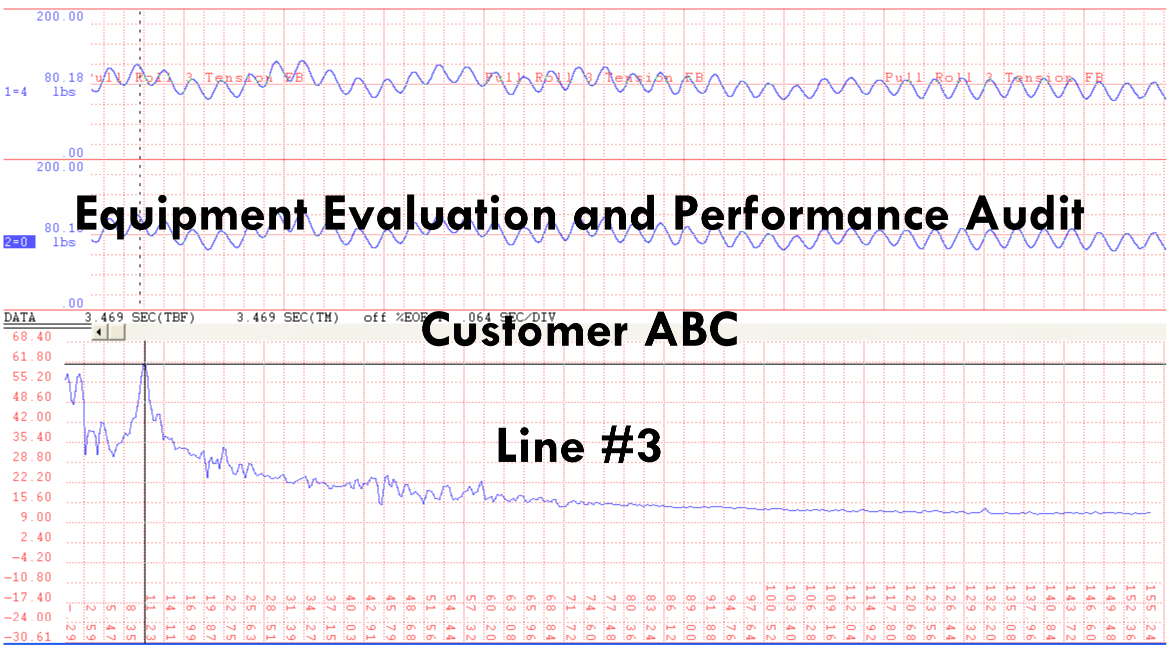
Equipment Evaluation and Performance Audit

Customer ABC

Line #3



Overview

This is a detailed audit report for Line 3 at CUSTOMER ABC. The purpose of the audit was to determine the causes for deficiencies in the machines performance, evaluate the extent of performance degradation for each cause, propose various improvement options for the identified deficiencies, and analyze the pro's and con's of each solution.

Information for this report was compiled from a 2 hour interview with CUSTOMER ABC's technical staff and a 3 day onsite investigation. This included additional interviews with operators, maintenance staff, and laboratory personnel (quality assurance), a review of the drive, PLC, and HMI programming and architecture, observations of the equipment while running a variety of products, and over 40 hours of recorded drive data for measuring performance.

The machine frame is from ORIGINAL OEM. The controls have seen several additions and updates, with the last major overhaul being circa 1993.

Activities

Telephone Conference:

Date: January 13th, 2005. 1pm-3pm.
Circonix Attendees: Edward Colletti
CUSTOMER ABC Attendees: Removed for Confidentiality

Onsite Audit:

Date: January 24th - 26th, 2005
Auditors: Edward Colletti

Machine Specifics

Process

Line speed:	0 to 125 ypm
Ramps:	Variable
Tension range:	Wide, Low (70lbs) to High (800lbs)
Extensible range:	Wide, very stiff to stretchy
Tension zone length:	Wide, varies with lead from long to short
Measurement type:	All load-cells, including Unwind and Rewind
Measurement range:	Some zones have dual amplifiers for Hi/Low tension range

PLC

Type:	Square D Model 400
Remote racks:	3 – Unwind, Rewind, and Burner Control
Programming:	DOS based pc interface.

Drives

Type:	ABB Veritron PAD 4, Analog
Module:	Memory module for tension and diameter calcs
Current loop:	Base drive with self-tune
Speed loop:	Base drive PI optimiz'able' after self-tune
Tension loop:	Memory module with extensible switch for PI parameters

HMI

Platform:	Factorylink 4.0 (DOS)
PC HW:	circa 1994 for Proc/clock, HD
Supervisory Control:	Set-points, Sequencing
Recipe:	Yes, 100+ recipes.
Real-time trend:	Yes, 1 pen @ ~ 1 sample/min
Historical trend:	Yes, view 1 pen @ ~ 1 sample/min resolution
Communications:	Serial

E-stop

Regenerative:	Yes
Coordinated:	No
Safety relay:	No

Roller integrity

Alignment:	No signs of misalignment
Idlers:	Heavy/High Inertia – approximately 60lbs
Idler balance:	undetermined
Roll Coupling:	Non zero-backlash

Web guiding

Type:	Fife, hydraulic, air edge detect
Performance:	OK

Other notes

Line has suction aprons running in torque mode with slip.
Dryer 4,5,6 web support rolls are direct drive in torque control.

Known issues

1. Variations in coat weight.
2. Tension variation during speed change.
3. Tension variation during splice or transfer.
4. Rewind wrinkles
5. Rewind telescoping, flat spots, and other related roll issues.
6. Splices catch & break at applicator roll knife (roughly 60% success)
7. Over 40 hours of down time per month can be attributed to web conveyance problems

General Observations

Heavy idlers

The idlers were most likely selected to withstand potential damage from products running around 2000 lbs. ***Since the line doesn't produce products in this range, the idlers are not the optimum selection.*** In fact, they are a poor selection for running the lower tension products and contribute to destabilizing the tension control as well as generating static. ***In addition, calibrating load-cells to 2000 lbs and having max set-points around 600 lbs is sacrificing resolution on the tension feedback which only serves to decrease response time and increase steady state variations.***

The machine can be broken down into tension control sections where one particular drive is responsible for controlling each section. Ideally, the tension in that zone would always be equal to set-point and would be consistent regardless of where in the zone it was measured. On this machine the idler rolls weigh in at approximately 60lbs each. The energy to accelerate and decelerate the idlers must be transferred to those rolls through the web. This causes partial tension isolation between idlers resulting in a tension drift across the zone. Stated another way, if a drive is pulling a cluster of idlers along behind it in its tension zone, the drag of each idler causes a cumulative drift in the tension.

For Example, if during a speed change each idler has 10 lbs of drag, the tension will decrease 10 lbs as you pass over each idler. After ten idlers, the tension could be 100lbs off set-point. The trouble with this scenario is the "partial isolation". The drive will only respond to tension feedback measured at the load-cell. Therefore, the tension in the web at the load-cell will hover around the set-point. 10 idlers away from the load-cell, the tension within the same control zone may be 100 lbs high and causing wrinkles, or 100lbs low causing slack or web walking. The idler rolls are not idling as their name implies. They are more like fly-wheels and contribute to tension instability in the line during speed changes. Fortunately, the tension disturbance is limited due to slip. Unfortunately, this gives rise to another problem, static.

Aluminum and steel are relatively neutral in the triboelectric series. Nylon and glass are very positive. Polyurethane, polyethylene, polypropylene, vinyl (PVC), silicon, and Teflon are all very negative. Since steel is neutral, dragging a non-neutral material across it results in the build up of a static charge. ***In the case of the machine, most of the product materials are far from neutral in the triboelectric series so when the steel idlers slip (even at steady state) they generate static in the web. When one considers the Class 1 Division 1 (flammable vapor) area that the web runs in, static discharge is a paramount concern.*** As a result, there is an inordinate amount of static control devices on the machine.

Suction Belts

These devices are less than optimal for controlling the web. Since the suction belts run in over-speed, with a torque limit, and tend to slip due to limited suction, they essentially perform just like heavy idlers. The suction belts cause partial tension isolation as discussed above and don't actually contribute to the tension control or web conveyance. In addition, they induce static in the web. In fact, the suction belt design is almost an exact replica of a classical VanDeGraff generator used to demonstrate static buildup in High School classes around the globe. Once again, the static is obviously undesirable, especially in a C1D1 environment.

While the suction belts are not necessary for web conveyance, they do perform one very useful function. Upon a web break, the suction belts prevent material from wrapping into the coaters averting some potentially huge cleanups and possible coater damage.

Splices traversing coater units

While it was clear that splices sometimes cause trouble at the coating units, various personnel put several conflicting observations and theories forward. Since no problems were evident during the audit, it is difficult to narrow down the true nature of the issue or issues. Based on a consensus of observations, the increased thickness of the splice either results in wiping buildup off the coater blade, or some other phenomenon which causes an increase in coat weight resulting in a high LEL alarm. This issue might warrant further monitoring and investigation if it persists after other line improvements have been implemented.

Coater blade gap

A pair of gauges measures the coat weight and the coater blade gap is adjusted automatically to track the set-point. In this manner, whenever the coat weight starts to move noticeably away from set-point, the controls adjust. ***It is evident that tension oscillations at steady state are affecting the coating, and it is unclear as to whether or not the gauge system chases the tension variation thereby compounding the problem. To determine this, it would be necessary to setup position feedback for the gap but only as a secondary option after tension control is optimized.***

When the line ramps up to speed, the coat weight dips and the operators walk the line up-to-speed gradually allowing the gauge controls to catch up. The poor tension performance during ramping certainly contributes to the gauge controls having to make large corrections. There may also be a dynamic viscosity factor where the gap position varies with line speed. ***Determining this function and adding it as a feed forward to the gauge control, should improve the consistency of the coat weight during ramping.***

It should be made clear that since little data was collected regarding coat weight, it would be imprudent to make large changes. ***It is recommended to correct or minimize the tension variations at steady state and during ramping. This will remove one of the factors affecting the coat weight. Then some trials could be run to determine the variation during ramping. If the variation is significant and the gap position isn't adjusting fast enough, then a feed forward function should be considered to better model the system.***

Cooling Roll condensate

The circulation valve for the chill water to the cooling roll is manually actuated. Therefore the operator must remember to turn off the valve during extended stops to prevent the roll from sweating in the summer time. ***This can be a problem on some webs such as paper which may break when wet. The valve can easily be tied into PLC control.***

Brake Unwinds

When transferring from manual to auto mode the operators sometimes observe a dip in the tension. This means the brake releases briefly at the switch. The brake is on a timer and switches to auto 2 minutes after the line is started. It remains unknown why there is a two-minute delay. ***Also, it should be configurable to have a bump-less switch from manual to auto.***

Recipes

There exist two recipes for the machine. One is in the FactoryLink application and sets the web conveyance and process parameters. The other configures the gauge setup. The FactoryLink recipe does not specify to the gauge computer what gauge recipe to use. ***Tying these two recipes together may be worth consideration.***

Drives & Tension Control

Tension control throughout the line is weak. Response to tension transients is poor and stability at steady state is less than optimal. Many web breaks are caused by slack, which results in the web pasting to itself or wrapping into a coater. During speed changes, the operators do not use the machines ramps, but instead they walk the set-point in small steps to allow the tension control to keep up. And finally, while in production and at a steady state, the variation in tension at the coaters is evident and results in fluctuation of the coat weight.

Startup

When the machine starts, if there is slack in individual zones it takes considerable time to be corrected. This results in wraparounds at the C unit or Cooling roll since the web path in these areas doesn't allow for much slack. When the operators press the run button the line turns on and immediately ramps to set-point. No consideration to tension control and the disruptive nature of starting the machine is given in this sequence.

Reprogramming the start sequence can make significant tension control improvement. When the run pushbutton is pressed, several things should happen at zero line speed. If the unwinds and rewinds have a zero speed stall tension, they should now switch to operating tension. The remaining line drives should all turn on and pull up tension in their respective control zones. This removes all the slack and tensions the web before attempting to transition into a run.

After a pause of about 5 seconds, tension should have stabilized at zero speed and the line should go to a min speed, not line speed set-point. Transitioning from a static to a dynamic state is disruptive to drive controls, particularly since there is a step change between static and dynamic frictions. By going to a min speed, perhaps 10 ypm, the controls have a moment to damp out the initial disturbance of starting up. In addition, it gives the operators a chance to inspect the web, check the edge guiding, coating, etc… and make sure they are ready for production. Also, if an edge-nick or splice is going to cause a web break once tension is applied to it, it happens at min speed and not while ramping up to production. Once the operators are content with the machine setup, they can cue the line to go to line speed set-point for production.

This sequence was simulated with noticeable improvement by starting the machine with a zero speed set-point and then manually going to a min speed and then line speed. It was clear that this sequence helped minimize slack and web-breaks, and it also helped highlight other issues in the tension control. It took almost a minute for the line to stabilize tension at zero rather than a few seconds which is typical. ***This indicates that tuning the drive speed and tension loops can make a significant difference.***

Steady state response

Tension control at a fixed line speed was stable although some zones had slightly large variance. The base speed loops appear to control adequately but the tension loops have a lethargic response to a disturbance. The tuning is soft, trading in performance for setup latitude. In some zones, such as the A unit coater, the collected data shows a slow but strong oscillation in the web. +/-30lbs over a 5 second period. It is interesting to note that the gauge scanner takes 45 seconds to traverse the web thus scanning a diagonal cross section. A 5 second tension oscillation would occur 9 times over 45 seconds and appear as a sine or triangle wave to the scanner. ***The oscillation was recorded and the lab staff verified seeing the oscillation in the coat profile. In this case, the tension control is stable enough to convey web, but not stable enough to coat properly.***

Dynamic response

The base drives do not add compensation for static and dynamic friction nor do they for acceleration. Without these compensations, a change in the main speed reference will result in a "shift" in the synchronized speeds of the rolls.

For example, the cooling roll is very heavy and has a high inertia. During an acceleration ramp, it may lag the other driven rolls slightly. No matter how perfect the speed loop is tuned, it inherently cannot compensate for the cooling rolls lag. That is because, like all PID loops, the speed loop must first see an error before it can correct it. ***However, acceleration compensation can instantly detect a change in line speed and provide the necessary torque boost to accelerate the roll.*** In doing so, the speed and tension loops are left undisturbed and do not have to calculate out and back again as the line goes into and out of acceleration.

Tuning PID models

The machine has a selection for paper or film, which switches between two sets of tension PID parameters for each drive. These "constants" in conjunction with the PID algorithm form a mathematical model representing a mechanical system, specifically, a tension zone. Since the elasticity of the web is a large factor in this model, it makes sense that two different sets of parameters would be required for tuning stretchable paper versus rigid film. Distance is another factor in the model and so by the same token, very long tension zones require a different set of PID parameters than short zones. This is where the current drive programming is deficient. When the operator switches from paper to film, the machine switches PID parameters. ***But when changing the lead section tension zones switch from long to short or vice versa, no change is made in the tuning parameters resulting in a model that doesn't match the actual system.***

The machine appears to have been built as a pilot line. It is easily configurable to run a wide variety of products across a huge tension range and utilizes a multitude of drive control modes. This is both its greatest strength and its greatest weakness. While the line can be setup to run almost anything, it is optimized to run nothing. The machine can be configured for anything but then it must be tweaked at the drive and PLC level to perform well. ***For a production line that runs a limited number of similar products, it is better to remove some of the versatility in order to optimize performance.***

Winder profile

Some time should be dedicated to experimenting with winder profile settings. There are some complaints about soft rolls with flat spots or hard rolls that telescope. There does not appear to be anything wrong with the winder specifically, but perhaps the tension profile does need adjusting for some products. ***The machine currently computes a linear taper calculation, which can be modified in the PLC to also allow hyperbolic calculations. This may allow for better profiles to be determined empirically.***

Another possible factor affecting roll quality is the diameter calculation. ***The diameter calculation appeared to lag the actual roll size, particularly at core, where the diameter builds up the quickest. In this case, the tension loop must compensate for the inaccurate diameter value. Often, this sets up an oscillation between the tension and diameter control.***

Dancers versus load-cells

Consideration should be given to installing dancers at the roll stands. While the monitored tension control at the rewind was quite sufficient to produce a good roll, a dancer would perform better. Dancers are intrinsically constant tension devices. They damp out turret or splicing arm movements and use variable position to provide constant tension. To the contrary, load-cells have fixed position and varying tension by design. Every rewind transfer seriously disturbs the tension and comes precariously close to slacking out the web. The operators seem to know from experience not to go below certain tensions or the web will slack during transfer. Ideally, the rewind should be able to run any tension, even just 10lbs, and transfer without incident.

E-Stop

The E-stop circuit on the machine should incorporate a safety relay in accordance with today's safety codes and regulations. Typically, the safety relay has redundant internal contacts to ensure the circuit breaks and cannot be reset should either set fail.

Additionally, the E-stop is not coordinated. Every drive simply regens to a stop. ***Utilizing a short E-stop ramp, the machine could stop without breaking the web.*** During an actual web break, this also helps minimize back wrapping and multiple breaks.

Master Speed Ref

There is no drive to drive communication. Nor is there a broadcast being executed from the PLC to the drives. The sole means of communications is via serial telegrams addressed specifically to each drive. That means only every 19^{th} telegram sent from the PLC is intended for a particular drive. At 19.2 kbps that's a long time between messages and results in the speed reference appearing as a series of steps instead of a smooth reference. The steps are filtered in the drive, but there is still a noticeable time shift between when the first drive is told to ramp and when the last drive gets the message. This is another contributing factor to the poor dynamic response of the line.

Basic Recommendations

- ***If static control or scratches on the web surface are an issue, replace the idlers with lighter rolls.***
- ***Don't use the suction belts except as insurance to keep web breaks out of the coater. Once the machines performance and reliability has improved, stop using the suction belts.***
- ***Add an automatically controlled shut-off valve for the cooling roll circulation***
- ***Optimize the web paths by permanently selecting Pull Roll 4 as the lead drive.***
- ***Don't skip Pull Roll 2 and the edge guide in the web path when the release coater is bypassed. This gives edge guiding and tension isolation from the unwind for A unit coater.***
- ***Mount threading illustrations on the machine to prevent operator errors.***
- ***Update the E-stop circuit to today's code. Implement a coordinated e-stop if drive upgrades are made.***
- ***Collect data collating rewind tension and taper with roll quality. Let's see if every roll that telescopes after 4 days in the rack is run the same way.***
- ***Configure the unwinds to have a bump-less switch from manual to auto.***
- ***Tie the FactorLink and Gauge recipes together***
- ***Reprogramming the start sequence can make significant tension control improvement.***
- ***Complete re-tune of the existing drive system. This however would take considerable time to optimize and greatly impact production due to the duration required to optimize and reprogram for all products and web paths. See drive recommendations below.***
- ***Consideration should be given to installing dancers at the roll stands.***
- ***Implement acceleration torque boost algorithms.***

Drives

The drawbacks of the existing drive system are that it is old, analog, and DC. Fewer and fewer people possess the know-how to re-install or modify such equipment. Like all older machines, parts are more likely to fail and electronics are no exception. Replacements become harder to obtain, downtime and maintenance costs increase, and the owner must determine whether or not the point of diminishing returns has been passed. Modern drives perform better, are readily available, and offer new features. AC drives perform as well as the DC's but have cheaper maintenance free motors. (No brushes.) A drive upgrade should be considered. Based on interviews, Intertape experiences over 40 hours per month down time due to machine performance issues. During the audit, we experienced approximately 10 hours. Add to this, line speed reductions, manual ramping and coat weight issues, it is clear that there is significant financial return to upgrading the line.

The following recommendations can be considered for the drive system.

1. Calculate in the PLC a torque feed forward for static, dynamic, and acceleration compensation for each drive. This would require an analog output being added from the PLC to each drive and significant setup/testing time. Retune the tension loops for one lead section and in both paper and film mode. This option is probably the least expensive but is also the lowest value compared to dollars spent. This option requires purchasing outdated PLC equipment to add functionality to outdated drives. In the end, it offers the least improvement. However, the improvement would still be marked compared to the current machine performance. The line should ramp without operator intervention and maintain tension.
2. Replace the drives in one segment of the machine such as the rewind or a coating unit and dryer. This would create spares for the rest of the machine and demonstrate some of the performance enhancements of modern drives. As needed, subsequent sections could be upgraded. The limited scope of the upgrade is relatively inexpensive and quick. This option targets improving only a specific problem area and not the whole line in general. This allows investing in new technology without having to commit to a massive overhaul. As a secondary option, the new drives should be paired with a new PLC. This simplifies the integration of the old system with a new one and allows for continued upgrades.
3. Replace the entire drive system and PLC. This is a complete drives and PLC overhaul. While it would be cheaper than a series of smaller upgrades, it requires the most downtime and is a large single expenditure.

PLC

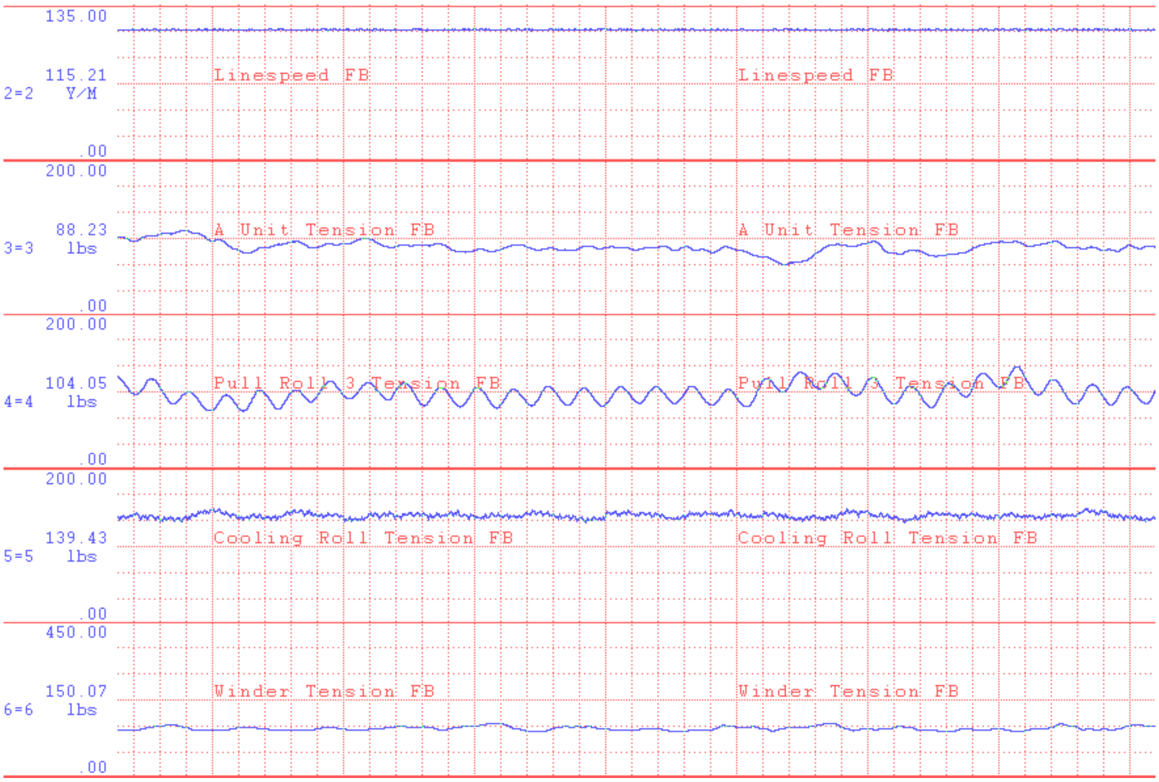
Due to its age, limited speed and limited capabilities, it is not recommended to use the existing PLC in conjunction with a SCADA upgrade or drive upgrade. A newer PLC would be required to interface with the upgrade equipment. However, the existing PLC should be left intact and remain in control of functions not included in an upgrade. It is not recommended to upgrade the PLC as a stand-alone project.

SCADA

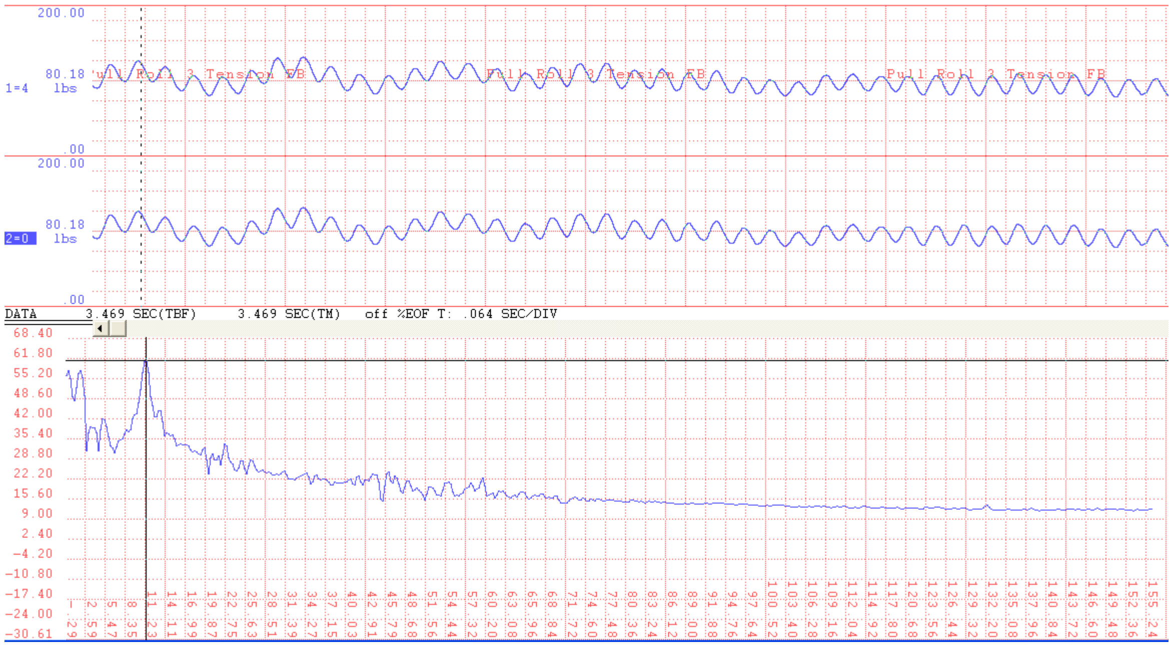
- Add a non-PC based industrial operator interface such as a Panelview to the machine. This allows full functionality of the machine minus recipes and trending should the PC go down. PC's have the shortest mean-time-between-failures of all equipment commonly found on a converting line. This is a highly recommended option.
- Replace the FactoryLink station with a new SCADA station. The existing application is slow, not very intuitive, and not very ergonomic. WonderWare is the recommended platform based on price, support, compatibility, and ease of programming. A new SCADA system would be a powerful diagnostic and validation tool. All tensions or temperatures could be plotted on a single graph with data points as close as 1 second.

Some data samples -

Below is actual data collected from the machine and diagnostics that can result from an evaluation of this type.

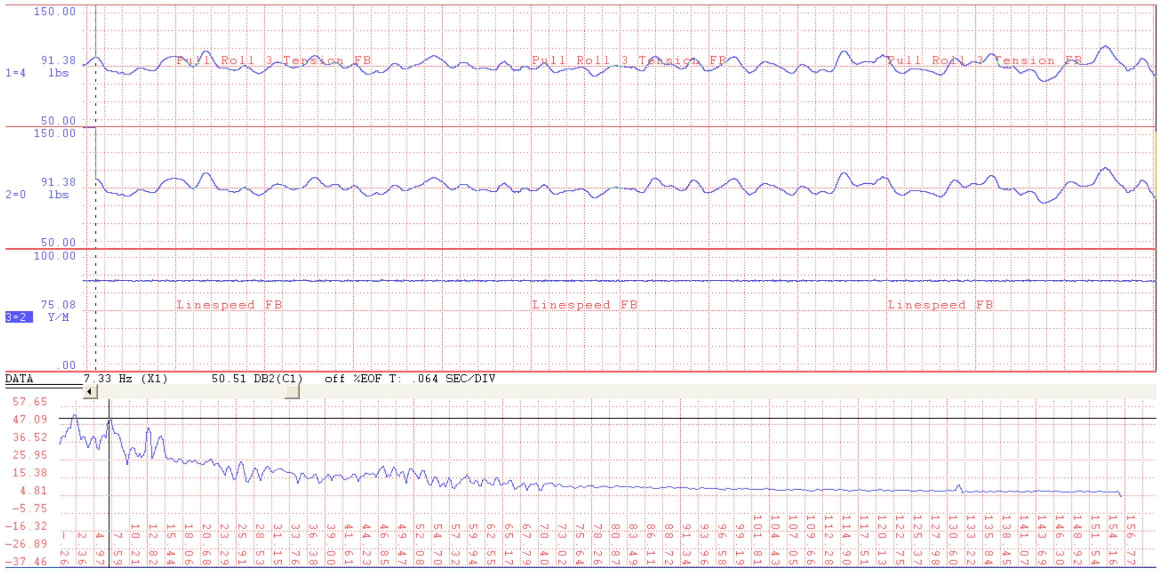


Note that the machine is running at 115 y/m and there is a very periodic oscillation apparent in Pull Roll #3 tension feedback.



Displaying PR#3 tension FB, the Inverse Fourier Transform, and the Fourier Transform shows the oscillation to be at 11.24 hertz.

Deleting 11.24 hz from the transform and recalculating the inverse, displays what the tension feedback would look like without the 11.24 hz oscillation. Now we must identify the source of the oscillation in order to attempt to correct it.



A roller that completes 11.24 revs/sec at 115 y/m would have a 1.954 inch diameter. At 75 y/m this roller would turn at 7.33 revs/sec. Notice in the graphs above, the line has slowed to 75 y/m and the 11.24 hz oscillation has shifted over to 7.33 hz. Note also that the frequency amplitude has dropped from 60 db to 47 db as the line slowed. The fixed constant diameter associated with this oscillation and the amplitude reduction with speed reduction implies a mechanical source to this vibration. If it's a roll, it would be approximately 2 inches in diameter, perhaps a smoothing bar. This oscillation's mechanical nature is evidenced by the pure sinusoid shape which results in a band in the coating that repeats every 6.139 inches. Due to the amplitude increase with speed, it should be clearly visible in the lab in samples taken above 100 y/m.

Closing

The next logical step is for CUSTOMER ABC personnel to review in detail the results of this report, followed by a conference call with Ed Colletti and Mike Murphy to answer questions, further explain the results and methodologies used and define a path forward.

There are many complexities and variables in Line #3 and many areas, small and large that can improve performance. Ultimately these decisions will be based on:

- Expected longevity of the machine
- Cost of lost production/hour
- Anticipated future products to be produced on the line
- Safety and Ease of operation for machine personnel
- Quality expectations and goals
- Capacity

Circonix Technologies would be happy to assist in any way to help CUSTOMER ABC accomplish the goals that have been set for Line #3.