Tension
2. Accumulator Exit Tension
3. Accumulator (Carriage) Height
4. Spindle A Speed
5. Spindle B Speed

A magneto-restrictive sensor mounted on the carriage is used to document carriage height. Spindle speed is captured in the coordinated line drives for the unwind. Pillow block style load cells were installed at the entrance and exit of the accumulator.

Referring to Figure #1 - the entrance load cell is the first roller on the lower frame. The exit load cell is the last roller on the lower frame. The load cells were carefully calibrated with full scale set to 400 N. Figure 4 shows a common installation for this style of load cell.

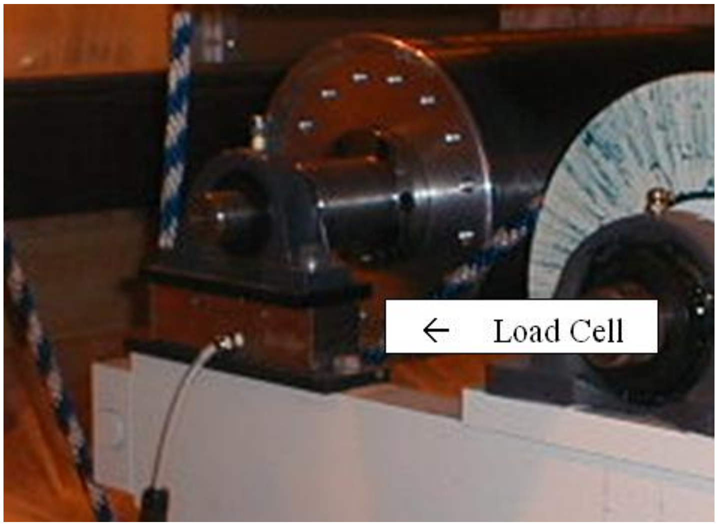


Figure 4 – Typical Pillow Block Style Load Cell Installation

DATA RESULTS AND OBSERVATIONS

Description of Data Presentation

It is difficult to display five data sets concurrently without causing confusion. For this reason entry tension, exit tension, and carriage height are grouped together on the primary vertical axis. The units are in percentage so they can use the same scale. Both tensions are based on a full scale of 400N. The festoon height is based on 5.1m. For example:

- A web tension of 30% tension is 120N.
- A festoon height of 35% height is 1.8m.

Spindle speed in RPM is shown on the right vertical axis. The horizontal axis is time. [Figure 5]

Load cell data is noisy and is difficult to present using black and white reproduction. The data has been averaged to reduce noise on Figure 5. Data labels are provided every two seconds to clean up the graph. The averaged data represents the tension transients within the accumulator - but the peak values have been reduced.

Actual tension values will be provided within this paper for analysis based on the raw data. The percentage of full scale tension will be shown in brackets when appropriate. For example:

- "Steady state tension at the entrance was 88N (22%)."

The unfiltered and filtered data can be provided upon request from the author.

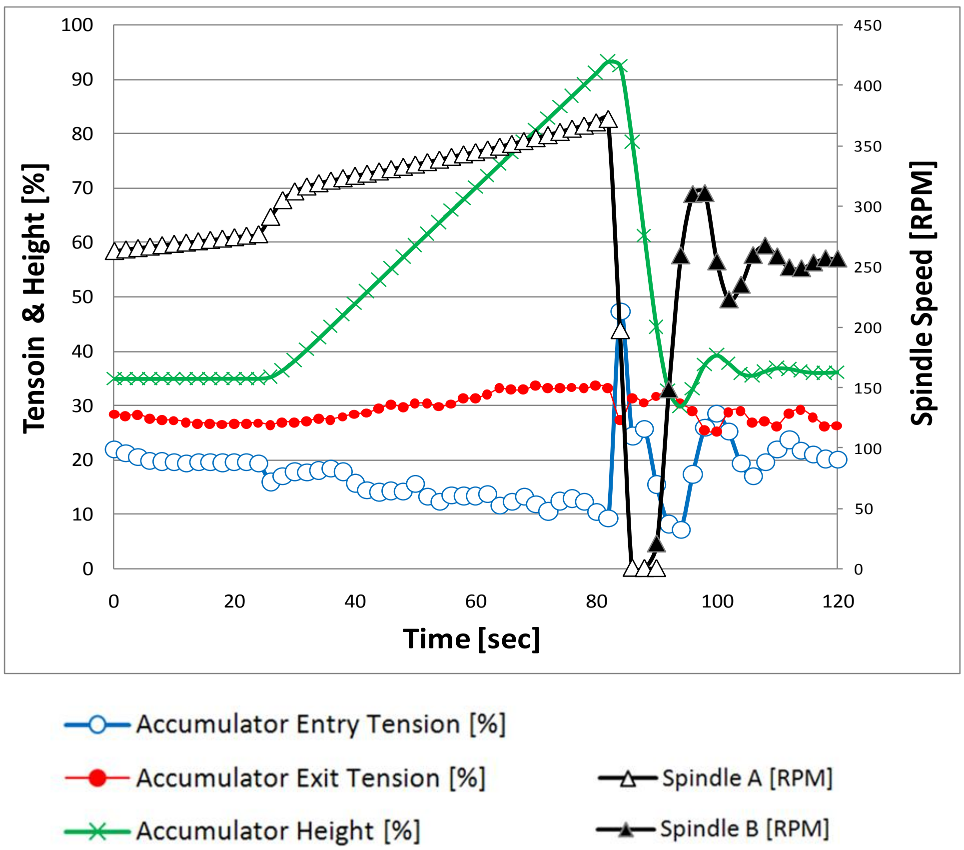


Figure 5 – Accumulator Data – Averaged

<u>Three Phases</u>

There are three phases that will be analyzed. [Figure 6]

1. Steady State Condition. Time = 2 – 20 sec.
2. Accumulator Fill Phase. Time = 20 – 80 sec.
3. Accumulator Feed Phase. Time = 80 – 120 sec.

Each phase will be independently analyzed. A list of questions will be presented at the end of each section.

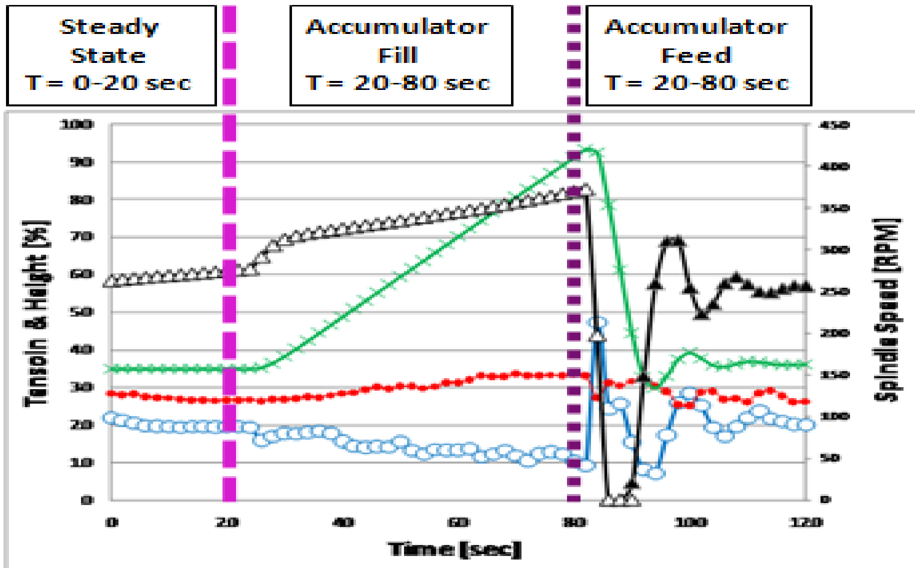


Figure 6 – Three Phases: Steady State, Fill and Feed

STEADY STATE PHASE

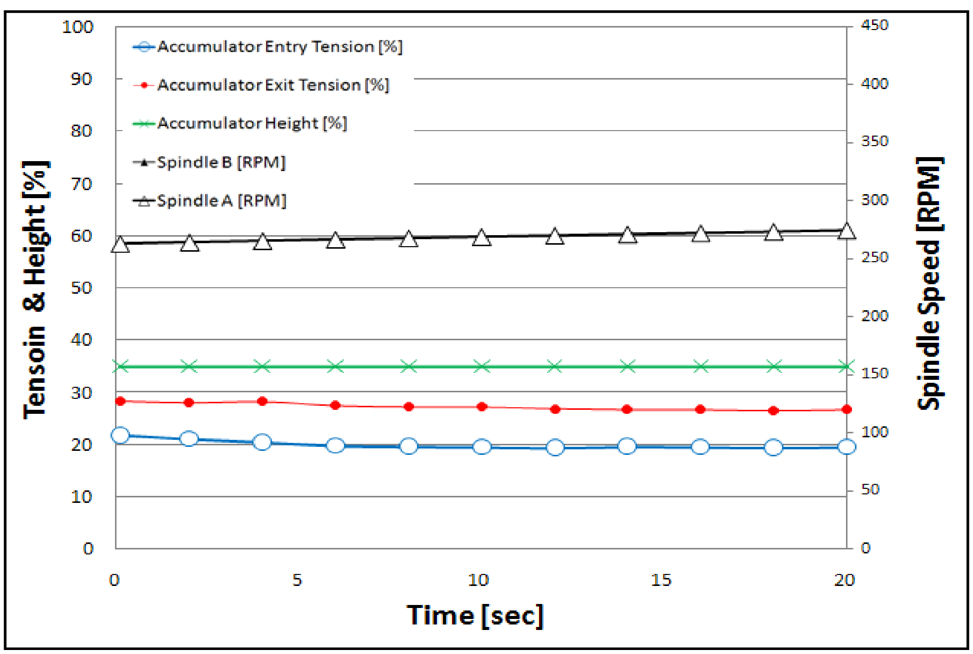


Figure 7 – Steady State (Time 0-20 sec)

Steady State - Analysis

- 'Steady State' condition is the time period up to 20 sec. [Figure 7]
- The carriage is held at 1.8m (35%) in height. This provides a total storage of 25.2m.
- Spindle A is slowly speeding up because the roll radius is decreasing.
- A position loop control is used for the accumulator. The carriage height sensor is used to trim the speed reference to the spindle speed controller.
- The carriage position is stable.
- Steady state tension at the entrance of the accumulator is 88N (22%). This represents a stress of 365KPa.
- The exit tension is 110N (27.5%). This represents a stress of 456KPa.
- Note that the exit tension is 20% higher than the entrance tension. This is due to the torque requirement to rotate 30 roller bearings.

Steady State - Questions

- What is the tradeoff between longer spans or more rollers for a given storage capacity?
- What criteria should be used to designate unacceptable tension increase within an accumulator?
- What is considered 'world class' for roller bearing performance as measured by rotational frictional torque and bearing life?
- What is the actual traction force of a highly porous web against a roller at high speed?

ACCUMULATOR FILL PHASE

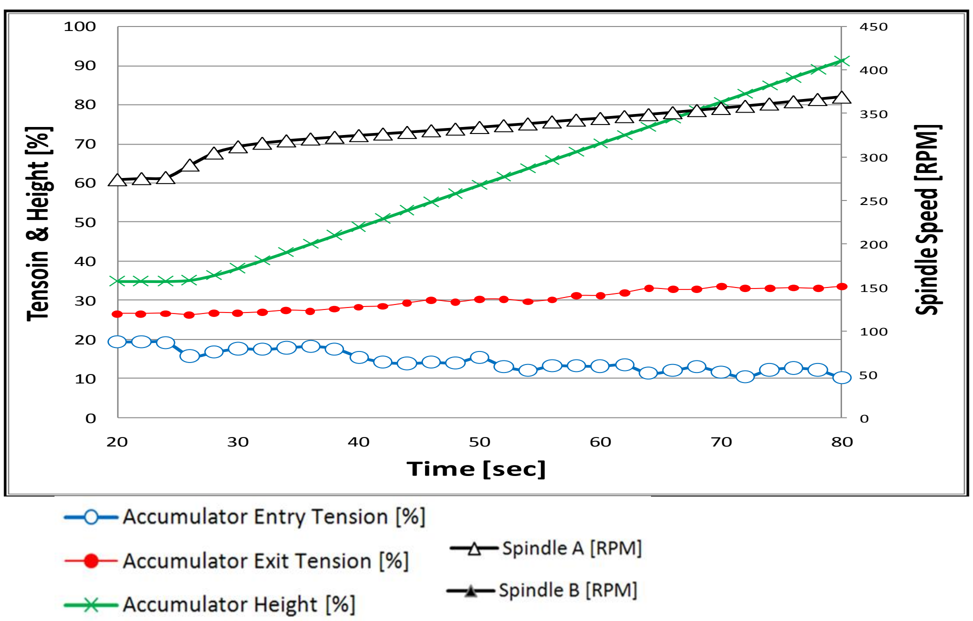


Figure 8 – Accumulator Fill Phase (Time 20-80 sec)

Accumulator Fill Phase - Analysis

- 'Accumulator Fill Phase' is the time period between 20 – 80 sec. [Figure 6]
- The programmable logic controller calls for the accumulator to fill when the expiring roll diameter reaches a pre-determined limit
- Spindle A is accelerated at a rate of 91.4 m/min/sec to begin to fill the accumulator
- Note that this acceleration only takes six seconds before the rate of change levels off (t = 24-30 sec)
- The carriage is raised at an average vertical velocity of 3.0 m/min
- Entry tension slowly decreases as the carriage continues to rise.
- The entry tension drops 64% (88N→32N) as the carriage slowly rises to its splice position (t = 24-80 sec)
- Note how the entry tension drops momentarily (t = 26 sec). This is associated with the initial acceleration of the roll.
- Tension at the entrance of the accumulator drops 64% as the carriage approaches its splice position
- Accumulator height at splice position is 4.7m (92%) for a total accumulation of 75.2m
- The exit tension increases 20% (110N to 132N) as the carriage rises
- The total load on the carriage was held constant.
- At splice height the entrance tension is 32N and the exit tension is 132N.
- This is a difference of 100N. The exit tension is more than four times higher than the entrance tension.

Accumulator Fill - Questions

- What determines how fast the web can be accumulated?
- What nominal tension should be established during steady state that will provide the best web handling performance in light of the dynamics that will take place during fill and feed?
- Which intermediate span will not see a tension change?
- Why does the loss of tension not stop after the 6 sec acceleration of the spindle?
- If the accumulator is controlled by feedback from a load cell which location is best: entrance or exit of the accumulator?
- What is the trade off for either location?
- What determines when rollers should be driven?
- If rollers are driven how should they be controlled?
- What low cost options are available that would avoid the cost and complexity of driving rollers?
- What critical length to width ratios should be avoided for a single span versus multiple spans?
- Which is more important: 65% loss of tension at the entrance or a fourfold increase in tension at the exit?
- What happens if the carriage is misaligned?
- Do multiple spans in misalignment act independent of each other or do they combine?
- What combination of non-ideal web properties (camber, baggy, et) in conjunction with carriage misalignment will cause more problems?

ACCUMULATOR FEED PHASE

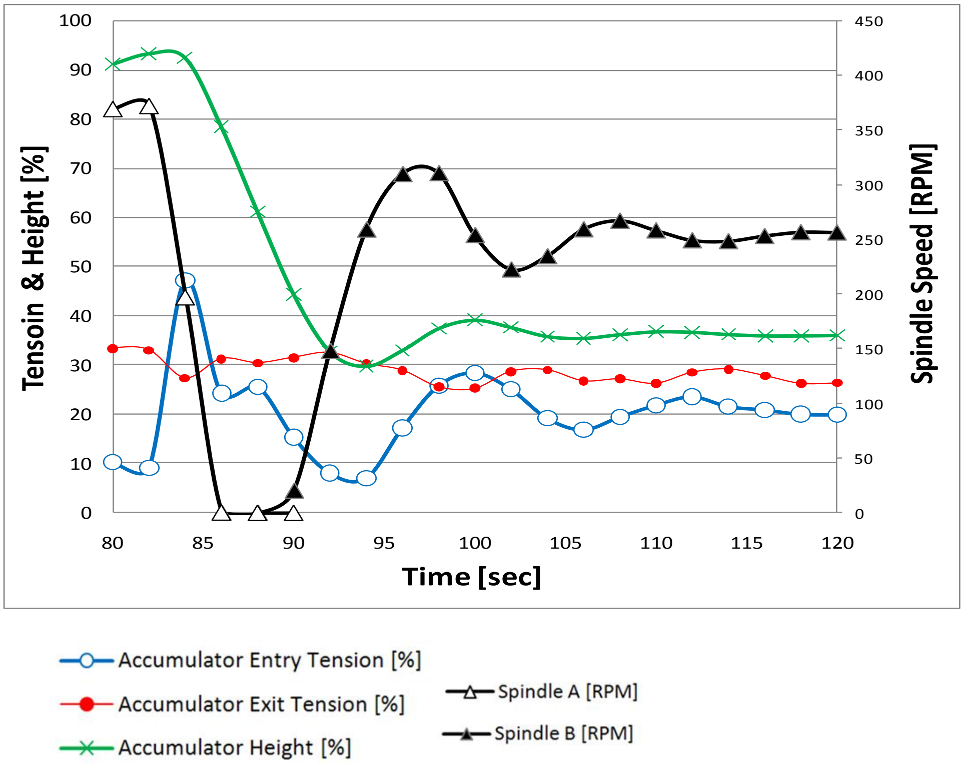
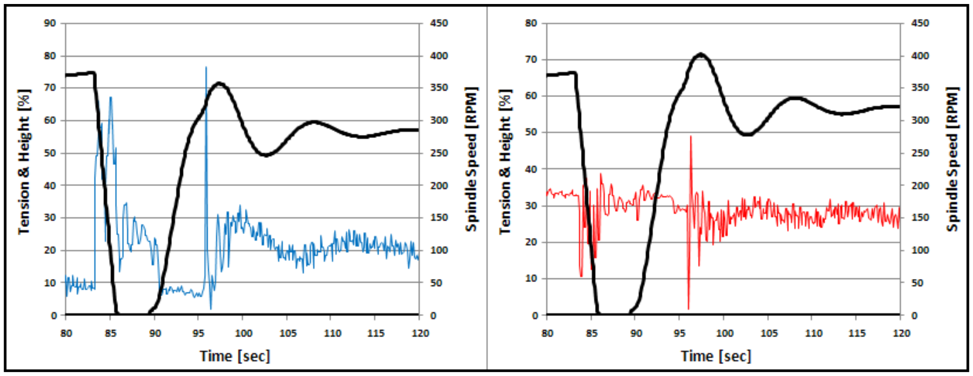


Figure 9 – Accumulator Feed Phase – Averaged Data

Accumulator Feed Phase - Analysis

- ‘Accumulator Feed Phase’ is the time period between 80 - 120 sec. [Figures 9 & 10]
- It takes 96 seconds to complete the splice. This includes the time required to raise the carriage, make the splice, and return to steady state conditions.
- The programmable logic controller begins to decelerate Spindle A at 91.4 m/min/sec. This starts at 83.1 sec. Spindle A is decelerated to a stop in 2.7 sec.
- For an unwind operation this is the most challenging period of time. Most problems happen during time that the accumulator is feeding material to the downstream process. Common issues are neckdown due to tension spike, wrinkles during acceleration, and web weave after the splice.
- The peak carriage height was 94%. The carriage then travels down at an average velocity of 19.2 m/min as Spindle A comes to a stop.
- The accumulator is at 78% fill when Spindle A comes to a stop. The carriage continues to travel down to allow the splice to take place.
- The splice bar was closed 3.7 sec
- The accumulator is at 53% fill by the time the splice bars open.

- Spindle B starts at 89.5 sec. Spindle B accelerates at 91.4 m/min/sec to bring the accumulator back to steady state conditions.
- The accumulator reaches a minimum fill of 30% before returning to a 35% fill set point.



Dark Line – Spindle Speed
Fine Line – Entrance Tension (Left); Exit Tension (Right)

Figure 10 – Accumulator Feed Phase – Entrance & Exit Tension
Raw Data – Not Averaged

<u>Accumulator Feed Phase – Analysis Continued</u>

- Recall that Figure 9 is averaged data. The peak tensions are ~ 60% lower than the raw data shown on Figure 10.
- Figure 10 is raw data for entry & exit tension versus spindle speed. Festoon position has been deleted to add clarity to the graph. The data markers have been eliminated as well. The spindle speed is the bold line. The tension data is the fine line. Note the noise in the raw tension data which comes primarily from roller imbalance. Entry tension is on the left; exit tension is on the right.
- Note how the entry tension spikes up as the spindle is brought to a stop. This makes sense because the entry load cell is close to the spindle.
- The entry tension spikes from 40N to 272N concurrent with the spindle coming to a stop. This is a 680% increase in tension during the 2.7 sec time needed to bring the spindle to a stop.
- It is common to see neckdown at the entrance of the festoon when the tension spikes. This often results in expansion wrinkles as the web moves downstream to a lower tension zone.
- Note how the entry tension drops back down to 32N (8%) as the next spindle (B) accelerates the roll back to steady state conditions.
- In general the tension at the exit of the accumulator does not see the same magnitude of changes as the entrance of the accumulator.
- The exit tension moves in the opposite direction of the entrance tension
- When the entrance spikes the exit drops. The opposite is also true.
- Note that the entry tension drops to 24N (6%) when Spindle B accelerates the new roll up to speed.

- Note that both entry and exit tension momentarily spikes (t = 96.5 sec) when spindle B slows down as the carriage approaches the 35% set point
- Figure 11 shows how the sum of the entry and exit tension changes during steady state, fill and feed.
- Note that the sum of the entrance and exit tension is 50N at the beginning of the graph (t = 0). The sum drops to 42N at the end of the fill phase.
- This is a 16% loss of total tension at splice height. The loading force on the carriage was not changed.

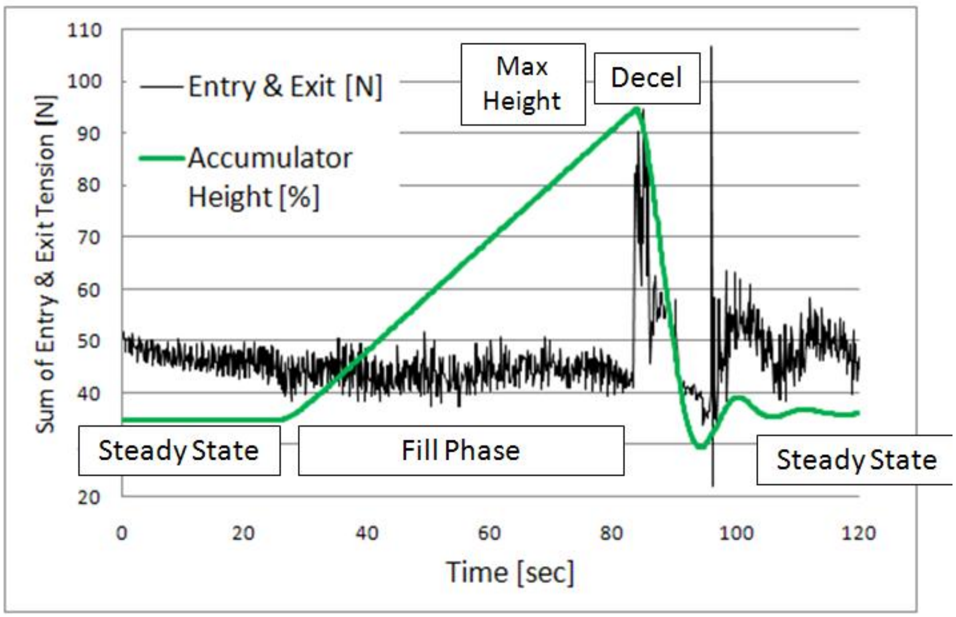


Figure 11 – Sum of Entry and Exit Tension versus Carriage Height

<u>Accumulator Feed - Questions</u>

- Why does the sum of the two tensions drop 16% as the carriage rises?
- Is this due to air drag from the additional 40.6m (+161%) of web accumulated?
- How does one dimension air drag on a single web in an open span?
- What happens to webs that run in opposite directions in close proximity of each other within an accumulator?
- How close can web spans running in opposite direction be located without causing web handling problems?
- Which is better: more rollers with shorter spans or few rollers with longer spans?
- What is the best approach to maintain proper tension within an accumulator?
- What low cost solutions are available to reduce the tension excursions within existing accumulators?
- What is considered world class tension control for an accumulator during fill and feed?

- How do we determine when an expansion wrinkle will occur?
- When should the rollers in the accumulator be driven?
- How should driven rollers be controlled?

INDUSTRIAL NEEDS FOR THE FUTURE

Current Research Status

Fundamental research for wrinkling has been solely focused on a single roller in an open span. There have been several dozen published papers that describe wrinkling, traction, and air lubrication. Most of these have been developed at the Web Handling Research Center or have been presented at one of the International Web Handling Conferences sponsored by the same organization. There have been a handful of papers that describe the air to web interaction. There are only five published papers that describe accumulators. [5][6][7][8][1] Equipment builders have not developed improved designs based on available research. Most information on accumulators is empirical and internal to the companies that operate this equipment.

Needed Research

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 model needs to be validated. What happens to a visco-elastic web as it travels thru an accumulator? How important is frictional force required to move the carriage? What low cost web handling aids can be used to improve an existing unwind? Should modern controls be used?

A couple of vendors have introduced driven rollers to replace web driven rollers in the festoon. [8][9] Should we drive our rollers? How many and where should they be located? How should they be controlled?

Industry Needs

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

The recent shift in the economy has pushed companies to produce lighter webs at high speeds. Lighter webs require improved tension control. 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 for non-ideal webs.

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. [1]

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